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Full Length Research Paper

New type of trap for monitoring banana weevil population

Juliana Silva Queiroz[1], Marilene Fancelli[2]*, Maurício Antonio Coelho Filho[2], Carlos Alberto da Silva Ledo[2] and César Guillén Sánches[3]

[1]Federal University of Recôncavo da Bahia, Campus Cruz das Almas, Caixa Postal 007, CEP 44380-000, Cruz das Almas, Bahia State, Brazil.
[2]Embrapa Cassava and Fruits, Rua Embrapa, s/n, Caixa Postal 007, CEP 44380-000, Cruz das Almas, Bahia State, Brazil.
[3]Corporación Bananera Nacional, Apartado Postal: 6504-1000, San José, Costa Rica.

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The objective of this study was to test the efficiency of a new model of trap by comparing it with the most recommended and used traps by producers to monitor *Cosmopolites sordidus* in areas of production of plantains. Three types of vegetable traps were tested: cheese, modified roof tile and a new trap called wedge. The experiment was carried out in five areas of production, measuring one hectare each, in which 20 traps of each type were distributed, totaling 300 traps. The traps were distributed fortnightly and the collections held weekly. The data of monthly averages of insects captured by trap were subjected to the F test for variance analysis in a randomized block design. The averages of the treatments were compared by the Tukey test at 5% probability. The average of *C. sordidus* adults caught in the wedge trap was superior to other traps tested, indicating greater attractiveness to insects. In this way, the use of this trap for monitoring banana weevil in plantations of plantains in the southern region of Bahia is recommended.

Key words: *Musa* spp., plantain, *Cosmopolites sordidus*, pest management.

INTRODUCTION

The plantains constitute one of the main starchy foods in developing countries. Brazil has no representation in the exportation of plantains, however all their production is destined to the domestic market. The production is estimated to be about 620 thousand tons, generating direct and indirect jobs, mainly for its majority family labor (Borges et al., 2015). North and Northeast regions are the largest producers and consumers. Bahia State has the largest production areas, with emphasis on the lowlands of Bahia as the main production region. The planted area of this region is approximately 16.5 thousand hectares and its production is 285 thousand tons (Borges et al., 2015).

The plantains are highly susceptible to banana weevil,

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*Corresponding author. E-mail: marilene.fancelli@embrapa.br.

Figure 1. Types of attractive traps used for the capture of *Cosmopolites sordidus*: cheese (A), modified roof tile (B), and wedge (C) traps.

Cosmopolites sordidus (Germar), which is considered as the most economically important pest for *Musa* spp., due to its wide distribution and damage (Gold et al., 2001; Ostmark, 1974). The adult insect has nocturnal habits, sheltering during the day between the leaf sheaths of the plants, remains of the culture and rhizomes of plants harvested, which makes its observation by farmers difficult (Gold et al., 2001; Vinatier and Vinatier, 2013).

Recent studies demonstrated the relation between *C. sordidus* and phytopathogens of banana plant as the causal agents of the *Fusarium* wilt Race 4 (Meldrum et al., 2013) and bacterial wilt (Were et al., 2015). Therefore, this fact reinforces the need of banana weevil control, which might reduce disease spread. Some alternative methods have been evaluated for minimizing the economic damage posed by *C. sordidus* (Aby et al., 2015; Gold et al., 2001; Masanza et al., 2005; Reddy et al., 2008; Tinzaara et al., 2007; Uzakah et al., 2015).

It is essential to understand the population dynamic of banana weevil to establish the measures of control of that pest. The monitoring is carried out by using vegetal traps made of pieces of pseudostem or rhizome (Cordeiro and Fancelli, 2008; Price, 1995), whose compounds attract the adults of banana weevil (Budenberg et al., 1993; Ndiege et al., 1996; Tinzaara et al., 2007). The most used are those of type roof tile and cheese (Mesquita et al., 2014).

These traps can be used as a method of control, however, the efficiency of capture of adults of *C. sordidus* is very low and the results are only achieved at long-term (Gold et al., 2001; Mesquita et al., 2014). Thus, researches have been conducted to determine sample models of the insect (Maldonado et al., 2016) as well as to increase the efficiency of capture of adults by evaluating different types of vegetal traps incorporated or not to the biological control (Aby et al., 2015; Navas Rivera, 2011).

The objective of this study was to test the efficiency of a new model of vegetal trap as compared to the most recommended and used traps in the monitoring of *C. sordidus* by producers in areas of production of plantains.

MATERIALS AND METHODS

The experiment was conducted in areas that produce plantain cv. Terra, located in the city of Tancredo Neves, Bahia, located at 13°23’793’ S, 039°19’945’ W at 122 m above sea level, from December 2014 to February 2015.

Three types of traps were used: cheese trap; modified roof tile (sandwich) trap, and the new model, called wedge trap, all made from pseudostem of harvested plants. The cheese trap was made by cutting the pseudostem, approximately 30 cm from the ground level, and making a new cut (partial) at the half of that height (Figure 1). The modified roof tile trap was obtained from the half of a piece of pseudostem of approximately 60 cm length, cut in two parts in the longitudinal direction. In this way, the pieces of pseudostem were overlaid and placed near the plant. To make the wedge trap, initially, the pseudostem was leveled at 50 cm height. Then, two cuts were made in the pseudostem approximately 15 cm above the ground in the V-shape horizontal, in which the superior part formed an angle of 45° in relation to the cut surface below, parallel to the ground level (Navas Rivera, 2011).

The experimental design was in randomized blocks in a 3 x 3 factorial scheme (three types of traps and three months of evaluation), with 5 replicates. Twenty traps of each type were distributed in each block, fortnightly, totaling 100 traps randomly distributed in 5.0 hectares of the production areas. The collections of the insects were conducted weekly, at 7 and 14 days after the distribution of the traps, when new traps were made, adopting the same procedure for the counts and collections of insects. For the evaluation of efficiency, a weekly accounting of the number of insects per trap was carried out. The adults captured were later destroyed in order to evaluate the potential use of traps as a strategy of pest control.

The data of monthly averages of insects captured per trap were subjected to F test of variance analysis. The averages of treatments were compared with the Tukey test at 5% probability. Statistical analyses were performed using the statistical software Sisvar (Ferreira, 2014).

Meteorological variables (rainfall, air temperature, global

Table 1. Meteorological variables collected for each period of evaluation during the months of December 2014 to February 2015.

Period of evaluation	Relative humidity (%)	Air mean temperature (°C)	Air maximum temperature (°C)	Air minimum temperature (°C)	Global radiation (MJ m^{-2} day^{-1})	Rainfall (mm)
1	84.4	23.7	24.3	23.1	19.7	48.0
2	85.0	24.3	24.8	23.9	18.5	139.8
3	86.0	24.5	24.9	24.0	16.9	119.2
4	84.2	24.3	25.0	23.8	23.3	32.2
5	81.5	24.4	25.0	23.8	25.2	10.2
6	83.8	24.1	24.7	23.5	22.3	27.4
7	80.2	24.3	25.0	23.8	25.0	5.0
8	81.2	24.9	25.5	24.3	24.3	17.6
9	79.4	24.9	25.5	24.2	25.4	1.3
10	79.7	25.5	26.2	25.0	22.8	0.1
11	81.7	24.9	25.6	24.3	22.6	5.6
12	87.8	24.0	24.5	23.5	13.8	15.8

Table 2. Summary of variance analysis for the average number of captured *Cosmopolites sordidus*.

Sources of variation	DF	Mean square
Area	4	470.06^{ns}
Month	2	295.70^{ns}
Trap	2	1,167.91**
Month x trap	4	$288,74^{ns}$
Experimental error	32	180,07
CV (%)		8.14
Average		165.76

**Significant by F test at 1% probability; ^{ns}, not-significant by F test at 5% probability.

Table 3. Total number of adults of *Cosmopolites sordidus* collected per type of trap and per month.

Type of traps	Area (ha)	Number of traps	Total number of trapped insects*			
			December	January	February	Total
Wedge	5	100	1132 (2.83)	860 (2.15)	1019 (2.55)	3011 (2.51)
Roof tile	5	100	656 (1.64)	731 (1.83)	847 (2.12)	2234 (1.86)
Cheese	5	100	842 (2.11)	786 (1.97)	586 (1.47)	2214 (1.85)

*Average number of trapped adults of *C. sordidus*/trap in brackets.

radiation and air relative humidity) were monitored daily (Table 1) and correlated with population density of the insects considering the twelve periods of assessments.

RESULTS AND DISCUSSION

There was no significant difference in the number of adults of *C. sordidus* considering the interaction between the month of evaluation and the type of trap (Table 2). However, a significant effect from the type of trap was noticed. The wedge trap type attracted more insects (3011) than those of modified roof tile (2234) and cheese trap (2214), contributing about 40% of the total of insects captured (Table 3). The average number of insects captured in the wedge trap (201) was statistically higher than the values recorded for modified roof tile (149) and cheese traps (148) (Figure 2A). In this way, the wedge trap was more efficient than the others. The number of captures recorded for the trap of modified roof tile was

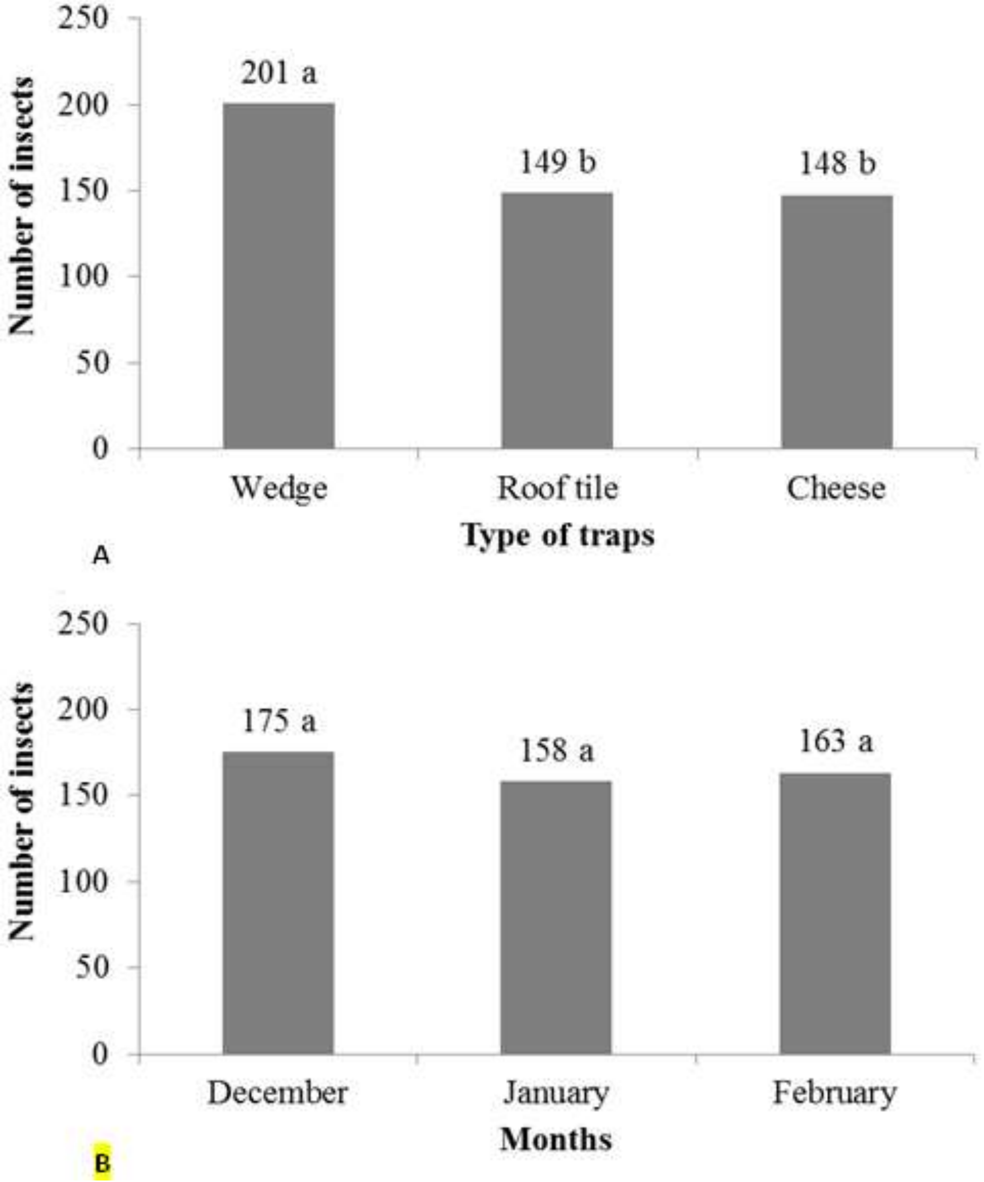

Figure 2. Average number of adults of *Cosmopolites sordidus* captured due to the type of traps (A) and the months of collection (B) (averages followed by the same letters do not statistically differ from each other by Tukey test at 5% significance level).

similar to the cheese trap, denoting its superiority as compared to the typical roof tile standard (Cordeiro and Fancelli, 2008; Gold et al., 2001).

There was no significant influence of the month on the number of adults of *C. sordidus* captured (Table 2). The values recorded for the months of December, January and February were 175, 158 and 163, respectively (Figure 2B). There was no significant correlation between the number of adults captured in the traps with rainfall, which contradicts the data obtained by Duyck et al. (2012) and Price (1995) (Table 4), but partially corroborates the results of Reddy et al. (2008) for nine of the ten locations evaluated in studies proving the efficiency of traps containing aggregation pheromone.

There was a significant and negative correlation among the values for adults captured in the wedge trap and temperature (minimum, mean and maximum) (Table 4). However, there was a negative and significant correlation between global radiation and capture in the wedge trap. Therefore, the reduction in *C. sordidus* trapping may be more related to exposure to radiation than to temperature itself. The same was observed for cheese traps, although there was no significant correlation between trapping and temperature.

Table 4. Spearman correlation between the climatic variables and the number of insects captured in each type of trap.

Variables	Type of traps		
	Wedge	Cheese	Roof tile
Air minimum temperature (°C)	-0.64*	-0.31^{ns}	-0.25^{ns}
Air mean temperature (°C)	-0.72**	-0.40^{ns}	0.20^{ns}
Air maximum temperature (°C)	-0.75**	-0.43^{ns}	0.18^{ns}
Rainfall (mm)	0.39^{ns}	0.32^{ns}	-0.02^{ns}
Global radiation (MJ m^{-2} day^{-1})	-0.71**	-0.78**	0.11 ^{ns}
Relative humidity (%)	0.83**	0.76**	-0.16^{ns}

*Significant at 5% probability; **significant at 1% probability; ^{ns}not significant at 5% probability.

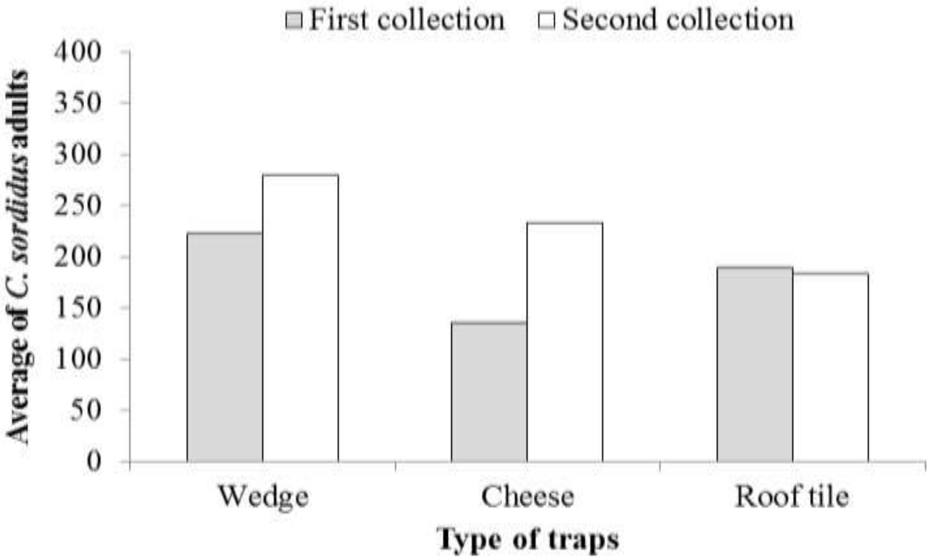

Figure 3. Average of adults of *Cosmopolites sordidus* on each collection per type of traps.

A significant and positive correlation was observed between the number of insects captured for wedge and cheese traps and the average relative humidity (Table 4). In this case, the highest relative humidity caused a greater capture of insects as a result of the best condition of the trap, because the adults are highly hygroscopic, corroborating the results of Gold et al. (2001) and Ostmark (1974).

Analyzing the average of adults monthly captured, it was observed that the values are closer to the inferior threshold for the insect control level, which varies from 2 to 5 insects per trap (Cordeiro and Fancelli, 2008) (Table 3). In addition, it was noticed that the traps of cheese and modified roof tile underestimated the number of adults captured. Considering that the action threshold is based on the average of adults trapped, this underestimation may lead to a delay in the implementation of control measures. Consequently, it might contribute to increase larval damage, in view of the great susceptibility of plantains to the pest (Fancelli et al., 2013; Gold et al., 2001).

The highest attractiveness of traps wedge can be attributed, in part, to its durability in relation to others, since the highest number of capture of adults was recorded on the second week of collection (Figure 3). Thus, to monitor this pest, a biweekly distribution of wedge traps, with two weekly assessments of the number of adults is recommended. As the efficiency of wedge traps was higher than the other trap types, manual collecting of insects using this kind of trap may constitute a good option for pest control, if properly evaluated. This can be especially useful in systems of organic production, where chemical control is not allowed. However, the results are only achieved at long-term (Gold et al., 2001; Mesquita et al., 2014). On the other hand, predators (Abera-Kalibata et al., 2007; Koppenhofer et al., 1994 and Ostmark, 1974) can contribute to improve biological control of *C. sordidus*. In addition to monitoring the insect through traps, it is recommended to assess the infestation either through direct evaluation in the rhizome (Borges et al., 2015; Carval et al., 2016; Cordeiro and Fancelli, 2008) or through non-invasive methods in development, such as the use of bio-acoustic sensors (Vinatier and Vinatier, 2013). However, in systems of conventional production, due to limitation of labor for this activity, the concomitant use of biological or chemical insecticides or synthetic pheromones is recommended (Cordeiro and Fancelli, 2008; Fancelli et al., 2013; Gold et al., 2001; Mesquita et al., 2014; Navas Rivera, 2011).

Particularly, for plantains, where the appearing of the rhizome is common, the low cut made to obtain the wedge and cheese traps could be a positive factor in the capture of a greater number of insects by exposure of rhizome and release of compounds responsible for their attractiveness (Budenberg et al., 1993; Ndiege et al., 1996; Tinzaara et al., 2007). However, this fact only occurred for the wedge trap, possibly due to the connection between rhizome and pseudostem provided by the partial cutting of the rhizome, contributing to a greater release of compounds in this type of trap and its appropriate humidity content. On the other hand, the effect of pheromones of aggregation (Duyck et al., 2012; Tinzaara et al., 2007), sexual (Uzakah et al., 2015) and possible visual stimuli (Reddy and Raman, 2011) in the increase of the number of adults caught by the effect of the compounds of the host plant should not be discarded. Considering this fact, in case of no adoption of the chemical or biological control of the insects, it is necessary to destroy the traps after the last evaluation, since adults can lay eggs on the traps tissues, increasing its population instead of reducing it (Mesquita et al., 2014).

The ease and speed of the wedge trap manufacturing as another positive point in its use should be noted. Thus, the producer may take advantage of the time of harvest to make the wedge trap.

In conclusion, the attractiveness of the wedge trap for adults of *C. sordidus* was superior to the traps of modified roof tile and cheese, respectively. Consequently, the use of wedge trap could be recommended for monitoring the banana weevil in plantation of plantains in the Southern region of lowlands of Bahia. Furthermore, the modified roof tile trap can be used preferably for the typical roof tile in crops not yet harvested.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Productive and physiological performance of lettuce cultivars at different planting densities in the Brazilian Semi-arid region

Hozano de Souza Lemos Neto[1*], Marcelo de Almeida Guimarães[1], Jean Paulo de Jesus Tello[2], Rosilene Oliveira Mesquita[1], Júlio César do Vale[1] and Benedito Pereira Lima Neto[1]

[1]Department of Fitotecnia, Federal University of Ceará (UFC), Brazil.
[2]Department of Fitotecnia, Federal University of Viçosa (UFV), Brazil.

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In regions of high temperature, production and quality in the lettuce is reduced. This requires finding of cultivars that are more adapted to such conditions and adjust the planting density for each cultivar. Consequently, the aim of this study was to evaluate the productive and physiological performance of lettuce cultivars at different planting densities under semi-arid conditions. The experiment was carried out at the Horticulture Teaching Garden of the Federal University of Ceará in Fortaleza, in a randomised block design with four replications, with the treatments arranged in a 4 × 4 factorial scheme. The first factor consisted of four lettuce cultivars (Red Salad Bowl, Salad Bowl Green, Mimosa Green Salad Bowl and Crespa Lollo Bionda) and the second factor of four planting densities (0.20 × 0.20 m, 0.25 × 0.25 m, 0.20 × 0.25 m 0.25 × 0.30 m between plants and rows). The characteristics of the lettuce such as qualitative (age at bolting and flowering, and state of health - pests and diseases), quantitative (plant height and diameter, fresh and dry commercial weight, fresh and dry non-commercial weight, and total fresh and dry weight), and physiological (gas exchange) were evaluated. The Salad Bowl Green and Mimosa Green Salad Bowl cultivars displayed average tolerance to bolting (63 days after sowing, DAS) and late flowering (95 DAS). 'Salad Bowl Green' had the highest total fresh and dry weight. For density, greater individual plant production was seen at 0.25 × 0.30 m; greater productivity of commercial fresh weight and total fresh weight was seen at 0.20 × 0.20 m for all cultivars. 'Salad Bowl Green' is the most promising for cultivation under semi-arid conditions when grown at lower densities.

Key words: *Lactuva sativa* L., early bolting, productivity, dry weight, gas exchange.

INTRODUCTION

Lettuce is one of the most consumed and marketed leafy vegetables in Brazil. Due to being highly perishable, and having little resistance to transportation and post-harvest handling, its production is concentrated close to urban centres (Souza et al., 2008).

Being a temperate crop it adapts better to warm temperatures, so that in tropical regions with high temperatures and luminosities, cultivation is hampered. This is due to the stimulation of early bolting and acceleration of the plant cycle, preventing expression of the maximum yield potential (Bezerra Neto et al., 2005; Guimarães et al., 2014). The demonstration of this potential depends on the genetic constitution (cultivar) and the conditions of soil and climate to which it is subjected.

There are several lettuce cultivars available on the market. It is therefore essential to find the one best suited to a given growing condition. As a result, the cultivar being used is important to the success of the adopted cropping system (Lima et al., 2004; Guimarães et al., 2011; Blind and Silva Filho, 2015).

In recent decades, with the advances in genetic improvement, companies have gradually launched onto the market lettuce cultivars tolerant to high temperatures. However, there is still a lack of information about their performance under high temperature conditions. This makes it difficult to recommend and produce good quality lettuce in different regions of the country (Sala and Costa, 2012).

As well as the cultivar, there are several cultural practices that comprise an improvement to the environment and affect the production of lettuce. Important among these is spacing, which influences performance regardless of the weather conditions to which the crop is submitted. Therefore, defining the best spacing to be adopted by the producer is essential. This is because plants respond to spacing by changes in architecture, development, weight, quality and finally, production (Mondin, 1989).

Some of the studies which test combinations between cultivars and spacings are intended to identify the combination which would result in greater productivity, precocity, product quality and tolerance to bolting (Echer et al., 2001; Lima et al., 2004). It is known that an increase in plants per unit area tends to increase production. However, as high plant densities do not always result in products of high commercial value, there is a limit to this increase (Correa et al., 2014). In very dense crops, there is greater competition among plants for light, water and nutrients, in which productivity tends to decrease. The aim of this study therefore, was to evaluate the productive and physiological performance of lettuce cultivars at different planting densities under semi-arid conditions.

MATERIALS AND METHODS

The experiment was carried out from August to October 2014 at the teaching garden of the Department for Phytotechnology of the Federal University of Ceará (UFC), on the Pici Campus in Fortaleza (3°36' S, 37°48' W, at an altitude of 21.0 m) in the State of Ceará, Brazil (CE). The climate, according to the Köppen classification, is of type Aw', that is, rainy tropical, with an average annual rainfall of 1,338 mm and minimum, maximum and average temperatures of respectively 23, 31 and 27°C.

The experimental design was of randomised blocks, with treatments arranged in a 4 × 4 factorial scheme, with four replications. The first factor comprised four cultivars (Red Salad Bowl, Salad Bowl Green, Crespa Lollo Bionda and Mimosa Green Salad Bowl) and the second comprised four spacings, 0.20 × 0.20 m (250,000 plants ha^{-1}), 0.25 × 0.25 m (160,000 plants ha^{-1}), 0.20 × 0.25 m (200,000 plants ha^{-1}) and 0.25 × 0.30 m (133,333 plants ha^{-1}), between plants and rows. One lot consisted of 16 plants, with the nine central plants used as the working area.

The cultivars used in the experiment 'Red Salad Bowl', 'Salad Bowl Green', 'Mimosa Green Salad Bowl' and 'Crespa Lollo Bionda', all of the 'Crisp Loose-leaf ' group, are very consistent, have leaves which are more separate (loose) with irregular leaf blades (crisp), and do not form a head. During the experiment, climate data relating to minimum and maximum temperature and rainfall were recorded (Figure 1).

The soil at the cultivation site is of a sandy-clay type, with a sandy-loam to clayey-loam texture. The production beds were constructed by hand with the aid of hoes, to have a soft-wavy relief. They were prepared with a length and width of 16 × 1 m, and a height of 0.2 m. Once built, the beds were fertilized with organic compost (a result of composting cattle manure and vegetable waste) and left for 15 days in order to improve the chemical and physical properties of the soil, a sample of which was then taken. The chemical analysis of the soil was based on Ribeiro et al. (1999) and gave the following result: pH (H_2O) = 6.62; P = 474.78 mg dm^{-3}; K^+ = 773.3 mg dm^{-3}; Na^+ = 146.35 mg dm^{-3}; Ca^{2+} = 6.11 cmolc dm^{-3}; Mg^{2+} = 4.19 cmolc dm^{-3}; (H+Al) = 1.43 cmolc dm^{-3}; BS = 12.92 cmolc dm^{-3}; T = 12.92 cmolc dm^{-3}; CEC = 14.34 cmolc dm^{-3}; V = 90% and PST = 4.5% .

Fertilisation at planting was based on the chemical analysis of the soil, and the fifth estimation handbook for the lettuce crop (Ribeiro et al., 1999), when the following were applied: 80 kg ha^{-1} urea (45% N); 1,344 kg ha^{-1} superphosphate (18.9% P_2O_5); 38 kg ha^{-1} potassium chloride (62% K_2O) and 12 kg ha^{-1} of micronutrient mixture (Agamix).

Lettuce seedlings were grown in polyethylene trays of 200 cells, with two seeds per cell. These were filled with organic compost (cattle manure and vegetables) and vermiculite at a ratio of 9:1 (v.v.). After sowing, the trays were placed in a greenhouse, which was covered in a white polyethylene diffuser film 150 µm thick, with a black shade screen retaining 30% of solar radiation flux. Irrigation was twice-daily by micro-sprinkler, once in the morning and once in the afternoon, in order to maintain the water content of the substrate close to field capacity.

At 14 days after sowing (DAS), the plants were thinned with the help of scissors, properly sanitised with 2% sodium hypochlorite, to leave only one seedling per cell. At 26 DAS, foliar fertilisation based on micronutrients was carried out using single mineral fertilizer (Nutr-I-Kelp), followed at 28 DAS by another foliar fertilisation with nitrogen (urea).

At 35 DAS, when the plants presented from four to six true leaves, they were transplanted to the beds at the pre-set densities, where holes had been marked out using a tape measure according to each spacing, and one seedling placed in each hole. This was done in the late afternoon (after 1600). Two applications of topdressing were made in the open, the first at 10 days after transplanting (DAT), when 80 kg ha^{-1} urea, 576 kg ha^{-1} superphosphate and 38 kg ha^{-1} potassium chloride were applied. The second was carried out at 20 DAT, applying 120 kg ha^{-1} urea

*Corresponding author. E-mail: hozanoneto@hotmail.com.

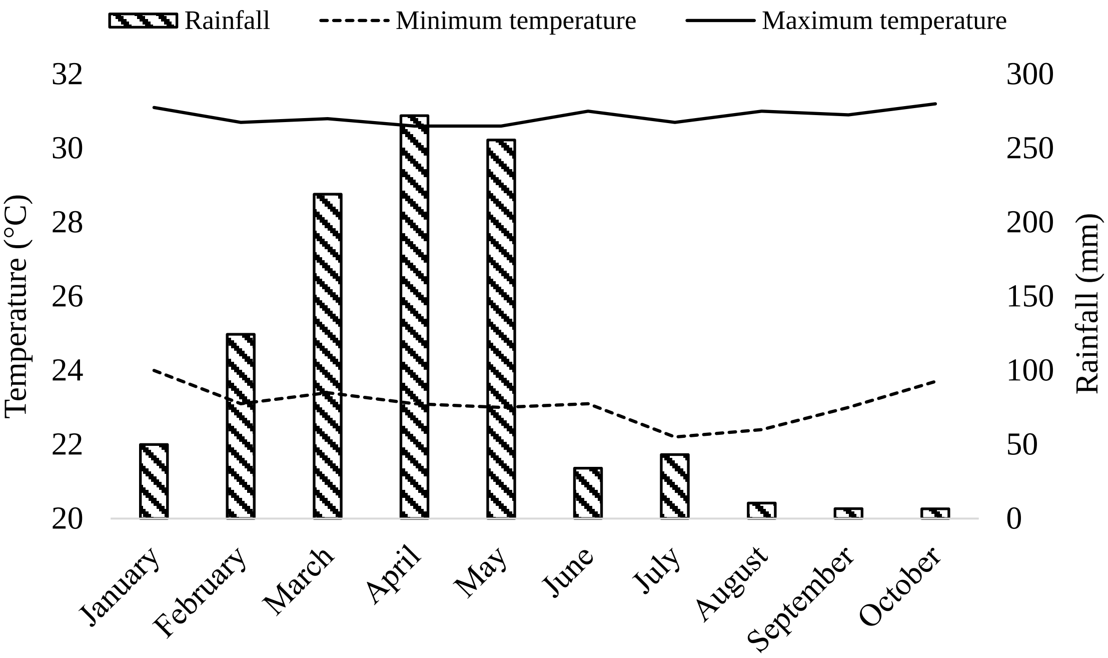

Figure 1. Temperature Analysis, maximum and minimum, and monthly rainfall in the municipality of Fortaleza-CE in 2014.

and 54 kg ha^{-1} potassium chloride. All topdressings were given based on the chemical analysis of the soil, as well as the fifth estimation for the lettuce crop (Ribeiro et al., 1999).

Weeding was by hand, with the weeds removed directly from the beds; pests and diseases were monitored throughout the experiment. No method of pest control was used as no infestation was found. For irrigation, a micro-sprinkler system was employed, with sprinklers having a working pressure, range, flow, head and size of 1.5-3.0 kg, 0.9-1.1 m, 33-55 L h^{-1}, 360° and 13 × 22 mm, respectively. The system was activated twice a day (early morning and late afternoon) in order to maintain the soil moisture close to field capacity. The irrigation depth was determined based on the water requirement of the crop, taking into account the crop coefficient for lettuce.

After 64 DAS, a physiological assessment was made on the third pair of fully expanded leaves, using an infrared gas analyser (IRGA), model LCi from ADC (Analytical Development Co. Ltd, Hoddesdon, UK). The CO_2 concentration of the sub-stomatal chamber (Ci - ppm) was determined, together with the stomatal conductance (*gs* - mol m^{-2} s^{-1}), the rate of photosynthesis (*A* - µmol m^{-2} s^{-1}), the ratio between the CO_2 concentration of the substomatal chamber and the CO_2 concentration of the environment (Ci/Ca), and the instantaneous carboxylation efficiency (*A*/Ci). The evaluations were made between 0800 and 1100, when the stomata were fully open, on a clear day, using artificial lighting of 1,000 µmol m^{-2} s $^{-1}$ in the evaluation chamber of the equipment, in order to maintain more homogeneous environmental conditions during the evaluations.

Shortly after, a qualitative evaluation was made of the age at bolting (AB), considering the number of days from sowing until at least one of the plants from each cultivar displayed evidence of changing from the vegetative to the reproductive phase, which consisted of stem elongation with obvious spacing between leaves; the state of health of the plants (diseases), evaluated from the damage caused by the disease, and based on a visual rating scale ranging from 1 to 5, where: 1 for plants with leaves strongly attacked by disease; 3 for plants with leaves moderately attacked by disease; 4 for plants with leaves rarely attacked by disease and 5 for plants with leaves with no apparent attack by disease (Mota et al., 2003); the state of health of the plants (pests), as attacked by pests and based on a visual rating scale by Mota et al. (2003); and the age at flowering (AF), considering the number of days from sowing to the point of 'silking', which consists of not only stem elongation, but also the beginning of the formation of floral structures (Kristkova et al., 2008). To evaluate the AF, six other plants were grown in the same area from each cultivar, at each of the determined spacings and in each block.

At 65 DAS, the plants were harvested for quantitative assessment of plant height (AP), measured from the ground level to the end of the stem at the insertion point of the last developing leaf, using a graduated ruler and expressed in cm; plant diameter (PD), measured as the greatest distance between the tips of the opposing edges of the leaves, expressed in cm; commercial fresh weight (CFW), the weight of the commercial part of the crop when harvested in the morning (0900), expressed in g plant^{-1}; non-commercial fresh weight (NCFW), the weight of the non-commercial part of the crop, harvested in the morning (0900), expressed in g plant^{-1}; total fresh weight (TFW), the sum of the CFW and NCFW; and commercial dry weight (CDW) and non-commercial dry weight (NCDW), the weight of the commercial and non-commercial parts after drying in a forced air oven (65°C for 48 h) to constant weight, expressed in g plant^{-1}; and total dry weight (TDW), as the sum of the CDW and NCDW.

The results were submitted for analysis of variance (ANOVA) by F-test. Where there was a significant effect, the mean values were compared by Scott-Knott test at 5% significance.

RESULTS AND DISCUSSION

Morphological differences were found between the

Table 1. Morphological aspects in lettuce cultivars for spacing (Fortaleza CE, UFC, 2014).

Cultivar	AB (DAS)[1]	SPHD[3]	SPHP[4]	AF (DAS)[5]
Red Salad Bowl	61	5	5	80
Salad Bowl Green	63	5	5	95
Mimosa Green Salad Bowl	63	5	5	95
Crespa Lollo Bionda	61	5	5	72

AB, Age at bolting (DAS[1]): <50 DAS (early); 50-70 DAS (medium); >70 (late); SPHD, State of plant health (disease)[3]; SPHP, State of plant health (pests)[4]; AF, Age at flowering (DAS)[5]: <60 DAS (early); 60-80 DAS (medium); >80 (late).

lettuce cultivars (Table 1). Regardless of the spacing used, the four cultivars displayed average tolerance to bolting (61 and 63 DAS), according to the classification proposed by Kristikova et al. (2008). However, ‘Salad Bowl Green’ and ‘Mimosa Green Salad Bowl’ proved to be slightly more tolerant to bolting, taking up to two extra days to start the process. When it comes to lettuce produced under the climatic conditions found at low altitudes and low latitudes, the longer the plants remain in the field with no evidence of bolting, and the consequent reduction in quality, the greater the accumulation of photoassimilates in the shoots, with a resultant increase in leaf area. Therefore, the longer period spent in the field by the plants of these cultivars may have favoured their growth, making them more productive.

The high temperatures recorded during the experiment, with a minimum of 23°C and a maximum of 30°C (Table 1), negatively influenced the productive behaviour of the lettuce cultivars. Under such conditions, there is a reduction in the vegetative stage and the harvest is brought forward. When this happens, the crop accumulates both quantitative and qualitative losses. Quantitatively, losses are caused mainly due to stem elongation and the consequent lower ‘investment’ in the production of leaves per plant. Qualitatively, the high temperatures induce early flowering, which is accompanied by latex production in the plant, making the leaves bitter and unpleasant (Vargas et al., 2014).

As to diseases and pests, none of the cultivars displayed apparent spots or any type of injury from insect predation, and were therefore considered healthy (Table 1). According to Sala and Costa (2012), lettuces classified as crisp have better resistance to disease, pests and transportation, and a greater post-harvest period when compared to other commercial groups of the same crop. This resistance is mainly related to the arrangement of the leaves on the plant. Because they are more upright and the plant architecture is more open, water does not accumulate during the hot, rainy summer, resulting in fewer losses due to rotting of the leaves and attack by pathogens.

‘Red Salad Bowl’ and ‘Crespa Lollo Bionda’ displayed average tolerance for AF, flowering at 80 and 72 DAS respectively. Whereas, ‘Salad Bowl Green’ and ‘Mimosa Green Salad Bowl’, flowering at 95 DAS, were classified as late for AF (Kristkova et al., 2008).

The combination of long days (more than 10 h light) and high temperatures (an average of approximately 27°C) had an influence on bolting and emission of the floral tassel. However, according to Vargas et al. (2014), flowering in the lettuce may be influenced by not only temperature and length of day, but also the genetic load of the cultivars. That statement can be confirmed in this work, since the cultivars presented different ages at bolting and flowering, despite being subjected to the same conditions of soil and climate.

There was interaction between cultivar and spacing ($p<0.01$) for all the quantitative characteristics under study, demonstrating that the cultivars respond differently as the spacing is changed. ‘Red Salad Bowl’ had the highest average plant height (Table 2). At the spacing of 0.25 × 0.25 m, the plants reached on average the greatest height for each cultivar.

Under conditions of high temperature and luminosity, such as those that occur in the climate of regions of low altitude and low latitude, greater plant height is related to early bolting (Santos et al., 2009). This claim was partially confirmed in this work, as ‘Red Salad Bowl’, one of the first to show signs of bolting, at 61 DAS, also had the highest average height among all the cultivars being evaluated. This different behaviour between cultivars is related to their gene load. The larger values for height may be related to early flowering. This is because, due to the heat, early bolting causes stem elongation and hampers the formation of a commercial head. The result is the plant being harvested while still small and of poor quality, not expressing all its productive genetic potential (Vargas et al., 2014).

‘Salad Bowl Green’ was the cultivar with the greatest average diameter. As for the spacings under evaluation, it should be noted that at 0.20 × 0.20 m the cultivars presented plants with an average diameter of 20.6 cm (Table 2).

The results of this study are similar to those seen by Batista et al. (2007), who worked with the Itapuã, Elba and Veneranda cultivars and found that plant diameter ranged from 20.4 to 23.5 cm. Rodrigues et al. (2008) also worked under conditions of high temperature in Manaus in the State of Amazonas, and observed a plant diameter of 13.6 cm in ‘Crespa Lollo Bionda’, similar to that found

Table 2. Height and diameter in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Plant height (cm)

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	6.37^{aA}	5.89^{aB}	4.66^{bD}	5.54^{aC}	5.61^{a}
Salad bowl green	5.75^{bA}	5.91^{aA}	5.15^{aB}	5.09^{bB}	5.47^{b}
Mimosa green salad bowl	4.71^{cB}	5.90^{aA}	4.46^{bB}	3.97^{cC}	4.76^{c}
Crespa Lollo Bionda	3.75^{dA}	3.81^{bA}	3.50^{cA}	3.73^{cA}	3.69^{d}
Mean	5.14^{B}	5.37^{A}	4.44^{D}	4.58^{C}	
C.V. (%)	3.55				

Plant diameter (cm)

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	18.28^{bA}	16.97^{bA}	16.55^{cA}	16.81^{cA}	17.15^{c}
Salad bowl green	24.72^{aA}	24.51^{aA}	25.83^{aA}	25.83^{aA}	25.22^{a}
Mimosa green salad bowl	25.72^{aA}	24.14^{aA}	22.59^{bA}	21.27^{bA}	23.42^{b}
Crespa Lollo Bionda	13.87^{cA}	14.35^{cA}	13.91^{dA}	14.12^{dA}	14.06^{d}
Mean	20.64^{A}	19.99^{B}	19.71^{B}	19.50^{B}	
CV (%)	5.74				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

Table 3. Commercial fresh weight (CFW), non-commercial fresh weight (NCFW), total fresh weight (TFW) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Commercial fresh weight (g plant^{-1})

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	14.01^{cA}	11.45^{cB}	9.47^{cB}	10.99^{cB}	11.47^{c}
Salad bowl green	46.04^{aD}	57.47^{aB}	53.33^{aC}	71.64^{aA}	57.14^{a}
Mimosa green salad bowl	28.37^{bC}	50.75^{bA}	37.15^{bB}	30.09^{bC}	36.59^{b}
Crespa Lollo Bionda	8.99^{dB}	11.00^{cB}	8.93^{cB}	13.47^{cA}	10.60^{c}
Mean	24.35^{C}	32.66^{A}	27.24^{B}	31.54^{A}	
CV (%)	6.11				

Non-commercial fresh weight (g plant^{-1})

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Me^{a}n
Red salad bowl	4.33^{dA}	3.27^{dB}	3.64^{cB}	3.41^{cB}	3.66^{d}
Salad bowl green	12.81^{aB}	17.57^{aA}	12.57^{aB}	13.44^{aB}	14.09^{a}
Mimosa green salad bowl	7.63^{bB}	11.36^{bA}	10.74^{bA}	6.03^{bC}	8.93^{b}
Crespa Lollo Bionda	6.25^{cB}	5.49^{cB}	4.18^{cA}	6.03^{bB}	5.49^{c}
Mean	7.75^{B}	9.42^{A}	7.78^{B}	7.22^{C}	
CV (%)	7.25				

Total fresh weight (g plant^{-1})

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Me^{a}n
Red salad bowl	18.34^{cA}	14.72^{cB}	13.11^{cB}	14.39^{dB}	15.14^{c}
Salad bowl green	58.85^{aD}	75.04^{aB}	66.01^{aC}	85.09^{aA}	71.24^{a}
Mimosa green salad bowl	35.99^{bC}	62.11^{bA}	47.89^{bB}	36.13^{bC}	45.53^{b}
Crespa Lollo Bionda	15.24^{dB}	16.50^{cB}	13.11^{cB}	19.51^{cA}	16.09^{c}
Mean	32.10^{D}	42.09^{A}	35.03^{C}	38.77^{B}	
CV (%)	5.22				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

in the present work for the same cultivar (14.06 cm). This similarity between results may be related to climate conditions at the two study sites. As for CFW, NCFW and TFW (Table 3), ‘Salad Bowl Green’ stands out with higher averages than the other cultivars. Among the spacings, at 0.25 × 0.25 m and 0.25 × 0.30 m the plants had, on average, the highest values for CFW, of 32.66 and 31.54 g plant^{-1} respectively. Yet, at the spacing of 0.25 × 0.25 m, the plants also achieved the greatest average values for NCFW and TFW.

The largest spacings between plants, 0.25 × 0.25 m and 0.25 × 0.30 m, contributed to the greatest increments in CFW, this because when plants are more widely spaced, there is a smaller overlap between the leaves, resulting in leaves which are larger and of better commercial quality. Santos et al. (2009), working with cultivars of crisp lettuce at a spacing of 0.25 × 0.30 m under high temperature conditions, in Cáceres in the State of Mato Groso, found values for CFW that ranged from 29.0 to 104.3 g plant^{-1}. Similarly, Rodrigues et al. (2008) evaluated different lettuce cultivars of the same group in Iranduba, Amazonas, which has similar mean temperatures to Fortaleza, CE. Those researchers found average values for CFW that varied from 25.5 to 96.7 g plant^{-1}.

With the Salad Bowl Green cultivar, it became clear that the largest spacings between plants afforded the greatest individual average values for production per plant. At the spacing of 0.25 × 0.30 m (133,333 plants ha^{-1}) for example, the average weight per plant was 85.09 g, compared to 75.04 g at the spacing of 0.25 × 0.25 m (160,000 plants ha^{-1}), 66.01 g at 0.20 × 0.25 m (200,000 plants ha^{-1}) and 58.85 g at 0.20 × 0.20 m (250,000 plants ha^{-1}).

This result may be related to less shading being produced between neighbouring plants at the larger spacings. Less shading allows more light to be intercepted by the plants, giving greater efficiency in carrying out photosynthesis, and consequently a greater production of photoassimilates that will contribute to the accumulation of mass and the production of plant tissue (Larcher, 2004). This hypothesis may be strengthened by observing the results of net photosynthesis on these treatments, where plants of this cultivar, when grown at the spacing of 0.25 × 0.30 m, had the greatest rates for net photosynthesis, with a lower mean value seen at the spacing of 0.20 × 0.20 m. For Mondim (1989), larger spacings tend to give an increase in shoot fresh weight, mainly due to less competition between plants for light, water and nutrients.

Rodrigues et al. (2008) in Iranduba, Amazonas, and Santos et al. (2009) in Cáceres, Mato Grosso, worked with different cultivars of crisp lettuce, and found average values for TFW of 29.33 to 104.61 g plant^{-1} and 52.50 to 111.50 g plant^{-1} respectively. Lima et al. (2004) worked with the Vera and Verônica cultivars at two spacings (0.20 × 0.20 m and 0.20 × 0.30 m), in Ribeirão Preto in Sâo Paulo, at maximum and minimum temperatures close to those seen during this study (31 and 20°C respectively). Those authors found that a spacing of 0.20 × 0.30 m, gave higher average values for TFW per plant in the Veronica cultivar.

Plants grown at larger spacings produced, on average, higher individual values for CFW and TFW. However, the smaller spacings were responsible for the largest average values for productivity, due to the larger number of plants per area. Echer et al. (2001) also found higher average values for production at a spacing of 0.20 × 0.20 m when growing lettuce, which may be related to the fact that as the spacing decreases and the population density increases within certain limits, there is a tendency for the total production per area to increase, which can result in greater profitability to the producer.

Similar responses were observed with the fresh and dry commercial, non-commercial and total weights (Table 4). Following the same trend, the Salad Bowl Green cultivar had average values higher than the other cultivars. Among the spacings, 0.25 × 0.25 m and 0.25 × 0.30 m should be noted, as they gave, on average, the greatest values for CDW. However, the former spacing also gave the largest values for NCDW and TDW.

Batista et al. (2007), working in Iguatu, CE, with the Itapuã, Elba and Veneranda cultivars, at a spacing of 0.25 × 0.25 m, found that CDW ranged from 12.7 to 15.3 g plant^{-1}. This variation was much higher than seen in the present work. This difference may be related to when the work was carried out. Although Iguatu has similar climatic conditions to Fortaleza, the experiment conducted by those authors was during the rainy season, when levels of radiation and temperature tend to be milder, favouring the development of the lettuce plants.

For the characteristics of gas exchange, the Red Salad Bowl cultivar displayed the highest internal CO_2 concentrations (Ci) and Ci/Ca ratio (Table 5). On the other hand, 'Salad Bowl Green', which had the highest average values for TFW and TDW, also displayed the lowest values for Ci and Ci/Ca, together with 'Mimosa Green Salad Bowl'. For spacing, the plants presented the highest average concentrations of Ci and Ci/Ca at the spacing of 0.20 × 0.20 m.

For instantaneous carboxylation efficiency (*A*/Ci), the Mimosa Green Salad Bowl and Salad Bowl Green cultivars displayed the highest average values, not differing from each other, but differing from the other cultivars. The spacing of 0.20 × 0.25 m gave the best average value for carboxylation efficiency between the cultivars.

In general, a joint interpretation is necessary to better understand the physiological characteristics. However, as this is a complex discussion, it was performed using only the most relevant search results, that is, the cultivar (Salad Bowl Green) that had the highest values for fresh and dry weight, and the spacing (0.20 × 0.20 m) which gave the greatest values for productivity by weight per hectare. 'Salad Bowl Green' had one of the lowest average values for Ci (Table 5). On the other hand, it had one of the higher average values for rate of photosynthesis (*A*). The higher the value of *A*, the faster

Table 4. Commercial dry weight (CDW), non-commercial dry weight (NCDW) and total dry weight (TDW) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Commercial dry weight (g plant^{-1})

Cultivar	**0.20 × 0.20**	**0.25 × 0.25**	**0.20 × 0.25**	**0.25 × 0.30**	**Mean**
Red salad bowl	0.89^{cA}	0.72^{cB}	0.59^{cB}	0.82^{cA}	0.75^{c}
Salad bowl green	2.47^{aD}	3.31^{aB}	3.03^{aC}	4.06^{aA}	3.21^{a}
Mimosa green salad bowl	1.79^{bC}	2.59^{bA}	2.15^{bB}	1.44^{bD}	1.99^{b}
Crespa Lollo Bionda	0.54^{dB}	0.75^{cA}	0.55^{cB}	0.80^{cA}	0.66^{d}
Mean	1.42^{C}	1.84^{A}	1.58^{B}	1.78^{A}	
CV (%)	5.64				

Non-commercial dry weight (g plant^{-1})

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Me^{a}n
Red salad bowl	0.37^{cA}	0.28^{dB}	0.29^{dB}	0.30^{dB}	0.31^{d}
Salad bowl green	0.69^{aC}	0.89^{aA}	0.78^{aB}	0.90^{aA}	0.81^{a}
Mimosa green salad bowl	0.49^{bA}	0.65^{bA}	0.65^{bA}	0.52^{bC}	0.54^{b}
Crespa Lollo Bionda	0.39^{cB}	0.42^{cB}	0.33^{cC}	0.37^{cA}	0.41^{c}
Mean	0.48^{C}	0.56^{A}	0.51^{B}	0.52^{B}	
CV (%)	4.51				

Total dry weight (g plant^{-1})

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	1.27^{cA}	1.00^{dB}	0.88^{cB}	1.12^{dA}	1.07^{c}
Salad bowl green	3.15^{aD}	4.20^{aB}	3.18^{aC}	4.96^{aA}	4.03^{a}
Mimosa green salad bowl	2.29^{bC}	3.24^{bA}	2.80^{bB}	1.81^{bD}	2.53^{b}
Crespa Lollo Bionda	0.93^{dA}	1.17^{cB}	0.88^{cB}	1.32^{cA}	1.07^{c}
Mean	1.91^{D}	2.41^{A}	2.09^{C}	2.30^{B}	
CV (%)	4.95				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

Table 5. Average values for internal CO_2 concentration (Ci), the Ci/Ca ratio and instantaneous carboxylation efficiency (*A*/Ci) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Internal CO_2 concentration (ppm)

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	316.94^{aA}	304.69^{aB}	290.81^{bC}	311.75^{aA}	306.04^{a}
Salad bowl green	298.94^{bA}	283.56^{bC}	289.50^{bB}	273.94^{dD}	286.48^{c}
Mimosa green salad bowl	291.25^{bA}	269.69^{cC}	281.19^{cB}	292.19^{bA}	283.57^{c}
Crespa Lollo Bionda	316.25^{aA}	287.56^{bC}	299.13^{aB}	284.06^{cC}	296.75^{b}
Mean	305.84^{A}	286.37^{B}	290.15^{B}	290.48^{B}	
CV (%)	1.88				

Ci/Ca ratio

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	0.86^{aA}	0.82^{aB}	0.78^{aC}	0.84^{aA}	0.82^{a}
Salad bowl green	0.81^{bA}	0.76^{cC}	0.78^{aB}	0.73^{dC}	0.77^{c}
Mimosa green salad bowl	0.78^{bA}	0.73^{dC}	0.75^{bB}	0.78^{bA}	0.76^{c}
Crespa Lollo Bionda	0.85^{aA}	0.79^{bB}	0.79^{aB}	0.76^{cC}	0.80^{b}
Mean	0.82^{A}	0.77^{B}	0.77^{B}	0.78^{B}	
CV (%)	1.96				

Instantaneous carboxylation efficiency

Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	0.04^{cD}	0.04^{dC}	0.05^{cA}	0.05^{cB}	0.052^{c}
Salad bowl green	0.05^{bC}	0.05^{bB}	0.06^{bB}	0.06^{aA}	0.060^{a}

Table 5. Contd.

Mimosa green salad bowl	0.06^{aB}	0.06^{aA}	0.07^{aA}	0.05^{cC}	0.061^{a}
Crespa Lollobionda	0.04^{bD}	0.05^{cC}	0.06^{bB}	0.06^{bA}	0.057^{b}
Mean	0.051^{D}	0.057^{C}	0.061^{A}	0.060^{B}	
CV (%)	2.55				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

Table 6. Mean values for stomatal conductance (*gs*) and photosynthesis (*A*) in four lettuce cultivars at different spacings (Fortaleza CE, UFC, 2014).

Stomatal conductance (mol m^{-2} s^{-1})					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	0.28^{cC}	0.29^{cC}	0.36^{bB}	0.44^{aA}	0.34^{d}
Salad bowl green	0.32^{cC}	0.59^{aA}	0.47^{aB}	0.36^{bC}	0.43^{b}
Mimosa green salad bowl	0.40^{bB}	0.32^{cC}	0.50^{aA}	0.28^{cC}	0.37^{c}
Crespa Lollo Bionda	0.57^{aA}	0.43^{bC}	0.51^{aB}	0.39^{bD}	0.47^{a}
Mean	0.39^{B}	0.41^{B}	0.46^{A}	0.36^{C}	
CV (%)	7.37				
Photosynthesis (μmol m^{-2} s^{-1})					
Cultivar	0.20 × 0.20	0.25 × 0.25	0.20 × 0.25	0.25 × 0.30	Mean
Red salad bowl	14.65^{cB}	14.89^{dB}	16.79^{bA}	16.79^{bA}	15.78^{b}
Salad bowl green	15.81^{bC}	16.65^{bB}	16.88^{bB}	18.20^{aA}	16.88^{a}
Mimosa green salad bowl	16.93^{aB}	17.56^{aA}	17.84^{aA}	16.15^{bC}	17.12^{a}
Crespa Lollo Bionda	15.61^{bB}	16.01^{cB}	17.87^{aA}	18.09^{aA}	16.89^{a}
Mean	15.75^{C}	16.27^{B}	17.34^{A}	17.30^{A}	
CV (%)	3.12				

Mean values followed by the same lowercase letter in a column and uppercase letter on a line, do not differ by Scott-Knott test at 5% significance.

the internal CO_2 is consumed, that is, the greater the carboxylation efficiency (*A*/Ci). With the reduction in internal CO_2, the plant stimulates opening of the stomata, favouring an increase in the value for stomatal conductance. The cultivar in question displayed one of the highest values for *A*/Ci and stomatal conductance (gs), with the latter indicating a greater stomatal opening than the other cultivars (Tables 5 and 6). When the internal CO_2 is consumed quickly, mainly due to the higher rates of photosynthesis, the Ci/Ca ratio, which estimates the relationship between the internal and external concentration of CO_2 in the leaf, tends to be lower. When this happens, the efficiency of the photosynthesis will be greater, which may have a positive effect on production (Kaschuk et al., 2012), as verified in 'Salad Bowl Green', with one of the lowest values for the Ci/Ca ratio.

The average results for the spacings under evaluation can also be interpreted in the same way. The smallest spacing (0.20 × 0.20 m) made it possible to obtain plants with a greater value for Ci (Table 5). In turn, higher values for Ci may be related to the shading caused by the plants to each other due to the high planting density. This can be confirmed by two other physiological characteristics, *A* and *A*/Ci. Moreover, the spacing may have resulted in a lower vapour pressure deficit (VPD) that justified this behaviour, especially of the stomata.

The said spacing resulted in the lowest average values for weight in the cultivars under study. With the reduced use of internal CO_2, plants subjected to this spacing end up having to open their stomata at a lower intensity, this reduces stomatal conductance and consequently the Ci/Ca ratio, which is influenced more by the internal concentration of CO_2 in the plant than by that of the atmosphere, which under normal conditions tends to be stable.

The Crespa Lollo Bionda cultivar had the highest average value for stomatal conductance (*gs*) (Table 6), while the spacing of 0.20 × 0.25 m gave the highest average value of *gs* for the cultivars.

Stomatal conductance is an important parameter in predicting water use and net photosynthesis, being controlled by the turgidity of the guard cells that regulate the opening or closing of the stomata. Luminous intensity, relative humidity and wind intensity, among others, are some of the main factors responsible for this process (Taiz and Zeiger, 2013).

It is important to point out that the densest spacings (0.20 × 0.20 m, 0.20 × 0.25 m and 0.25 × 0.25 m) generally displayed higher values for *gs*, indicating a wider opening of the stomatal pores. This may have been due to the existence of the factor known as decoupling, where the higher plant density causes a reduction in the speed of the atmospheric air currents, this reduces the effect of air exchange by the winds in the atmospheric stratum in which the shoots of the lettuce plants are inserted (Larcher, 2004; Taiz and Zeiger, 2013).

In addition to this effect, the wind also acts by removing the boundary layer of air. This layer, in turn, aids in reducing transpiration, as it acts as a barrier to the air both leaving and entering the stoma, which favours the stomatal pore remaining open. The denser the plants, the greater the protection one plant affords another against the wind, that is, if the air layer internal to the aerial part of the plant is moving slowly, the decoupling factor is high, and the stomata tend to remain open to a greater degree and for a longer period, which increases the *gs* when the measurement is taken. Whereas in crops where the spacings are larger, the plants tend to be influenced more by the winds. In this case, the decoupling factor is low or may be nil. Also the boundary layer of air that would enable a reduction in water loss by the stomata, keeping them open for longer and to a greater degree, once removed, causes a reduction in the level of stomatal opening, resulting in a decrease in *gs* (Larcher, 2004; Taiz and Zeiger, 2013). This plant mechanism can be considered as a defence, since it avoids an excessive loss of water through the stomatal pores.

The Salad Bowl Green, Green Mimosa Salad Bowl and Crespa Lollo Bionda cultivars displayed the highest rates of photosynthesis, as did the spacings of 0.20 × 0.25 m and 0.25 x 0.30 m.

The physiological results seen in the plants of all the cultivars when grown at a spacing of 0.20 × 0.20 m, include the lowest average value for fresh and dry weight achieved by the plants. However, as noted above, this result was offset by the greater quantity of plants produced per area, which, although they were smaller, resulted in greater productivity.

Conclusion

The Salad Bowl Green and Green Mimosa Salad Bowl cultivars displayed the best productive and physiological performance when grown at smaller spacings and under semi-arid conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Correlation and path coefficient analysis of top-cross and three-way cross hybrid maize populations

Sayo Sesay[1,2*], David Kolawole Ojo[2], Omolayo Johnson Ariyo[2], Silvestro Meseka[3], Lawrence Stephen Fayeun[4], Ayoola Oluwaseun Omikunle[2,3] and Adebiyi Oyeboade Oyetunde[2,3]

[1]Crop Improvement Program, Rokupr Agricultural Research Center, Rokupr - Sierra Leone Agricultural Research Institute, PMB 1313, Tower Hill, Freetown, Sierra Leone.
[2]Department of Plant Breeding and Seed Technology, College of Plant Science and Crop Production, Federal University of Agriculture, Abeokuta, Nigeria.
[3]Maize Improvement Program, International Institute of Tropical Agriculture, PMB 5320, Oyo Road, Ibadan, Nigeria.
[4]Department of Crop, Soil and Pest Management, Federal University of Technology, Akure, Ondo State, Nigeria.

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Grain yield is a complex quantitative trait that depends on a number of other traits for selection. This study was carried out to reveal the pattern of association with and contribution of traits to grain yield in two maize populations evaluated in three agro-ecological zones of South-Western Nigeria during the 2014 cropping season. The experiment consisted of 10 top-cross and 10 three-way cross maize hybrids, laid out in a randomised complete block design with three replications. Genotypic and phenotypic correlation coefficients and path co-efficient analyses were performed for each hybrid population across the three locations. Results showed significant ($p \leq 0.05$) differences between the two hybrid populations for all the traits mentioned except days to 50% anthesis, ear diameter and 100-grain weight. Field weight in both hybrid populations, number of kernel rows per cob, ear diameter and ear height in top-cross hybrids, as well as ear length and 100-grain weight in the three-way cross hybrids were directly correlated with grain yield. The link between direct and indirect effects on grain yield depends on hybrid population, although some traits showed similar direct effects in both hybrid populations. These traits can be used as the main criteria for grain yield improvement in the respective hybrid populations.

Key words: Correlation, path coefficient analysis, hybrid populations, maize (*Zea mays* L.), grain yield.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most superior cereal crops in the world due to its wide adaptation and varieties of utilisation. It is the most important cereal in Sub-Saharan Africa that is mainly used for food and feed with a small percentage used in agro-allied industries (IITA, 2009). The spread of maize cultivation in the world was

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*Corresponding author. E-mail: osaiosesay@yahoo.com. Tel: +23278084923.

due to its diversity, high adaptability and versatility (Obi, 1991). In Nigeria, maize is rapidly replacing in other cereals (sorghum and millet) in the Savannahs (Fakorede et al., 2003). This might be attributed to its high yields per unit area, husk protection against birds and ability to compete with weeds (Onwueme and Singha, 1991). Despite an increased area of land used for cultivation of maize since the mid- 2000s, production per hectare is still low (1.3 ton/hectare) compared to the 8.6 t/ha in developed countries (IITA, 2007). However, maize yield in Nigeria increased by 57% between 1994 and 2013 with average yield of 1.9 ton/hectare in 2012 and 2013 (FAOSTAT, 2015). This increase might be attributed to better inputs (fertilizer, agrochemicals, irrigations and improved seeds) especially the use of improved varieties.

Hybrid maize are known to be high yielding, superior and vigorous because of hybrid vigour (heterosis) arising from crossing two genetically unrelated parents. There are different types of hybrid this include; single cross, three way cross, double top cross and top cross. A top-cross is a cross between an inbred line and an open pollinated variety while a three-way hybrid is across between an inbred line and single cross hybrid. Top-cross hybrids are considered to be the quickest means of developing hybrids and produce good quantity of seeds compared to a single cross hybrid. The cost of producing top-cross hybrids is comparatively cheaper than conventional hybrid seeds (Bidinge et al., 2005). The decline in grain yield due to recycling top cross hybrid seed is half of that of classical hybrids (Pixley and Banziger, 2004). Given that many farmers recycle seeds set aside from their harvest, the use of non-conventional top cross hybrids could be one approach of enhancing yield levels in maize. Three-way cross hybrids are also regularly used since they are cheap in seed production. They are intermediate between single and double cross hybrids with respect to uniformity, yield, stability and the relative simplicity of selecting and testing (Weatherspoon, 1970).

Grain yield is a complex quantitative trait that depends on a number of other agronomic traits for selection (Fellahi et al., 2013). In order to achieve effective selection for grain yield, it is important to determine its relationship with other traits. The determination of correlation coefficients helps to measure the level of relationships among traits and to establish the level at which these traits are mutually different (Bocanski et al., 2009; Nagabhushan et al., 2011). Correlation coefficients give reliable and useful information on the relationship between the traits in terms of the nature, extent and direction of selection (Zeeshan et al., 2013). Path-coefficient analysis helps to know the nature, extent and direction of selection; it is the most valuable tool commonly used to establish the exact relationships in terms of cause and effect, identify the direct, indirect and total (direct plus indirect) causal effects, as well as to remove any spurious effect that may be present (Hefny, 2011). However, although several studies on relationships between grain yield and its component traits have been conducted in maize (Mohammadi et al., 2003; Saidaiah et al., 2008; Bello et al., 2010; Kumar et al., 2011; Pavan et al., 2011), most did not consider the simultaneous behaviour of such traits between different classes of hybrids. Teodoro et al. (2014) studied the primary and secondary components that are directly or indirectly related to grain maize grain yield. They found out that the link between direct and indirect effects on productivity depends on genetic class. It is therefore important to examine the simultaneous character association and contribution of each of the traits in top-cross and three-way cross hybrids in order to give more attention to those having the greatest influence on grain yield.

MATERIALS AND METHODS

The 20 hybrids comprising 10 top-cross and 10 three-way cross hybrid varieties, used for this study (Table 1) were collected from the Genetic Resources Centre (GRC) of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Field experiments were conducted during the 2014 cropping season at three diverse environments of South-Western Nigeria: The Teaching and Research Farm of the Federal University of Agriculture, Abeokuta, Ogun State [7° 14' North , 3° 26' East and 162 m above sea level (masl)]; National Institute of Horticultural Research, Ibadan, Oyo State (7° 24' N, 3° 50' E and 184 masl); and Federal University of Technology, Akure, Ondo State (7° 18' N, 5° 07' E and 380 masl). The mean monthly rainfall and temperature for each location during the experiment (June - November) are presented in Figures 1 to 3.

At each location, the soil was mechanically ploughed and harrowed. The trials were laid out in randomised complete block design with three replications. Each variety was planted in two-row plots 5 m long, at a spacing of 75 cm × 50 cm. Three seeds per hole were planted and later thinned to two plants per hole. A compound fertilizer of NPK 15:15:15 was applied at the rates of 60 kgN, 60 kgP and 60 kg K_2O ha^{-1} at two weeks after planting. An additional 60 kgN ha^{-1} was also applied as side dressing six weeks after planting (WAP) using urea (46%N). Other crop management practices were applied following the standard recommendations at each location. Sowing of seeds was done on 7th, 9th and 21st August, 2014 at Ibadan, Akure and Abeokuta, respectively.

For each entry, data were collected on plant height (cm), ear height (cm), ear length (cm), ear diameter (mm), 100-grain weight (g) and number of kernel rows per cob on 10 randomly selected plants, while the number of days to 50% anthesis (days), days to 50% silking (days), field weight (kg) and grain yield (t/ha) were determined on a plot basis.

Statistical analysis

Data for each hybrid population, averaged over the three locations, were grouped for each trait and compared by t-test at 5 and 1% probability levels. Data were also subjected to analysis of variance and covariance for each hybrid population across locations using the SAS software version 9.1 (SAS Institute, 2000). The generated components of the variance and covariance were used to estimate the genotypic and phenotypic correlation coefficients as suggested by Singh and Chaudhary (1985):

Table 1. List of maize hybrids used in the study.

Hybrids	Pedigree	Kernel colour
Top-cross maize hybrids		
M0926-7	WhiteDTSTRSyn/IWD-SYN-STR-C3-46-5-BB	White
M0926-8	WhiteDTSTRSyn/IWD-SYN-STR-C3-51-1-B	White
M0926-9	WhiteDTSTRSyn/IWD-SYN-STR-C3-52-2-B	White
M1026-1	IWDC2SynF2/1368xMi82-23-2-1-1-B*7	White
M1026-11	WhiteDTSTRSyn/IWD-SYN-STR-C3-52-4-B	White
M1026-13	WhiteDTSTRSyn/IWD-SYN-STR-C3-70-2-B	White
M1026-2	IWDC2SynF2/1368xMi82-23-2-1-4-B*6	White
M1026-3	IWDC2SYN/P43SRC9FS100-1-1-8-#1-B1-13-B1-B*8	White
M1026-4	WhiteDTSTRSyn/P43SRC9FS100-1-1-8-#1-B1-13-B1-B*8	White
M1226-2	DTSTR-WSYN2/IWD-SYN-STR-C3--52-3-BB	White
Three-way cross maize hybrids		
M1124-17	(1368/Mi82-23-2-1-2-B*7/P43SRC9FS100-1-1-8-#1-B1-13-B1-B*6)-1-1/((ACR-86-8-1-2-1-1-1-B-1-B*4/(Babangoyo/MO17LPA/Babangoyo-28-1-2-1-B*6))-38-1/IWD-SYN-STR-C3--70-2-BB	White
M1124-24	(1368/Mi82-23-2-1-2-B*7/P43SRC9FS100-1-1-8-#1-B1-13-B1-B*6)-65-1/DTPL-W-C7-S2-7-1-1-1-1-B-2-B*4/BabangoyoxMO17LPAxBabangoyo-23-1-3-1-B*6-23-1/IWD-SYN-STR-C3--35-3-BB	White
M1124-27	(1368/Mi82-23-2-1-2-B*7/P43SRC9FS100-1-1-8-#1-B1-13-B1-B*6)-58-1/DTPL-W-C7-S2-7-1-1-1-1-B-2-B*4/BabangoyoxMO17LPAxBabangoyo-23-1-3-1-B*6-9-1/IWD-SYN-STR-C3--51-1-BB	White
M1124-29	(1368/Mi82-28-1-1-2-B*7/P43SRC9FS100-1-1-8-#1-B1-13-B1-B*6)-40-1/DTPL-W-C7-S2-1-2-1-1-5-B-1-B*4/BabangoyoxMO17LPAxBabangoyo-23-4-3-3-B*6-46-1/IWD-SYN-STR-C3--51-1-BB	White
M1124-31	(KU1409/KU1414-SR/A619)-S2-2/9450xKI21-7-2-2-1-1-BB/(POP66SR/ACR91SUWAN1-SRC1/ACR91SUWAN1-SRC1-6X(MP420x4001xMP420)-3-1-3-1-B)S2-5-B*5	Yellow
M1227-14	(KU1409/KU1414-SR/KVI3)-S2-4-1-BB/9450xKI21-1-5-2-1-2-B*5/(SYN-Y-STR-34-1-1-1-1-2-1-B*5/NC354/SYN-Y-STR-34-1-1-1-1-2-1-B*5)-S2-7-5-BB-B-B-B-B	Yellow
M1227-18	(KU1409/KU1414-SR/A619)-S2-3-B/9450xKI21-1-4-1-1-2-B-B-B-B-B/(POP66SR/ACR91SUWAN1-SRC1/ACR91SUWAN1-SRC1-6X(MP420x4001xMP420)-3-1-3-1-B)S2-5-BB-B-B-B-B	Yellow
M1227-21	9450xKI21-7-2-2-1-1-B-B-B-B-B/(KU1409/KU1414-SR/NC350)-S2-24-1-BB/(POP66SR/ACR91SUWAN1-SRC1/ACR91SUWAN1-SRC1-6X(MP420x4001xMP420)-3-1-3-1-B)S2-10-BB-B	Yellow
M1227-6	1368 x Mi82-33-1-1-B-B-B-B-B-B/LATA-26-1-1-1-B-B-B-B-B-B-B/IWD-SYN-STR-C3--52-3-B-B-B	White
M1227-7	1368xHIx4269-1x1368-7-1-B-B-B-B-B-B-B-B-B/DTPL-W-C7-S2-1-2-1-1-5-B-1-B-B-B-B-B/IWD-SYN-STR-C3--47-1-B-B-B	White

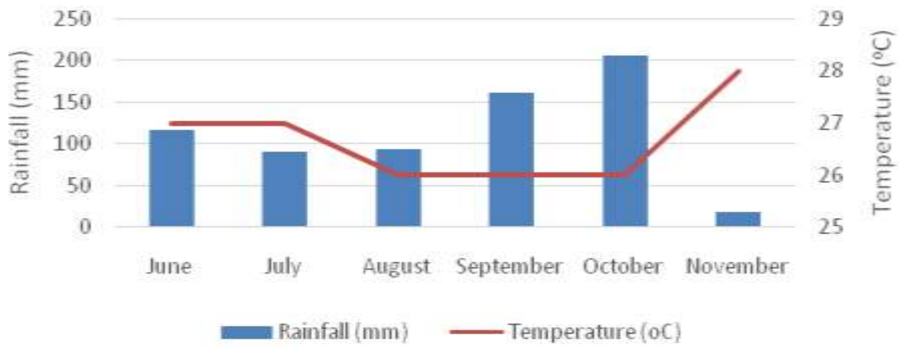

Figure 1. Mean monthly rainfall and temperature of location Abeokuta.

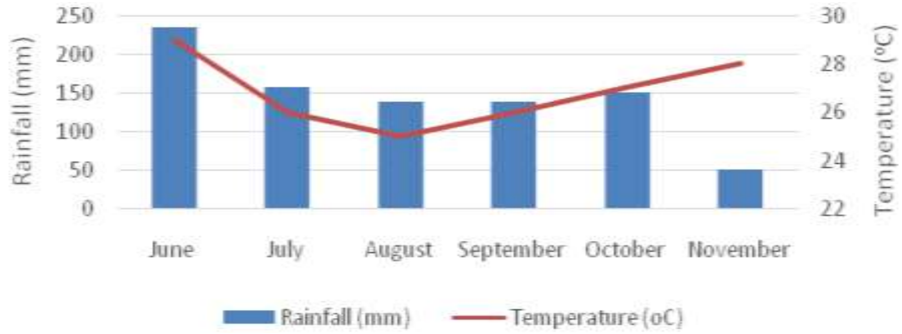

Figure 2. Mean monthly Rainfall and temperature of location Ibadan.

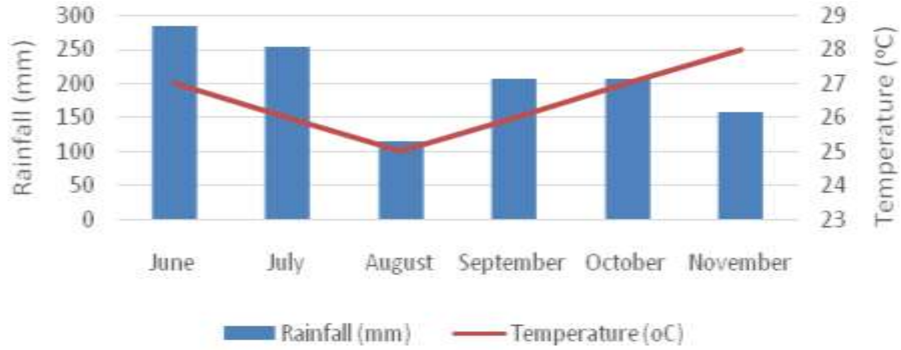

Figure 3. Mean monthly rainfall and temperature of location Akure.

i. Genotypic correlation coefficient (r_g) = $\frac{Cov_g(X_1.X_2)}{\sqrt{var_g X_1 . var_g X_2}}$

ii. Phenotypic correlation coefficient (r_p) = $\frac{Cov_p(X_1.X_2)}{\sqrt{var_p X_1 . var_p X_2}}$

Where: X_1 and X_2 = characters X; Cov_g = genotypic covariance and Cov_p= phenotypic covariance; Var_g = genotypic variance and Var_p= phenotypic variance.

Test of significance (at 5 and 1% probability levels) of correlation was done by comparing the computed values against table 'r' values given by Fisher and Yates (1963) at n-2 degree of freedom, where, n = number of genotypes x number of locations x number of replications.

The correlation coefficients of all the traits were partitioned into direct and indirect effects by path coefficient analysis using the R statistical package version 3.0.3 (R Core Team, 2014) following the procedure of Dewey and Lu (1959). The path coefficient simultaneous equations of Ahmed et al. (2002) were adopted.

$r_{1y} = P_1 + r_{12}P_1 + r_{13}P_3$

Table 2. Mean values of ten traits for ten top-cross and ten three-way cross hybrids across three locations, Nigeria, 2014.

Traits	Top-Cross	3-Way Cross	Mean difference	$CI_{0.95}$	CV (%)	T-value	P-value
DPOL	59.94	59.82	0.12	0.73 ± 0.97	0.17	0.29	0.78
DSLK	62.4	61.65	0.76	0.13 ± 1.38	0.86	2.39	0.02
PLHT	201.91	185.23	16.67	13.56 ± 19.77	6.09	10.65	0.00
EHT	87.71	82.83	4.81	1.34 ± 8.28	4.05	2.76	0.01
ELTH	17.4	16.59	0.82	0.28 ± 1.37	3.37	2.99	0.00
EDMT	48.38	48.39	-0.02	0.63 ± 0.59	0.01	-0.07	0.95
KROW	14.76	14.28	0.47	0.01 ± 0.96	2.34	1.95	0.04
GWT	30.29	29.99	0.29	0.89 ± 1.47	0.70	0.49	0.63
FDWT	6.25	5.93	0.32	0.03 ± 0.68	3.72	1.79	0.05
YLD	6.07	5.76	0.31	0.03 ± 0.65	3.59	1.83	0.05

Significant at 5 and 1% probability levels for t-test; CV, coefficient of variation, CI, confidence interval of mean difference, where the difference is not significant when the interval surpasses the contrast. DPOL= days to 50% anthesis, DSLK = days to 50% silking, PLHT = plant height, EHT= ear height, ELTH = ear length, EDMT = ear diameter, KROW = number of kernel rows per cob, GWT = 100-grain weight, FDWT = field weight and YLD = grain yield.

Similarly for r_{2y} and r_{3y}

$r_{2y} = r_{21}P_1 + P_2 + r_{23}P_3$;
$r_{3y} = r_{31}P_1 + r_{32}P_2 + P_3$.

The residual effect was obtained as $P_x = 1 - P_{xy}\, r_{xy}$. Where, P_x = residual effect of variable X;
$P_{xy}r_{xy}$= product of direct effect of variance X and its correlation (r) with yield (Y).

RESULTS

Table 2 presents the mean values of traits for ten top-cross and ten three-way cross hybrids across the three locations. The results showed significant ($p \leq 0.05$) differences between the top-cross and three-way cross hybrids for days to 50% silking, plant height, ear height, ear length, number of kernel rows per cob, field weight and grain yield. However, there were no significant differences observed between the two hybrid populations for days to 50% anthesis, ear diameter and 100-grain weight.

Estimation of genotypic and phenotypic correlation coefficients of grain yield and other yield-related traits are presented for top-cross hybrids (Table 3) and three-way hybrids (Table 4). Table 3 shows a positive and highly significant genotypic and phenotypic correlation ($p<0.01$) between grain yield with plant height (r_g = 0.50 for genotypic correlation and r_p = 0.47 for phenotypic correlation), ear height (0.79 and 0.74), ear diameter (0.68 and 0.63), number of kernel rows per cob (0.35 and 0.33) and field weight (0.98 and 0.97). On the other hand, a negative and significant correlation with days to 50% silking (-0.51 and -0.43 $p<0.01$). There was a positive and highly significant genotypic and phenotypic correlation between 100-grain weight, days to 50% anthesis, days to 50% silking, plant height and ear length. Table 4 shows that grain yield had a positive and highly significant genotypic and phenotypic correlation with ear length [r_g= 0.27 ($p<0.01$) and r_p= 0.26 ($p<0.05$)], ear diameter [0.61 and 0.60 ($p<0.01$)], 100-grain weight [0.35 and 0.34 ($p<0.01$)] and field weight [0.98 and 0.96 ($p<0.01$)]. However, we noticed a negative and significant correlation with days to 50% anthesis [-0.38 and -0.26 ($p<0.01$)]. The genotypic and phenotypic correlation of 100-grain weight with ear diameter and field weight was positive and highly significant

Table 5 presents the genotypic direct and indirect effects of nine traits on grain yield for the top-cross hybrids. There was maximum positive direct effect on grain yield by days to 50% anthesis (0.52), ear diameter (0.47), ear height (0.36), field weight (0.34), ear length (0.23) and number of kernel rows per cob (0.19). However, days to 50% silking (-0.21), 100-grain weight (-0.19) and plant height (-0.02) exerted negative direct effects on grain yield. The genotypic direct and indirect effects of nine traits on grain yield for the three-way cross hybrids are presented in Table 6. The highest positive direct effect on grain yield was recorded for field weight (0.99) and number of kernel rows per cob (0.99) followed by 100-grain weight (0.98), plant height (0.59), ear length (0.49) and days to 50% silking (0.41). On the other hand, ear height (-0.93), ear diameter (-0.89) and days to 50% anthesis (-0.21) had negative direct effects on grain yield. Traits in three-way cross hybrids contributed higher values on grain yield than those in top-cross hybrids.

DISCUSSION

Significant and positive correlation between two traits suggests that these traits can be improved simultaneously in a selection programme, because of mutual relationships that exist among traits (Hayes et al., 1955). This study revealed that both genotypic and phenotypic correlation coefficients were significant in most of the

Table 3. Genotypic (G) and Phenotypic (P) correlation coefficients among grain yield and other related traits in 10 top- cross hybrids combined across three locations, Nigeria, 2014.

Character	R	DPOL	DSLK	PLHT	EHT	ELTH	EDMT	KROW	GWT	FDWT	YLD
DPOL	G	1.00	0.92**	0.31**	0.04	0.71**	-0.67**	-0.84**	0.85**	-0.23*	-0.20
	P	1.00	0.89**	0.26*	0.03	0.63**	-0.59**	-0.75**	0.71**	-0.18	-0.19
DSLK	G		1.00	0.21*	-0.14	0.67**	-0.89**	-0.85**	0.66**	-0.55**	-0.51**
	P		1.00	0.14	-0.14	0.56**	-0.73**	-0.73**	0.51**	-0.42**	-0.43**
PLHT	G			1.00	0.77**	0.48**	-0.06	-0.38**	0.41**	0.51**	0.50**
	P			1.00	0.77**	0.48**	-0.05	-0.34**	0.40**	0.48**	0.47**
EHT	G				1.00	0.05	0.21*	0.16	0.10	0.77**	0.79**
	P				1.00	0.06	0.20	0.17	0.10	0.71**	0.74**
ELTH	G					1.00	-0.39**	-0.75**	0.77**	0.05	0.03
	P					1.00	-0.38**	-0.72**	0.76**	0.06	0.02
EDMT	G						1.00	0.61**	-0.19	0.71**	0.68**
	P						1.00	0.58**	-0.17	0.65**	0.63**
KROW	G							1.00	-0.77**	0.32**	0.35**
	P							1.00	-0.73**	0.30**	0.33**
GWT	G								1.00	0.18	0.16
	P								1.00	0.16	0.15
FDWT	G									1.00	0.98**
	P									1.00	0.97**
YLD	G										1.00
	P										1.00

*, **Significant at 0.05 and 0.01 probability levels, respectively. The values without asterisk are not significant; n = 90, degree of freedom = n-2 = 88. DPOL = days to 50% anthesis, DSLK = days to 50% silking, PLHT = plant height, EHT = ear height, ELTH = ear length, EDMT = ear diameter, KROW = number of kernel rows per cob, GWT = 100-grain weight, FDWT = field weight and YLD = grain yield.

Table 4. Genotypic (G) and phenotypic (P) correlation coefficients among grain yield and other related traits in 10 three-way cross hybrids combined across three locations, Nigeria, 2014.

Character	R	DPOL	DSLK	PLHT	EHT	ELTH	EDMT	KROW	GWT	FDWT	YLD
DPOL	G	1.00	0.98**	0.69**	0.96**	0.40**	-0.40**	0.19	-0.42**	-0.37**	-0.38**
	P	1.00	0.75**	0.43**	0.63**	0.26*	-0.27**	0.11	-0.28**	-0.26*	-0.26*
DSLK	G		1.00	0.50**	0.89**	0.56**	-0.25*	0.21*	-0.39**	-0.11	-0.13
	P		1.00	0.42**	0.80**	0.49**	-0.22*	0.17	-0.36**	-0.15	-0.12
PLHT	G			1.00	0.75**	0.28**	-0.40**	-0.13	-0.30**	0.05	0.04
	P			1.00	0.74**	0.26*	-0.37**	-0.13	-0.27**	0.04	0.02
EHT	G				1.00	0.50**	-0.05	0.18	-0.23*	0.19	0.19
	P				1.00	0.47**	-0.04	0.15	-0.21*	0.18	0.16

Table 4. contd.

ELTH	G					1.00	-0.20	-0.45**	0.01	0.23**	0.27**
	P					1.00	-0.16	-0.37**	0.01	0.23**	0.26*
EDMT	G						1.00	0.39**	0.52**	0.63**	0.61**
	P						1.00	0.36**	0.50**	0.60**	0.60**
KROW	G							1.00	-0.47**	-0.03	-0.05
	P							1.00	-0.45**	-0.03	-0.07
GWT	G								1.00	0.33**	0.35**
	P								1.00	0.31**	0.34**
FDWT	G									1.00	0.98**
	P									1.00	0.96**
YLD	G										1.00
	P										1.00

*, ** significant at 0.05 and 0.01 probability levels, respectively. The values without asterisk are not significant; n = 90, degree of freedom = n-2 = 88. DPOL = days to 50% anthesis, DSLK = days to 50% silking, PLHT = plant height, EHT = ear height, ELTH = ear length, EDMT = ear diameter, KROW = number of kernel rows per cob, GWT = 100-grain weight, FDWT = field weight and YLD = grain yield.

Table 5. Direct (diagonal bold) and indirect effects of nine traits on grain yield of 10 top-cross maize hybrids at genotypic level evaluated across three locations, Nigeria, 2014.

Trait	DPOL	DSLK	PLHT	EHT	ELTH	EDMT	KROW	GWT	FDWT	Rg
DPOL	**0.52**	-0.17	-0.05	0.01	0.17	-0.28	-0.16	-0.16	-0.08	-0.20
DSLK	0.48	**-0.21**	-0.06	-0.05	0.16	-0.39	-0.15	-0.12	-0.17	-0.51
PLHT	0.16	-0.04	**-0.02**	0.27	0.11	-0.03	-0.06	-0.07	0.17	0.50
EHT	0.02	0.03	0.00	**0.36**	0.01	0.10	0.03	-0.02	0.26	0.79
ELTH	0.37	-0.12	-0.08	0.02	**0.23**	-0.16	-0.13	-0.12	0.02	0.03
EDMT	-0.36	0.19	0.03	0.07	-0.11	**0.47**	0.12	0.04	0.24	0.68
KROW	-0.44	0.18	0.01	0.06	-0.19	0.28	**0.19**	0.14	0.11	0.35
GWT	0.44	-0.14	-0.03	0.04	0.18	-0.06	-0.15	**-0.19**	0.06	0.16
FDWT	-0.06	0.11	-0.06	0.27	0.01	0.33	0.06	-0.03	**0.34**	0.98

Residual effect = 0.02; rg = genotypic correlation coefficient, DPOL = days to 50% anthesis, DSLK = days to 50% silking, PLHT = plant height, EHT = ear height, ELTH = ear length, EDMT = ear diameter, KROW = number of kernel rows per cob, GWT = 100-grain weight, FDWT = field weight and YLD= grain yield.

character association and the magnitude of genotypic correlation coefficients for most of the characters was higher than their corresponding phenotypic correlation coefficients, except in a few cases, in both hybrid populations. This indicates the low influence of the environment in the total expression of the hybrids. This also indicates an inherent relationship between the traits studied. Such results are in line with the findings of Hefny

Table 6. Direct (diagonal bold) and indirect effects of nine traits on grain yield of 10 three-way cross maize hybrids at genotypic level evaluated across three locations, Nigeria, 2014.

Trait	DPOL	DSLK	PLHT	EHT	ELTH	EDMT	KROW	GWT	FDWT	rg
DPOL	**-0.21**	0.44	0.39	-0.89	0.19	0.36	0.23	-0.41	-0.48	-0.38
DSLK	-0.22	**0.41**	0.28	-0.83	0.27	0.22	0.25	-0.38	-0.14	-0.13
PLHT	-0.14	0.20	**0.57**	-0.70	0.14	0.36	-0.16	-0.29	0.07	0.04
EHT	-0.20	0.36	0.43	**-0.93**	0.24	0.04	0.22	-0.22	0.25	0.19
ELTH	-0.08	0.23	0.16	-0.46	**0.49**	0.18	-0.54	0.01	0.30	0.27
EDMT	0.08	-0.10	-0.23	0.05	-0.10	**-0.89**	0.47	0.51	0.82	0.61
KROW	-0.04	0.09	-0.07	-0.17	-0.22	-0.35	**0.99**	-0.24	-0.04	-0.05
GWT	0.09	-0.16	-0.17	0.21	0.00	-0.46	-0.57	**0.98**	0.43	0.35
FDWT	0.08	-0.05	0.03	0.00	0.11	-0.47	-0.04	0.32	**0.99**	0.98

Residual effect = 0.009; rg = genotypic correlation coefficient, DPOL = days to 50% anthesis, DSLK = days to 50% silking, PLHT = plant height, EHT = ear height, ELTH = ear length, EDMT = ear diameter, KROW = number of kernel rows per cob, GWT = 100-grain weight, FDWT = field weight and YLD = grain yield.

(2011), Zeeshan et al. (2013) and Nataraj et al. (2014). The observed positive and significant genotypic and phenotypic correlations of grain yield with plant height, ear height, ear diameter, number of kernel rows per cob and field weight in top-cross hybrids, ear length, ear diameter, 100-grain weight and field weight in three-way cross hybrids indicate that these traits are essential yield components, reflective estimators and selection for them in the respective hybrid populations may lead to a substantial improved grain yield. Nataraj et al. (2014) reported similar observations in both hybrid classes. Furthermore, in top-cross hybrids, ear height, ear diameter, field weight and grain yield had positive and significant genotypic correlation with each other. This means that an increase in one trait would ultimately increase another and thereby increase grain yield. The negative significant genotypic and phenotypic correlations between grain yield and days to 50% silking in top-cross hybrids and days to 50% anthesis in three-way cross hybrids will enhance the development of early maturing and high-yielding varieties in the respective hybrid populations. Similar results confirming these results have been reported by Nataraj et al. (2014). Hefny (2011) reported negative non-significant genotypic and phenotypic correlation between yield plant^{-1}, days to 50% anthesis and days to 50% silking under optimal sowing conditions. However, in both hybrid populations, the genotypic and phenotypic correlations between grain yield, ear diameter and field weight were positive and significant, suggesting the reliability of these traits as good selection indices for high grain yield in both hybrid populations. Contrary to this result, Teodoro et al. (2014) reported a positive correlation between yield, weight of 100-grains and number of kernels per row in both genetic classes of single and triple-cross maize hybrids. The present study further confirms the notion that the association of characters with yield in maize depends on the genetic class. Also, the significant positive correlations between 100-grain weight, days to 50% anthesis, days to 50% silking, plant height, and ear length further confirm the finding by Ojo et al. (2006) that 100-grain weight is a good index for selection.

With the magnitude of the contribution by each trait to grain yield, each hybrid population can be improved using the path information. Field weight, ear length and kernel rows per cob had positive direct effects on grain yield in both hybrid populations. In addition, days to 50% anthesis, ear diameter and ear height exhibited positive direct effects on grain yield in top-cross hybrids, whereas days to 50% silking, plant height and 100-grain weight had positive direct effects on grain yield in the three-way cross hybrids. This indicates that a slight increase in any of the above traits in the respective hybrid populations may directly contribute to an increase in grain yield. Similar results were reported by various researchers. For instance, Teodoro et al. (2014) reported a high direct effect of number of grains row^{-1} and weight of 100-grains on grain yield in both genetic classes. Similarly, Hefny (2011) observed a direct positive effect of ear weight plant^{-1}, days to 50% anthesis, 100-grain weight and ear length (at early sowing); and ear diameter, days to 50% silking and days to 50% anthesis (at late sowing) on yield. The negative direct effects observed in this study by days to 50% silking, 100-grain weight and plant height in top-cross hybrids, and ear height, ear diameter and days to 50% anthesis in three-way cross hybrids indicate that these traits only contribute to grain yield mainly through their high and positive indirect effects on other characters in the respective hybrid populations. Days to 50% silking and 100-grain weight showed the highest positive indirect effect on grain yield through days to 50% anthesis, while plant height had the highest positive indirect effect on grain yield via ear height in the top-cross hybrids. In the three-way cross hybrids, maximum positive indirect effect on grain yield was exhibited by days to 50% anthesis and ear height via days to 50%

silking and plant height (and field weight in addition to ear height), whereas ear diameter showed the highest positive indirect effect on grain yield through field weight and 100-grain weight. Rigon et al. (2014) reported a direct negative effect of number of grains per ear and weight of 100 grains in maize. They found that these traits had the highest positive indirect effect on yield through mass per ear.

Conclusions

From the study, field weight in both hybrid populations, number of kernel rows per cob, ear diameter and ear height in the top-cross hybrids, as well as ear length and 100-grain weight in the three-way cross hybrids were directly correlated with grain yield. These traits can be used as the main criteria for grain yield improvement in the respective hybrid populations. Some traits showed similar direct effects in both hybrid populations, but the link between direct and indirect effects on grain yield depends on hybrid population.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Micronutrients application on cultivation of sugarcane billets

Fernanda Forli[1]*, Rafael Otto[2], Godofredo César Vitti[2], Diego Wylliam do Vale[3] and Rodrigo Takashi Maruki Miyake[3]

[1]University of Western São Paulo - UNOESTE. Raposo Tavares Highway, Km 572, 19067-175 Presidente Prudente (SP), Brazil.
[2]Soil Science Department, University of São Paulo ESALQ/USP, 13418-900, Piracicaba/SP, Brazil.
[3]Santa Clara Agroscience, 14025186, Ribeirão Preto/SP, Brazil.

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The production of sugarcane is constantly growing in Brazil, and by the 2016/2017 season, it is estimated to have reached 691 million tons. However, productivity has not shown significant increase, this is due largely to inadequate nutritional supplementation of sugarcane plantations, especially the micronutrients. The aim of this study was to evaluate the effect of micronutrients application on the billets and quality of sugarcane in the groove of sugarcane plantation. The experiment was carried out in randomized blocks of six treatments, with application of micronutrients sources in the planting furrow, with 4 repetitions. Number of stems, leaf nutrient content, sugarcane yield and total recoverable sugar (ATR) of sugarcane were evaluated. The use of micronutrients Cu, Mn and Zn chelated associated with sources of K_2O, B and Mo promoted increased productivity of billets (TCH) 10 and 15% with doses of 1.0 and 1.5 L ha^{-1} complex nutrient respectively. The exclusive application of Boric Acid and Zinc Sulphate in dosages of 2.03 kg ha^{-1} did not increase the productivity of sugarcane. Nutrient sources applied on billets did not result in increases in technological quality of sugarcane, assessed by ATR.

Key words: *Saccharum* spp, boron, copper, zinc, manganese, molybdenum, fertilization, soil fertility.

INTRODUCTION

The sugarcane industry is of great economic, social and strategic importance to Brazil, and the world at large due to the sustainable use of biomass energy (Agrianual, 2015). Projection for the crop production in Brazil in 2016/2017 was around 30 billion liters, slightly lower than production in the previous harvest, because of climatic factors and nutrition of sugarcane plantations. Domestic consumption for 2018 is projected at 30.3 billion liters and exports at 11.3 billion (Agrianual, 2015). There are many agronomic techniques used in the production of sugarcane, such as the choice of suitable varieties of the soil and climate, conservation and chemical correction of soil, pests and weeds control, etc. The search for the most appropriate fertilizer, as well as the most balanced fertilization for the purpose of maximum productivity is on constant increase. The fertilization of sugarcane should

*Corresponding author. E-mail: fernandaforli@unoeste.br.

be performed with the application of macro and micronutrients needed to trigger the physiological processes of plants, which determine the final crop yield. The micronutrients perform vital functions in plant metabolism or as part of compounds responsible for metabolic and/or physiological processes as enzyme activators (Malavolta et al., 1974; Epstein, 1975). Although most of the work carried out in the Center-South of Brazil did not show responses of sugarcane to the application of micronutrients (Alvarez and Wutke, 1963; Espironelo 1972, Alvarez et al., 1979; Siqueira et al., 1979 and Azeredo and Bolsanello, 1981) in some studies in São Paulo, there was a significant effect on production of stems in a Oxisol Dark, sandy phase, with the application of Cu and Zn in the form of chelates (Alvarez, 1984) and a Yellow Red Latosol, sandy phase, with the application of Zn (Cambria et al., 1989). In the country's northeast region, symptoms of micronutrient deficiencies have been common, with responses to the application of Cu and Zn (Marinhoe Albuquerque, 1981). Regarding boron, Alvarez and Wutke (1963) studied the application of various micronutrients to sugarcane, planted in Argisol Red Yellow and Purple Latosol, and getting positive reaction of boron on the first floor. According Orlando Filho et al., (2001), sugarcane often presents the phenomenon of "hidden hunger" in relation to micronutrients, this means when there is deficiency which economically limits productivity, but the plant has no visible symptoms. Several factors influence the absorption of micronutrients by sugarcane, the main soil type, crop variety, and plant age (Orlando Filho et al., 1983). The export of micronutrients by sugarcane is given in the following order: iron (Fe) > manganese (Mn) > zinc (Zn) > copper (Cu) > boron (B) > molybdenum (Mo). In this context, the objective was to evaluate the effect of application of different sources of micronutrients in productivity and quality of sugarcane.

MATERIALS AND METHODS

The experiment was conducted in the municipality of Rafard-SP (23° 00 '43 "S, 47° 31' 37" O) in Retiro site in an area cultivated with the crop of sugarcane variety SP 83-2847. Before the experiment was setup, soil sampling was performed at 0 to 20 and 20 to 40 cm, removing 15 sub-samples for each of the two composite samples for the purpose of characterization (physical and chemical parameters) of the second experimental area recommendations (Raij and Cantarella, 1997), (Table 1). The experimental area received of N, P and K_2O, respectively. The area application of 1 t ha^{-1} of limestone, two months before the experiment and 500 kg ha-1 of magnesium thermophosphate without micronutrients in total area. Fertilization was carried out at planting with the application of 40, 100 and 100 kg ha^{-1} received the application of 300 g ha^{-1} Regent® (Fipronil) and 6.5 L ha^{-1} Furadan® (Carbofuran) in the planting furrow at the time of mating of the seedlings. The experimental design was randomized blocks with 6 treatments and 4 replications, totaling 24 experimental units. Each experimental unit consisted of 14 lines of 10 m with 1.4 m line spacing, totaling 196 m^2. The treatments consisted of application of micronutrients on billets at planting of sugarcane. Treatments applied in the planting furrow were 1.0 L ha^{-1} Wuxal Semillion® (T1); 1.5 L ha^{-1} Wuxal Semillion® (T2); 2 L ha^{-1} Wuxal Semillion® (T3); 1 L ha^{-1} Wuxal Semillion® + 600 g ha^{-1} of Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid) (T4); 600 g ha^{-1} of Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid) (T5) and control treatment (T6). The guarantee of complex micronutrient applied in the treatments. The guarantee of complex micronutrient applied in the treatments were: Wuxal Semilon®: K_2O: 150 g L^{-1}; 39 g L^{-1}; B: 15 g L^{-1}; Cu: 7.5 g L^{-1}; Mn: 15 g L^{-1}; Mo: 22.5 g L^{-1}; Zn: 22.5 g L^{-1}; Wuxal Polimicro®: B: 25 g L^{-1}; Mn: 25 g L^{-1}; Mo: 25 g L^{-1}; Zn: 49 g L^{-1}; S: 15 g L^{-1}. The number of stems in two meters in the three main lines of the experiment at 120 days after the beginning of the experiment was determined. The harvest of stalk was performed at 10 meters from the centerlines of each experimental unit, so that each of the ends of the lines was discarded. The stems were weighed using truck transshipment fitted with load cell. Prior to harvest, 10 culms were randomly retired, tied identified and then sent to the plant laboratory to determine the technological parameters. The results were submitted to analysis of variance (ANOVA) using the F test at 5% probability. When there was significance in ANOVA was made average comparison test by Tukey test (p = 0.05 and 0.10) using the statistical program SAS (2002).

RESULTS AND DISCUSSION

The number of culms was not affected by the application of micronutrient sources on the sugarcane stalks (Table 2). The number of culms is a biometric variable that mostly affects the productivity of sugarcane. Many studies which evaluate fertilization with macronutrients, especially nitrogen; show high correlation between number of stems, and yield of sugarcane (Vale et al., 2012). It is noteworthy that the average number of stems found in this study (11.9 tillers per meter) is adequate and sufficient to ensure high productivity (Weber et al., 2001).Different letters differ according to Tukey's test at 5% probability. T1: 1.0 L ha^{-1} Wuxal Semillion®; T2: 1.5 L ha^{-1} Wuxal Semillion®); T3: 2 L ha^{-1} Wuxal Semillion®; T4: 1 L ha^{-1} Wuxal Semillion® + 600 g ha^{-1} Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid); T5: 600 g ha^{-1} of Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid) and T6: Treatment control. The nutrient content in leaf +1 sugar cane, except manganese, showed no effect of the application of micronutrient sources on the billets (Table 3).

Different letters in the same column differ according to Tukey's test at 5% probability. T1: 1.0 L ha^{-1} Wuxal Semillion®; T2: 1.5 L ha^{-1} Wuxal Semillion®); T3: 2 L ha^{-1} Wuxal Semillion®; T4: 1 L ha^{-1} Wuxal Semillion® + 600 g ha^{-1} Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid); T5: 600 g ha^{-1} of Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid) and T6: Treatment control.Although there was no effect of the application of micronutrients in the planting furrow in the leaf content of these essential elements, the importance of nutrition culture, such as borate ion like complex sugars, should be noted, indicating the

Table 1. Chemical and physical properties of the soil before the experiment.

Depth	MO	pH	P	S	K	H	Mg	Al	H	H + Al	SB	CTC	V
cm	**gdm $^{-3}$**	**$CaCl_2$**	**mg dm $^{-3}$**					**mmol dm $^{-3}$**					**%**
0-20	10	4.4	10	32	1.1	13	3	5	21.9	27	17.3	44.2	39
20-40	9	4.4	7	30	0.5	7	2	6	22.0	28	9.7	37.7	26
Depth	B	Cu	Fe	Mn	Zn					Clay	Silt	Sand	-
cm			**mg dm $^{-3}$**								**g kg $^{-1}$**		**-**
0-20	0.13	0.3	64	6.0	0.5					146	124	731	-
20-40	0.10	0.3	37	2.6	0.4					133	144	724	-

Table 2. Average number of stems per meter depending on the application of micronutrient sources in the planting furrow.

Treatment	Number of culms
1	12.6
2	12.1
3	11.6
4	11.6
5	11.7
6	12.1
DMS	1.8
CV (%)	9.0

Table 3. Macro Foliar and sugarcane micronutrients due to the application of micronutrient sources in the planting furrow.

Treatments	N	P	K	Ca	Mg	S	B	Zn	Mn	Fe	Cu
			g kg $^{-1}$						**mg kg $^{-1}$**		
T1	17.1	0.9	5.8	2.8	1.3	2.2	6.3	15.8	40.0^{b}	110.6	5.8
T2	17.4	0.9	6.2	2.8	1.5	1.9	6.9	13.4	43.8^{b}	118.1	5.1
T3	16.7	0.8	6.4	2.6	1.3	2.2	7.1	14.6	48.8^{ab}	117.5	5.4
T4	17.7	0.8	6.0	3.0	1.7	1.6	7.3	14.9	50.6^{a}	116.9	5.9
T5	17.3	0.9	6.0	2.8	1.4	1.7	6.7	14.7	50.0^{a}	122.5	5.7
T6	18.2	0.9	5.2	3.2	1.6	1.7	7.5	14.4	47.5^{ab}	118.1	5.4
DMS	1.55	0.11	1.32	0.69	0.32	0.50	1.06	2.72	11.4	12.99	1.70
CV (%)	5.5	7.9	13.9	15.2	13.9	16.9	9.6	11.7	15.4	6.9	14.4

likelihood of their participation in the transport of carbohydrates from the leaves toother organs, a fact important in the culture of sugarcane (Orlando Filho et al., 2001). Furthermore, it is suggested that boron acts in the division, cell maturation and differentiation, lignification of cell walls and inhibition of starch formation by boron combination with the active site of phosphorylase, which prevents excessive polymerization of sugars in their local synthesis (Sobral and Weber, 1983). Copper is one of the most important micronutrients for sugarcane, acting as an activator of several enzymes, such as the fenolase, laccase, polifenoxolidase, etc. It also operates in the process of photosynthesis, presenting important role in electron transport via plastocyanin (Taiz and Zeiger, 2004). Manganese plays important role, participating in various reactions of the Krebs cycle, in protein synthesis, cell proliferation, photosynthesis and enzyme activation of

Table 4. Average cane yield (TCH), total recoverable sugars (ATR) due to the application of micronutrient sources in the planting furrow.

Treatment	Productivity (t ha^{-1})	ATR ($kg.t^{-1}$)	Relative Yield (%)
1	150.9^a	146.4	110.6
2	156.9^a	149.7	115.0
3	147.7^b	144.9	108.3
4	146.8^b	143.4	107.6
5	147.8^b	142.9	108.4
6	136.4^b	146.9	100.0
Average	147.8	145.7	
DMS	13.2	6.9	
CV (%)	12.0	5.8	

sugarcane (Sobral and Weber, 1983). Molybdenum has a direct effect on nitrogenase enzymes and nitrate reductase, which makes proper nutrition with this important micronutrient for the occurrence of biological nitrogen fixation by sugarcane and assimilation of NO_3 in organic compounds (Sobral and Weber, 1983; Orlando Filho et al., 2001). Zinc directly affects the growth of sugarcane plants, since the nutrient is essential for the synthesis of tryptophan which is a precursor of indole acetic acid (IAA), which will form the enzymes responsible for cell growth and elongation. This micronutrient is also involved in the activation of various enzymes (Sobral and Weber, 1983; Orlando Filho et al., 2001; Taiz and Zeiger, 2004). The differences between the observed levels and the ones reported in the literature can be justified due to the sampling time, and was considered sampling at 4 months after planting while according to Raij and Cantarella (1997), sampling refer to full development of culture, which occurs after 4 months of sprouting and also to other factors, such as cultivars soil and climatic conditions, different productivities and the dilution effect portrayed by Jarrell and Beverly (1981), where the concentration of nutrients is diluted with the greatest growth plant. Gomez Alvarez (1974), adds that the concentration of nutrients in the leaves of sugarcane is affected by the age of the culture, climate variations (especially cloudiness) and even the time of day, which indicates as ideal from 6 to 8 h in the morning. Thus, it appears that several factors can influence the nutrient content, thus explaining the differences between the levels found and the ones recorded in the literature. The sugarcane yield had the effect of the application of micronutrients on bill at planting (Table 4). However the levels of total recoverable sugars (ATR) do not have this management (Table 4). Applying Wuxal Semillion at a dose of 1.0 and 1.5 L ha^{-1}, provided yields of 10 and 15% higher respectively compared to the control (Table 4). Studies evaluating the effect of the application of micronutrients in sugarcane began in the 60s, where Alvarez and Wutke (1963) found positive responses in Argisol for isolated applications B, Mo, Fe and Cu which increased production of sugarcane in 21.6; 12.1; 1.6 and 8.3 t ha^{-1} respectively. Alvarez (1984) observed an increase in the production of stems in Rhodic, sandy texture, with the application of copper and zinc in the form of chelates. Azeredo and Bolsanello (1981), had increases of 30% in productivity of sugar cane plant with the use of 5 kg ha-1 of Mn in the groove or spraying with a solution containing 5 g L^{-1} of micronutrient. Different letters in the same column differ according to Tukey's test at 5% probability. T1: 1.0 L ha^{-1} Wuxal Semillion®; T2: 1.5 L ha^{-1} Wuxal Semillion®); T3: 2 L ha^{-1} Wuxal Semillion®; T4: 1 L ha^{-1} Wuxal Semillion® + 600 g ha^{-1} Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid); T5: 600 g ha^{-1} of Zn (zinc sulfate) + 350 g ha^{-1} B (boric acid) and T6: Treatment control. Regarding the application of B and Zn, Franco et al. (2011), found that the application of 2 and 4 kg ha^{-1} of B in planting caused a rise in the production of stem in plant cane. But the authors found that the Zn did not promote increased productivity in plant cane, but increased productivity (14 t ha^{-1} in the control) and the ATR of ratoon. Malavolta (1990), with two foliar applications of 0.175 kg ha^{-1} (of B could increase the order of 18% in the productivity of sugarcane. Mellis et al., 2008), evaluated the response of plant cane for Cu, Zn, Mn and Mo in eight major producing regions of sugarcane states of Sao Paulo and found significant responses for Zn, Mn, Mo and Cu, checking 18% increase in the production of stems and the highest responses were obtained to Zn and Mo. Significant responses were observed in these ratoon stalk production due to the application of Zn, Cu, Mn and Mo. These results demonstrate that the application of micronutrients in the planting furrow may be the most viable way to manage micronutrients in the culture of sugarcane (Mellis et al., 2010).

Conclusions

The use of the micronutrient source of Cu, Mn and Zn chelate associated with sources of K2O, B and Mo increased the productivity of stems (TCH) 10 and 15% when applied at doses of 1.0 and 1.5 L ha^{-1} respectively. The exclusive application of Boric Acid and Zinc Sulphate in dosages of 2:03 kg ha^{-1} did not result in increased sugarcane productivity. Micronutrient sources applied on the stems did not result in significant increases in the content of total recoverable sugars from sugarcane.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Contributive effect of growth regulator Trinexapac-Ethyl to oats yield in Brazil

Anderson Marolli[1*], José Antonio Gonzalez da Silva[2], Marcos Vinicios Romitti[3], Rúbia Diana Mantai[1], Osmar Bruneslau Scremin[1], Rafael Zancan Frantz[1], Sandro Sawicki[1], Emilio Ghisleni Arenhardt[4], Maria Eduarda Gzergorczick[2] and Andressa Raquel Cyzeski de Lima[2]

[1]Department of Exact Sciences and Engineering, Regional University of the Northwest of Rio Grande do Sul State (UNIJUÍ), Lulu Ingenfritz Street, 480, 98700-000, RS, Ijuí, Brazil.
[2]Department of Agrarian Studies, Regional University of the Northwest of Rio Grande do Sul State (UNIJUÍ), Street of trade, 3000, 98700-000, RS, Ijuí, Brazil.
[3]Department of Natural and Exact Sciences, Federal University of Santa Maria (UFSM), Roraima Avenue, Building 13, Room 1123, 9105-900, RS, Santa Maria, Brazil.
[4]Department of Crop Plants, Federal University of Rio Grande do Sul (UFRS), Bento Gonçalves Avenue, 7712, 91540-000, RS, Porto Alegre, Brazil.

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Studies on efficient use of the plant growth regulator can make this technology possible for leveraging oat yield in Brazil. This study aims to define the optimal dose growth regulator in oat, which allows plant lodging at most 5%. Establishing equations describe the yield indicators behavior and by using the optimal growth regulator dose for lodging, simulate the expression of these indicators regardless of reduced, high and very high conditions of nitrogen fertilization and favorable and unfavorable cultivation year. The study was conducted in 2013, 2014 and 2015, in carrying out two experiments, one to quantify the biomass yield and another aiming at estimating grain yield and lodging. The experimental design was a randomized block with four replications, following factorial scheme 4 x 3 to growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and N-fertilizer rates (30, 90 and 150 kg ha^{-1}), respectively. The use of 495 mL ha^{-1} growth regulator trinexapac-ethyl active principle is shown efficient at the reduction of oat plant lodging, regardless of the agricultural year condition and N-fertilizer rate. In the expression of grain yield and harvest index, quadratic behavior is obtained, however with decreasing linearity on the biomass yield and straw by increasing the growth regulator dose. The optimal dose of growth regulator in reducing oat lodging does not affect grain yield, but it reduces biological yield via biomass straw with elevation on the harvest index.

Key words: *Avena sativa*, biomass, straw, harvest index, multiple linear regression

INTRODUCTION

Oats have been shaping up as an important cultivation species in Brazil, either as coverage and soil protection or as human and animal consumption, for the plant and grains high nutritional and functional value.The search for healthy foods rich in protein and fiber has increased the demand for oats in the national market (Hawerroth et al., 2015; Silva et al., 2015).

High oats yield is associated with the cultivars performance, management technologies, favorable climate and soil (Fontaneli et al., 2012; Silva et al., 2015). Within the technologies management, nitrogen fertilization has significant effect in increasing yield (Costa et al., 2013; Mantai et al., 2015). In wheat (Flores et al., 2012) and oat (Mantai et al., 2015), increasing the dose and the right time of N-fertilizer application with the favorable growing conditions promote significant increase in grain yield. However, in unfavorable years, the nitrogen use efficiency may be compromised, reducing yield and increasing production costs (Benin et al., 2012; Silva et al., 2015). Flores et al. (2012) and Silva et al. (2015) also point out that the increase of nitrogen together with favorable climatic conditions increase the plant´s vegetative growth of the plant, facilitating the lodging occurrence.

The lodging is a complex phenomenon in which the plant loses its vertical position, leans and falls on the soil, resulting in recurved plants or even stems breakage, directly affecting the yield and the grains quality, besides bringing difficulties in harvesting (Silva et al., 2015; Hawerroth et al., 2015). Its expression depends on genetic factors, inter-related with external factors, such as wind, rainfall, soil, plant density and handling techniques, being the oats, a highly sensitive specie to lodging (Silveira et al., 2011; Silva et al., 2015). The lodging affects the morphological structure of the plant and the earlier it occurs, the greater the reduction in yield and grain quality (Trevizan et al., 2015). To minimize the lodging occurrence, there have been evaluated the use of growth regulators, as trinexapac-ethyl in crops such as soybeans (Souza et al., 2013), rice (Arf et al., 2012), wheat (Schwerz et al., 2015) and crotalaria (Kappes et al., 2011). The trinexapac-ethyl acts by reducing cell elongation in the vegetative stage and obstructing the gibberellic acid biosynthesis, plant hormone responsible for growth (Heckman et al., 2002; Kaspary et al., 2015). The growth regulators have been used to make the plants architecture more adapted and efficient at the use of natural resources and agricultural inputs, and to ensure high yield with quality (Souza et al., 2013; Hawerroth et al., 2015).

The biomass yield is related to the photosynthesis and respiration processes during the oats´ vegetative and reproductive phase (Demétrio et al., 2012). The relation between grain yield and biomass yield allows the determination of the harvest index, important parameter to define the efficiency with which the plant converts its photoassimilated into straw and grains (Silva et al., 2012). Expression of these traits is influenced by genotype, cultivation techniques, water availability, nutrients and climatic conditions (Mantai et al., 2015).
Thus, studies of use efficiency of the growth regulator on the expression of lodging and its impact on yield indicators can enable the use of this technology for the yield oats in Brazil.

The aim of the study was to define the optimal dose growth regulator in oat, which allows plant lodging at most 5%. To establish equations describing the yield indicators behavior and by using the optimal dose growth regulator for lodging, to simulate the expression of these indicators independent of reduced, high and very high conditions of nitrogen fertilization along with both favorable and unfavorable cultivation year.

MATERIALS AND METHODS

The study was developed in the field during the agricultural years 2013, 2014 and 2015, in Augusto Pestana city, RS State, Brazil (28°26'30" South latitude and 54°00'58" West longitude). The experimental soil of the area is classified as Distrofic Red Latosol Typical, which its U.S. equivalent is Rhodic Hapludox (USDA, 2014), and the climate of the region, according to Köppen classification, is 'Cfa type', with hot summer without a dry season. In the study, ten days before sowing, soil analysis was performed and it was identified the following chemical characteristics of the local: pH = 6.2; P = 33.9 mg dm^{-3}; K =200 mg dm^{-3}; Organic Matter = 3.0%; Al= 0.0 cmol$_c$ dm^{-3}; Ca = 6.5 cmol$_c$ dm^{-3} and Mg = 2.5 cmol$_c$ dm^{-3}. In the years of study, the sowing was carried out on the vegetation cover of reduced C/N relation (soybean/oat system), between the dates of May 15th to June 30th, with seeder-fertilizer for composition of 5 rows of 5 m in length and row spacing of 0.20 m, forming the experimental unit of 5 m^2. At the oats sowing time 60 and 50 kg ha^{-1} of P_2O_5 and K_2O, were applied, respectively, based on levels of P and K in the soil and nitrogen base with 10 kg ha^{-1} and rest in order to contemplate the doses proposed as coverage at the stage of fourth leave expanded, with nitrogen available as urea. The seeds were submitted to germination and vigor tests in the laboratory in order to correct the desired density of 300 viable seeds m^{-2} for carrying out two experiments in each cultivation year. During the study execution, tebuconazole fungicide applications, trademark FOLICUR® CE were made at the dosage of 0.75 L ha^{-1}. Moreover, the weeds control was carried out with metsulfuron-methyl herbicide, trademark ALLY® C, at a dose of 4 g ha^{-1} and additional weeding whenever necessary. The growth regulator (Trinexapac-ethyl) was applied by spraying at constant pressure of 30 pol^{-2}, by compressed CO_2, with flat fan nozzle at the stage between the 1st and 2nd stem nodes oats visible.

In the study, two experiments were conducted, one to quantify the total biomass yield and another to estimate grain yield and lodging. In both experiments the experimental design was randomized blocks with four repetitions, following factorial scheme 4 x 3 the sources of variation of the growth regulator doses (0, 200, 400 and 600 mL ha^{-1}) and N-fertilizer rates (urea source) (30, 90 and 150 kg ha^{-1}), respectively, totaling 96 experimental units. The

*Corresponding author. Email: marollia@yahoo.com.br harvest of experiments to estimate the biomass and grain yield occurred manually by cutting three central rows of each plot, stage near the harvesting point (120 days), with grain moisture around 15%. The plots directed to grain harvest were threshed with a stationary harvester and directed the laboratory to correct grain moisture to 13%, and weighing to estimate grain yield per hectare (GY, kg ha^{-1}). The plots for biomass analysis were directed to forced-air oven at a temperature 65°C, until it reached constant weight to the biomass yield estimation per hectare (BY, kg ha^{-1}). From these determinations, the straw yield was estimated (SY, kg ha^{-1}) by subtraction $\mathrm{BY} - \mathrm{GY}$ and the harvest index (HI, kg kg^{-1}) by division GY/BY. The lodging was estimated visually and expressed in percentage, having considered the angle formed in the vertical position of the plants culm in relation to the ground and the area of lodged plants. For this estimate it was used the methodology suggested by Moes and Stobbe (1991), modified, with the lodging (LODG) defined by the equation: LODG% = I x LODG x 2; where: (I) reflects the plants inclination degree, ranging from 0 to 5 (0, absence of inclination and 5, all plants completely lodged); LODG represents the area with lodged plants in the plot, which ranges from 0 to 10, where 0 corresponds to the absence of lodged plants in the plot and 10 to lodged plants over the whole plot, regardless of their inclination. Therefore, this equation considered the incidence and severity of plants lodging.

To meet the homogeneity and normality assumptions via *Bartlett* tests, analysis of variance were performed for detection of the main effects and interaction. Through the regression, equations were obtained that describe the lodging behavior, grain yield, biomass yield, straw yield and harvest index. It was proceeded the adjustment of the linear equation ($Y=b_0 \pm b_1x$) considering the possibility of plant lodging of at most 5%, value added to the parameter "Y" of the equation, to estimate the optimal dose growth regulator, obtained by $x= [(Y - b_0)/(\pm b_1)]$. Finally, the simulation of oat yield indicators was performed using the optimal dose of growth regulator by lodging, in the fertilization conditions with nitrogen and the cultivation year. The average grain yield values per crop year along with the maximum temperature and rainfall information in the oat crop cycle, were used to classify the years as favorable, intermediate and unfavorable. For all the determinations the computational program GENES was employed (Cruz, 2013) was used.

RESULTS AND DISCUSSION

In Figure 1, of the moment of N-fertilizer application in 2014, the averages of maximum temperature showed more elevated (±27°C) in relation to 2013 and 2015. The nitrogen topdressing applied in 2014 was followed by rainfall volume higher than 50 mm, volume also observed near to the grain harvest. These facts justify the lower yield obtained this year (Table 1), by the loss of the nutrient by leaching and losses by excessive rainfall in the maturation, characterizing unfavorable year (UY). In 2015, the maximum temperature next to the N-fertilizer application was the smallest (±12°C) compared to the other years. At the time of N-fertilizer application, the soil presented with conditions of adequate moisture by the rainfall accumulation from the previous days (Figure 1). On the other hand, the high rainfall volume during the culture cycle afforded periods of lowest insolation, possibly causing lower photosynthesis efficiency by the plant. Thus, the weather conditions with the grain yield average of Table 1, justifies a reasonable yield, characterizing as an intermediate year (IY) of cultivation. In 2013, the maximum temperature obtained at the time of N-fertilizer application was around 20°C and N-fertilizer application occurred in favorable conditions of soil moisture (Figure 1). In this condition, although the total volume of rainfall has been further reduced (Table 1), proper distribution of rainfall throughout the cycle (Figure 1) was decisive in the highest grain yield, more than 4 t ha^{-1}, characterizing favorable year (FY) of cultivation. Rainfall has been the main weather variable that affects agricultural productivity, although temperature, light and sunlight are also important (Battisti et al., 2013). Stress caused by lack or excess of water adversely affects the wheat and oats´ development (Benin et al., 2012; Mantai et al., 2015). Arenhardt et al. (2015) highlight that the rainfall defines the favorable and unfavorable year condition to the wheat cultivation.

In the analysis of the sources of variation year, N-fertilizer rate and growth regulator dose, differences between the main effects and interaction were observed (data not shown). Therefore, in the Tables 2, 3, 4 and 5, the decomposition of these interactions are illustrated in the distinct fertilization conditions with N-fertilizer and favorable year (FY), intermediate (IY) and unfavorable (UY) of cultivation. In Table 2, the reduced N-fertilizer rate (30 kg ha^{-1}) showed the largest plants lodging in 2014 (UY), independent of growth regulator dose. In the high nitrogen rate (90 kg ha^{-1}), high lodging was also observed in 2014, in the presence of the regulator doses. This same trend was also observed at the highest N-fertilizer rate (150 kg ha^{-1}). In high and higher N-fertilizer rates, the absence of regulator use indicated higher plant lodging in the most favorable cultivation year. Moreover, the point of 400 mL ha^{-1} indicated the lowest average lodging, similar to the highest dose of the product (600 mL ha^{-1}), which suggests the optimal dose adjustment at this concentration range. In generally, trend of reduction in the lodging was observed with increasing growth regulator dose, regardless of the year condition and N-fertilizer. Studies performed on wheat (Chavarria et al., 2015; Schwerz et al., 2015), rice (Arf et al., 2012), crotalaria (Kappes et al., 2011) and oats (Hawerroth et al., 2015; Kaspary et al., 2015) point out that regardless of N-fertilizer, the increasing of the growth regulator doses decreases the plant height and consequently the lodging. Hawerroth et al. (2015) still claim that the regulator use is effective when administered in favorable oat cultivation years.

In the estimation of the optimal dose of growth regulator for lodging expression (Table 3), the tested regression equations identified linear trend, regardless of year and N-fertilizer rate. For this estimate, the possibility of plant lodging was taken into consideration at most 5%, value added to the parameter "Y" of each equation.

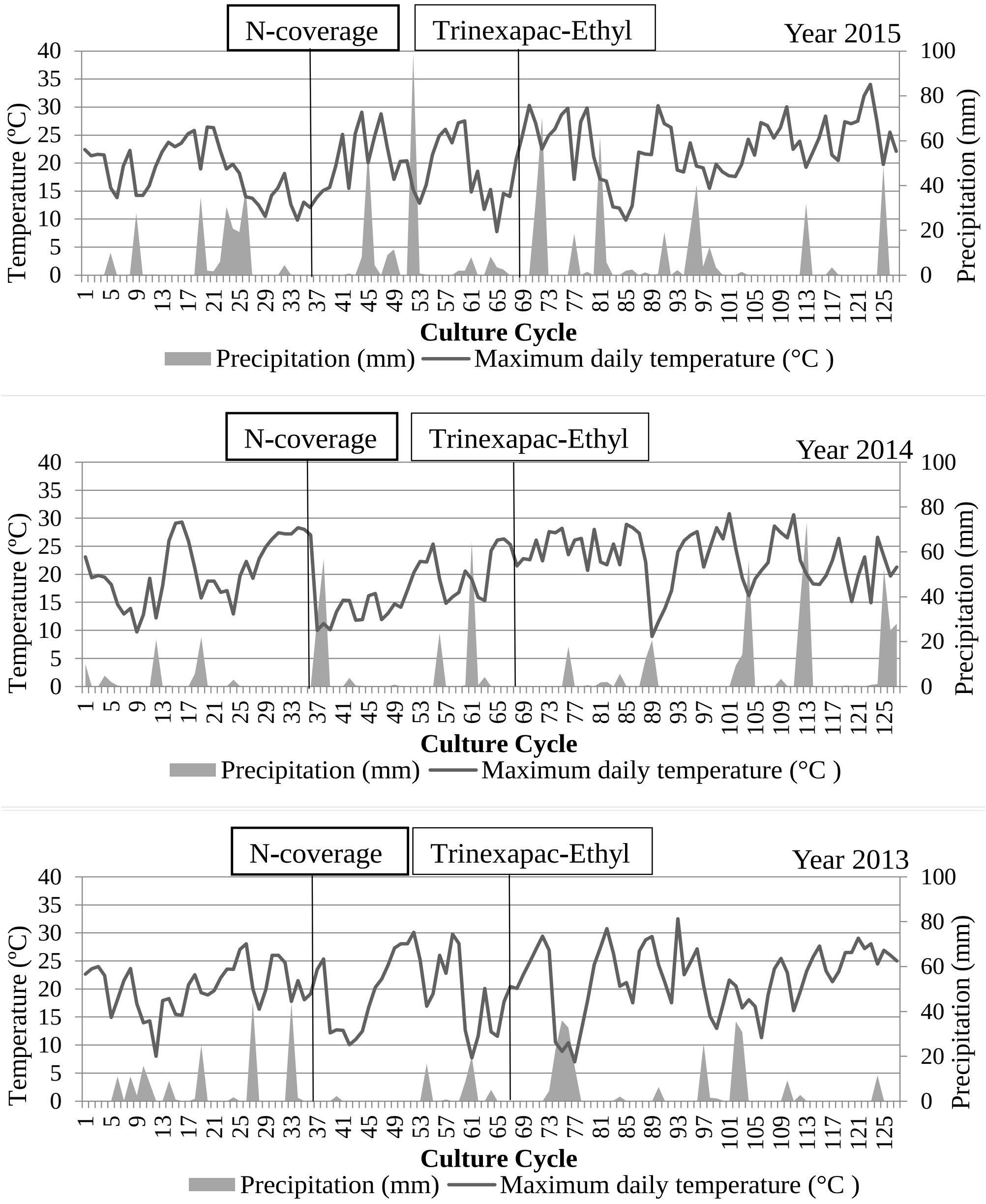

Figure 1. Precipitation and maximum temperature during the oat cycle. Application of N-fertilizer and Trinexapac-ethyl

Regardless of the cultivation year condition, the growth regulator doses averages obtained for the different N-fertilizer rates remained between 460 and 523 mL ha^{-1}. In general, regardless of year and N-fertilizer, the optimal dose of growth regulator proved to be adjusted to 495 mL ha^{-1}, concentration that would theoretically nullify the oat plants lodging.

In wheat (Pagliosa et al., 2013; Trevizan et al., 2015) and rice (Arf et al., 2012; Alvarez et al., 2014) observed reduction in plant lodging with the use dose of 400 mL ha^{-1} of regulator. In crotalaria (Kappes et al., 2011) and soybean (Souza et al., 2013) the efficient reduction of the lodging was obtained with the dose application of 500 mL ha^{-1} of regulator. Kaspary et al. (2015) and Guerreiro and Oliveira (2012), studying the growth regulator effects on grain yield and quality of oat seeds, claim that the dose of 500 mL ha^{-1} reduced the plant height by 60% and, consequently, altering the expression of plants lodging.

In Table 4, the analysis of grain yield behavior (GY), regardless of year and N-fertilizer rate, the two-degree equation was adequate. In this equation, the including of the optimal dose of growth regulator for lodging (Table 3),

Table 1. Temperature and precipitation data in the months and years of oat cultivation and average grain yield.

Year	Month	Temperature (°C)			Precipitation (mm)		$GY_{\bar{x}}$ (kg ha^{-1})	Class
		Minimum	Maximum	Average	Average*	Occurred		
2015	May	10.5	22.7	16.6	149	100	3404	IY
	June	07.9	18.4	13.1	162	191		
	July	08.3	19.2	13.7	135	200		
	August	09.3	20.4	14.8	138	223		
	September	09.5	23.7	16.6	167	046		
	October	12.2	25.1	18.6	156	211		
	Total	-	-	-	909	973		
2014	May	11.1	24.5	17.8	149	020	2841	UY
	June	09.3	19.7	14.5	162	059		
	July	07.4	17.5	12.4	135	176		
	August	12.9	23.4	18.1	138	061		
	September	12.0	23.0	17.5	167	194		
	October	15.0	25.5	20.2	156	286		
	Total	-	-	-	909	798		
2013	May	10.0	22.6	16.3	149	108	4163	FY
	June	08.9	20.0	14.5	162	086		
	July	07.0	20.6	13.8	135	097		
	August	06.6	19.8	13.2	138	163		
	September	09.6	21.0	15.3	167	119		
	October	13.2	27.1	20.2	156	138		
	Total	-	-	-	909	712		

*= Average rainfall obtained in the months from May to October 1982 to 2007; FY= Favorable year; UY= Unfavorable year; IY= Intermediate year; $GY_{\bar{x}}$= average grain yield; Class= classification of the year.

Table 2. Averages oat plant lodging by year and N-fertilizer rate in response to the use of growth regulator.

N-coverage (kg ha^{-1})	Year	Growth regulator dose (mL ha^{-1})			
		0	200	400	600
		LODG (%)			
30	2015 (IY)	28^{b}	08^{c}	02^{b}	01^{b}
	2014 (UY)	48^{a}	38^{a}	22^{a}	21^{a}
	2013 (FY)	22^{b}	17^{b}	03^{b}	02^{b}
$\bar{x}_{30}$		33	21	09	08
90	2015 (IY)	61^{b}	35^{b}	05^{b}	02^{b}
	2014 (UY)	62^{b}	68^{a}	35^{a}	33^{a}
	2013 (FY)	82^{a}	27^{b}	03^{b}	01^{b}
$\bar{x}_{90}$		68	43	14	12
150	2015 (IY)	87^{a}	51^{a}	10^{b}	03^{b}
	2014 (UY)	58^{b}	57^{a}	38^{a}	33^{a}
	2013 (FY)	83^{a}	32^{b}	05^{b}	05^{b}
$\bar{x}_{150}$		76	46	18	14
$\bar{x}_{\text{overall}}$		59	36	14	12

Averages followed by different letters are statistically different group by Scott-Knott test at 5% error probability; $\bar{x}_{N}$= average obtained lodging in the three years of study; $\bar{x}_{\text{overall}}$= overall average.

Table 3. Estimate the optimal dose of growth regulator by year and N-fertilizer rate of the predictability maximum lodging of 5%.

N-coverage (kg ha^{-1})	Year	Equation $\mathbf{LODG = a \pm bx}$	R²	P (bx)	Y_E (%)	Optimal dose (mL ha^{-1})
30	2015 (IY)	$23.55 - 0.045x$	0.80	*	(5)	≅410
	2014 (UY)	$29.62 - 0.050x$	0.92	*		≅495
	2013 (FY)	$22.52 - 0.037x$	0.89	*		≅475
$\bar{x}_{30}$						≅460
90	2015 (IY)	$56.82 - 0.103x$	0.91	*	(5)	≅500
	2014 (UY)	$46.00 - 0.080x$	0.82	*		≅510
	2013 (FY)	$48.75 - 0.088x$	0.93	*		≅490
$\bar{x}_{90}$						≅500
150	2015 (IY)	$82.35 - 0.147x$	0.93	*	(5)	≅525
	2014 (UY)	$71.25 - 0.127x$	0.89	*		≅520
	2013 (FY)	$75.15 - 0.133x$	0.94	*		≅525
$\bar{x}_{150}$						≅523
$\bar{x}_{\text{overall}}$						≅495

P(bx)= parameter that measures the line slope; R²= determination coefficient; * = Significant at 5% error probability by t test.; ( ) = considering the possibility the maximum lodging of 5%; $\bar{x}_N$= average obtained in the three years of study; $\bar{x}_{\text{overall}}$= overall average; Y_E = estimated value; Optimal dose = dose regulator that allows maximum lodging of 5%.

indicates grain yield expectation greater than 3000 kg ha^{-1}, except for the year 2012 (UY) in the reduced dose of N-fertilizer (30 kg ha^{-1}). In the average of the years for the reduced of N-fertilizer condition, the optimal dose of growth regulator was 460 mL ha^{-1}, with grain yield expectation in 3490 kg ha^{-1}. In high rate (90 kg ha^{-1}) and highest (150 kg ha^{-1}) of N-fertilizer, regardless of the agricultural year condition, little change was obtained in the regulator dose, ranging from 500 and 520 mL ha^{-1}, with grain yield expectation of 3544 and 3900 kg ha^{-1}, respectively. In the low and highest dose of nitrogen rate the variation of the growth regulator dose was between 460 and 520 mL ha^{-1}, respectively. On the general average, regardless of year and N-fertilizer rate, the use of 495 mL ha^{-1} of growth regulator brings a grain yield expectation of 3645 kg ha^{-1}.

In Table 4, in the analysis of biological yield (BY), regardless of year and N-fertilizer rate, the linear equations proved adjusted, indicating that the increasing of growth regulator dose causes a reduction in the total biomass. The inclusion of the optimum dose of growth regulator obtained for the lodging (Table 3), in the equation that describes the behavior of biological yield, indicated high expression values and, with strong dependence of the cultivation year, condition most favored in 2013 (FY). In the years' average, the supply of 30 kg ha^{-1} of N-fertilizer with use of the optimal dose regulator (460 mL ha^{-1}) showed biological yield of 7725kg ha^{-1}. The nitrogen in high rate (90 kg ha^{-1}) and highest (150 kg ha^{-1}), indicate biological yield of approximately 9000 kg ha^{-1}, in the adjusted rates of 500 and 520 mL ha^{-1} of regulator, respectively, regardless of agricultural year condition. On the general average, the use of 495 mL ha^{-1} of growth regulator indicated biological yield of 8570 kg ha^{-1}.

Effects of trinexapac-ethyl on the biological yield and grain vary according to the species, the genotype within the species and concentration used (Arf et al., 2012; Silva et al., 2015). The growth regulators use in the bean crop (Bernardes et al., 2010) and rice (Alvarez et al., 2014), contributed to control the excessive vegetative growth, without causing changes in grain yield. In maize, the regulator use causes increase in width and decreases the leaves length without effect on yield components (Zagonel and Ferreira, 2013). Researching the use of growth regulator on wheat, in different nitrogen rates, Zagonel et al. (2002) observed that even in higher nitrogen rates, the regulator use provided decrease in plant height, without effect on stem diameter and mass of dried plants. These authors highlight that in adverse conditions by weather, the plant lodging can be avoided with the regulator use. These results differ from those obtained by Espindula et al. (2010) who reported wheat yield reductions with the use of trinexapac-ethyl. In oats, Guerreiro and Oliveira (2012) note that the use of trinexapac-ethyl causes reduction in plant height and negatively affects the grain yield. Result contrary to that obtained by Kaspary et al. (2015) who claim that the

Table 4. Regression equation to estimate grain yield (GY) and biological yield (BY) in oat using the optimal dose of growth regulator.

N-coverage (kg ha^{-1})	Year	Equation	R²	P (cx²)	Optimal dose (mL ha^{-1})	Y_E (kg ha^{-1})
		$\mathbf{GY = a \pm bx \pm cx^2}$				
	2015 (IY)	$3447 + 2.33x - 4.9.10^{-3}x^2$	0.88	*	410	3580
30	2014 (UY)	$2978 + 0.94x - 2.8.10^{-3}x^2$	0.86	*	495	2760
	2013 (FY)	$4024 + 0.95x - 1.5.10^{-3}x^2$	0.96	*	475	4140
$\bar{x}_{30}$	-	$3483 + 1.40x - 3.0.10^{-3}x^2$	0.90	*	460	3490
	2015 (IY)	$3991 + 1.13x - 2.9.10^{-3}x^2$	0.90	*	500	3831
90	2014 (UY)	$3368 + 0.87x - 2.0.10^{-3}x^2$	0.99	*	510	3295
	2013 (FY)	$3952 + 0.80x - 2.0.10^{-3}x^2$	0.91	*	490	3508
$\bar{x}_{90}$	-	$3926 + 0.93x - 2.3.10^{-3}x^2$	0.93	*	500	3544
	2015 (IY)	$3849 + 0.64x - 1.1.10^{-3}x^2$	0.95	*	525	3882
150	2014 (UY)	$3408 + 1.60x - 2.8.10^{-3}x^2$	0.83	*	520	3483
	2013 (FY)	$4381 + 0.41x - 0.8.10^{-3}x^2$	0.95	*	525	4375
$\bar{x}_{150}$	-	$3879 + 0.88x - 1.6.10^{-3}x^2$	0.91	*	520	3900
$\bar{x}_{overall}$	-	$3762 + 1.07x - 2.3.10^{-3}x^2$	0.91	*	495	3645
		$BY = a \pm bx$				
	2015 (IY)	$8929 - 4.32x$	0.86	*	410	7157
30	2014 (UY)	$8636 - 3.62x$	0.71	*	495	6840
	2013 (FY)	$11061 - 3.96x$	0.94	*	475	9180
$\bar{x}_{30}$	-	$9542 - 3.96x$	0.84	*	460	7725
	2015 (IY)	$9958 - 1.75x$	0.99	*	500	9083
90	2014 (UY)	$8758 - 0.73x$	0.97	*	510	8385
	2013 (FY)	$12511 - 6.03x$	0.98	*	490	9557
$\bar{x}_{90}$	-	$10409 - 2.83x$	0.98	*	500	9000
	2015 (IY)	$9950 - 2.95x$	0.95	*	525	8402
150	2014 (UY)	$9692 - 3.55x$	0.98	*	520	7846
	2013 (FY)	$12719 - 3.84x$	0.85	*	525	10700
$\bar{x}_{150}$	-	$10787 - 3.44x$	0.93	*	520	8982
$\bar{x}_{overall}$	-	$10246 - 3.41x$	0.92	*	495	8570

P(cx²)= parameter that measures the slope of the line; R²= determination coefficient; * = Significant at 5% error probability by t test.; $\bar{x}_N$= average obtained in the three years of study; $\bar{x}_{overall}$= overall average; Y_E = estimated value; Optimal dose = dose regulator that allows maximum lodging of 5%.

growth regulator use generates increase in grain yield, but with reduced physiological seed quality. According to Rodrigues et al. (2003), the effect of growth regulator is dependent on the dose, environmental conditions and nutrition and plant health culture.

In Table 5, the behavior of straw yield (SY), regardless of year and N-fertilizer rate, decreasing linear trend is observed, similar to that obtained in biological yield (Table 4). It highlighted that the effects of reducing the biological productivity (Table 4) by the use of the regulator are fully achieved by reducing the straw yield (Table 5) and not by changes in grain yield. In average years, the reduction of N-fertilizer condition (30 kg ha^{-1}), with use of the optimal dose regulator showed expected straw yield of 4510 kg ha^{-1}. In high (90 kg ha^{-1}) and highest doses (150 kg ha^{-1}) of N-fertilizer, regardless of the agricultural year condition, the use of optimal dose regulator under these conditions indicates straw yield expectation of 5290 and 5160 kg ha^{-1}, respectively. On the general average, the optimal dose of regulator, regardless of year and N-fertilizer dose (495 mL ha^{-1}) scales an expectation of straw yield of 4987 kg ha^{-1}. For

Table 5. Regression equation to estimate straw yield (SY) and harvest index (HI) in oat using the optimal dose of growth regulator.

N-coverage (kg ha^{-1})	Year	Equation	R²	P (bx)	Optimal dose (mL ha^{-1})	Y_E (kg ha^{-1})
		$\mathbf{SY = a \pm bx}$				
30	2015 (IY)	$5284 - 3.69x$	0.81	*	410	3770
	2014 (UY)	$5547 - 2.92x$	0.94	*	495	4102
	2013 (FY)	$6977 - 4.02x$	0.98	*	475	5065
$\bar{x}_{30}$	-	$5936 - 3.54x$	0.91	*	460	4510
90	2015 (IY)	$5847 - 1.09x$	0.86	*	500	5303
	2014 (UY)	$5310 - 0.41x$	0.93	*	510	5100
	2013 (FY)	$8619 - 6.42x$	0.99	*	490	5470
$\bar{x}_{90}$	-	$6592 - 2.64x$	0.93	*	500	5290
150	2015 (IY)	$6056 - 2.34x$	0.90	*	525	4827
	2014 (UY)	$6172 - 3.48x$	0.93	*	520	4363
	2013 (FY)	$8371 - 3.94x$	0.78	*	525	6303
$\bar{x}_{150}$	-	$6866 - 3.25x$	0.87	*	520	5160
$\bar{x}_{\text{overall}}$	-	$6464 - 3.14x$	0.90	*	495	4987
		$\mathbf{HI = a \pm bx \pm cx^2}$				
30	2015 (IY)	$0.37 + 7.4.10^{-4}x - 9.8.10^{-7}x^2$	0.98	*	410	0.51
	2014 (UY)	$0.33 + 6.2.10^{-4}x - 9.2.10^{-7}x^2$	0.99	*	495	0.41
	2013 (FY)	$0.37 + 1.2.10^{-4}x - 1.9.10^{-7}x^2$	0.97	*	475	0.38
$\bar{x}_{30}$	-	$0.35 + 4.9.10^{-4}x - 6.9.10^{-7}x^2$	0.98	*	460	0.43
90	2015 (IY)	$0.40 + 1.8.10^{-4}x - 3.0.10^{-7}x^2$	0.94	*	500	0.42
	2014 (UY)	$0.38 + 1.4.10^{-4}x - 2.5.10^{-7}x^2$	0.99	*	510	0.39
	2013 (FY)	$0.31 + 1.2.10^{-4}x - 2.3.10^{-7}x^2$	0.99	*	490	0.32
$\bar{x}_{90}$	-	$0.36 + 1.4.10^{-4}x - 2.6.10^{-7}x^2$	0.97	*	500	0.38
150	2015 (IY)	$0.37 + 2.8.10^{-4}x - 3.6.10^{-7}x^2$	0.99	*	525	0.43
	2014 (UY)	$0.35 + 3.8.10^{-4}x - 3.7.10^{-7}x^2$	0.93	*	520	0.48
	2013 (FY)	$0.33 + 3.0.10^{-4}x - 3.0.10^{-7}x^2$	0.91	*	525	0.40
$\bar{x}_{150}$	-	$0.35 + 3.2.10^{-4}x - 3.4.10^{-7}x^2$	0.94	*	520	0.44
$\bar{x}_{\text{overall}}$	-	$0.35 + 3.2.10^{-4}x - 4.3.10^{-7}x^2$	0.96	*	495	0.42

P(bx)= parameter that measures the slope of the line; R²= determination coefficient; * = Significant at 5% error probability by t test.; $\bar{x}_N$= average obtained in the three years of study; $\bar{x}_{\text{overall}}$= overall average; Y_E = estimated value; Optimal dose = dose regulator that allows maximum lodging of 5%.

Mantai et al. (2015), the oats straw on the soil is essential for preserving and improving the physical, chemical and biological attributes, as well as help protect against erosion as well as reduce soil loss water by evaporation. Silva et al. (2012) also commented on the straw layer ability to control weeds on the soil surface. Hawerroth et al. (2015) stated that the use of trinexapac-ethyl growth regulator in oats is responsible for the reduction of vegetative growth, thereby decreasing the straw volume.

On analysis of the harvest index (Table 5), regardless of year and N-fertilizer dose, the two-degree equation was adequate. In this equation, at the inclusion of the optimal dose of growth regulator (Table 3) showed lower harvest index in 2013 (FY). In fact, the grain yield reached stability based on the quadratic behavior, which in biological yield, mainly via straw, the linear behavior promotes steady growth, reducing the harvest index. Thus, in oats, observed high harvest index reflected in greater efficiency, though occasionally, as in favorable condition, greater use is obtained via straw yield.

Schaedler et al. (2009) studying the genetic variability of the physiological parameters of oat yield, observed harvest index between 0.33 and 0.45. The results found by these authors are in line with those obtained in this study which revealed that with the use of optimal dose regulator dedicated the lodging plants at most 5%, ranging from 0.38 to 0.44, regardless of the agricultural year condition and N-fertilizer rate. Mantai et al. (2015) and Silva et al. (2012) highlighted that the sowing density, nitrogen fertilization and the favorable weather conditions are the main factors which affect the harvest index expression of the cereals. In oats, Mantai et al. (2015) point out that the reduction in harvest index in favorable year does not express the efficiency obtained for the grains elaboration, because the increase in grain yield does not follow the same way as the expression of biological yield, causing reduction of the harvest index by higher volume of biomass via straw. In wheat, with regulator application, Zagonel and Fernandes (2007) observed decrease in harvest index with increasing nitrogen rate. Trevisan et al. (2015) pointed out that the growth regulator application increase the harvest index by reducing the biomass straw.

On average, Table 4 revealed the zero regulator dose (y=a), and the grain yield estimate of 3762 kg ha^{-1}, as similar to those obtained using the optimal dose (495 mL ha^{-1}), with 3645 kg ha^{-1}. On the other hand, there was significant reduction of the biological yield estimate from zero to the optimal dose, with 10246 to 8570 kg ha^{-1}, respectively. This behavior is better understood by the general average estimate of straw yield (Table 5), which showed significant reduction in the zero point to the use of optimal dose, from 6464 to 4987 kg ha^{-1}, confirming that the reduction of biological yield occurs at the expense of straw yield and not by grain yield. This fact also justifies the increase of expression in the estimate of the harvest index (Table 5) at the zero dose to optimal dose regulator from 0.35 to 0.42, respectively, because the grains relation versus straw by the harvest index is obtained by the division between grain yield by the biological yield (grain + straw). Therefore, a reduction of the biological yield without changing the grain yield promotes natural increase of the harvest index. The results presented by the growth regulators used in other species, corroborate with the ones obtained in oat, indicating that the use of trinexapac-ethyl efficiently reduces the plant lodging without losses in grain yield; however it reduces biological yield at the expense of biomass straw, consequently promoting an increase on the harvest index.

Conclusions

The use of 495 mL ha^{-1} of the growth regulator of trinexapac-ethyl active principle shows to be efficient in reducing the oat plant lodging, regardless of the agricultural year condition and N-fertilizer rate. In the expression of grain yield and harvest index, quadratic behavior is obtained, however, with decreasing linearity on the biomass and straw yield at higher doses the growth regulator. The growth regulator optimal dose in reducing oat lodging does not affect grain yield, but it reduces biological yield via biomass straw with elevation on the harvest index.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Phytosociological survey of arboreous species in conserved and desertified areas in the semi-arid region of Paraíba, Brazil

Jhony Vendruscolo[1*], Aldrin Martin Perez Marin[1, 2], Bruno de Oliveira Dias[1, 2], Evaldo dos Santos Felix[1], Allana dos Anjos Coutinho[2] and Karoline Ruiz Ferreira[3]

[1]Ciência do Solo, Universidade Federal da Paraíba, Areia, PB. Brazil.
[2]Instituto Nacional do Semiárido, Brazil.
[3]Engenharia Florestal, Universidade Federal de Rondônia, Brazil.

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The objective of this study is to perform a phytosociological survey of the arboreous composition in conserved and desertified areas of the semiarid region of Paraiba State. Twenty-two conserved areas (CA) with native vegetation (Caatinga) where there has been no clear cut logging since 1984, and Twenty-two desertified areas (DA) having a difficult re-establishment of vegetal coverage over the past 10 years were selected. Plots with 100 m^2 were established and the species were identified. The perimeter at 0.30 m ground level (PGL) and at breast height, 1.30 m (PBH) was measured. Subsequently, the absolute density (AD), relative density (RD), absolute frequency (AF), relative frequency (RF), absolute dominance (ADo), relative dominance (RDo), importance value index (IVI) and coverage value index (CVI) were calculated. There were 63 species of trees in CA and 9 in DA. The most frequent species were *Caesalpinia pyramidalis* and *Croton sonderianus* in CA, and *Mimosa tenuiflora* and *Croton sonderianus* in DA. CA showed an AD (4,845 I ha^{-1}) higher than DA (895 I ha^{-1}). The ADo order was *C. pyramidalis* > *Anadenanthera colubrina* > *Myracrodruon urundeuva in* CA, and *M. tenuiflora* > *C. pyramidalis* > *Aspidosperma pyrifolium* in DA. *C. sonderianus* (CA) and *M. tenuiflora* (DA) reached the highest IVI and CVI.

Key words: Caatinga, vegetation, biodiversity, environmental quality.

INTRODUCTION

The desertification process triggers major changes in the floristic composition of the Caatinga (Sousa et al., 2015). This happens mainly due to anthropic actions known as deforestation for firewood purposes, exploration of clay deposits, and intensive use of the land through inappropriate agricultural mechanisms (cutting and

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*Corresponding author. E-mail: jhoven2@hotmail.com.

burning), salinization, extensive grazing and overgrazing (Nimer, 1988; Galindo et al., 2008; Alves et al., 2009; Costa et al., 2009; Sá et al., 2010; Aquino and Oliveira, 2012). The adoption of strategies is mandatory to minimize this problem (Damasceno and Souto, 2014; Barros, 2011).

The impact of the anthropic action on the physiological dynamics of vegetation causes its features to change to an even lower and thinner Caatinga, with a severe selection of species (Alves, 2009). In this context, it is clear that the phytosociologycal survey provides information about the geographical distribution of the species and about the vegetation structure, depicting the impact of the anthropic action on the vegetation-soil-climate complex. This data can be used for action planning to preserve, conserve and recover the forest ecosystems (Chaves et al., 2013). This consequently leads to the development of more sustainable activities in the semi-arid areas.

Despite the importance of phytosociological studies, the studies carried out in Brazil are still insufficient, and a thorough analysis is necessary so actions on the conservation of natural resources can be taken (Freitas and Magalhães, 2012).

Considering the importance of the vegetal structure for planning the conservation and recovery of the natural resources and for the mitigation of the consequences of the desertification process, this study aimed to perform a phytosociological survey of tree layers in areas of conservation and desertification in the semi-arid region of Paraíba State.

MATERIALS AND METHODS

This study was carried out in 22 conserved areas (CA) and 22 desertified areas (DA) (Figure 1) of the semi-arid region of Paraíba State, Brazil, from October 2015 to May 2016. The region has a semi-arid climate, with a dry period of 6 to 11 months in 85.3% of the area (Nimer, 1979) where the annual precipitation is lower than 800 mm (Sousa et al., 2012).

The conserved areas (CA) were selected considering the non-occurrence of clear cutting since 1984, based on temporal images of the past 30 years, using the Landsat Annual Timelapse 1984-2012. Subsequently, the selected areas were compared with the images of the Landsat satellite 8, and confirmed in the field.

The desertified areas (DA) were selected considering the difficulty of the vegetation cover to re-establish, using temporal images (past 10 years) Landsat 7 (bands 3, 4 and 5) and 8 (bands 4, 5 and 6), with the help of the Earthengine. The period of the images is correspondent with the period of the highest rainfall and low incidence of clouds, which excludes water as a limiting factor for plant growth. After selecting the areas, based on remote sensing techniques, the next step was to locate them, by using Google Earth and Garmin 60CSX GPS navigation, and to evaluate the arboreous coverage of the field.

The evaluation of the arboreous vegetation was carried out in 100 m^2 (10 x 10 m) plots. In each plot, the identification of the arboreous species was based on regional knowledge, with the help of a local guide, and on literature (Lorenzi, 1992; Lorenzi, 1998, 2009; Siqueira Filho et al., 2009; NUPEEA, 2010; Castro and Cavalcante, 2011; INSA, 2011; Maia-Silva et al., 2012). Every tree whose base of the trunk was in the plot was included, even when the stem and canopy were over the borders.

After measuring the arboreal component, the following phytosociological parameters were calculated:

I - Absolute Density per area proportional (AD): represents the average number of trees of a given species, per unit of area (I ha^{-1}).

$$ADi = Ni / A \quad (1)$$

Where:
Ni = number of units of the species i;
A = total area sampled (ha).

II - Relative Density (RD): Percentage of the number of units of a given species in relation to the total number of sampled units.

$$RDi = (Ni \times 100)/n \quad (2)$$

Where:
Ni = number of units of the species i;
N = total number of units.

III - Absolute Frequency (AF): is the percentage of sample units with occurrence of the species, in relation to the total number of sample units.

$$AFi = (Pi \times 100)/P \quad (3)$$

Where:
Pi = number of plots in which the species occurred;
P = total number of plots.

III - Absolute Frequency (AF): is the percentage of plots with occurrence of the species, in relation to the total number of plots.

$$AFi = (Pi \times 100)/P \quad (4)$$

Where:
Pi = number of plots in which the species occurred;
P = total number of plots.

V - Relative Frequency (RF): obtained from the relationship between the absolute frequency of each species and the sum of the absolute frequencies of all sampled species.

$$RFi = (AFi \times 100) / \Sigma AFi \quad (5)$$

VI - Absolute Dominance (ADo): occupancy rate of the environment by units of a species (m^2 ha^{-1}), calculated from the sum of basal area.

$$ADoi= BAi / A \quad (6)$$

Where:
BAi = individual basal area of a species (m^2), based on the diameter of the stem from 0.3 m or 1.3 m of the ground, when the units were lower or taller than 1.3 m, respectively;
A = total sampled area (ha).

VII - Relative Dominance (RDo): represents the relationship between the basal area of a species and the total basal area of all sampled species.

$$RDo = (BAi/TBA) \times 100 \quad (7)$$

Where:
BAi = is the basal area of each unit of the species;

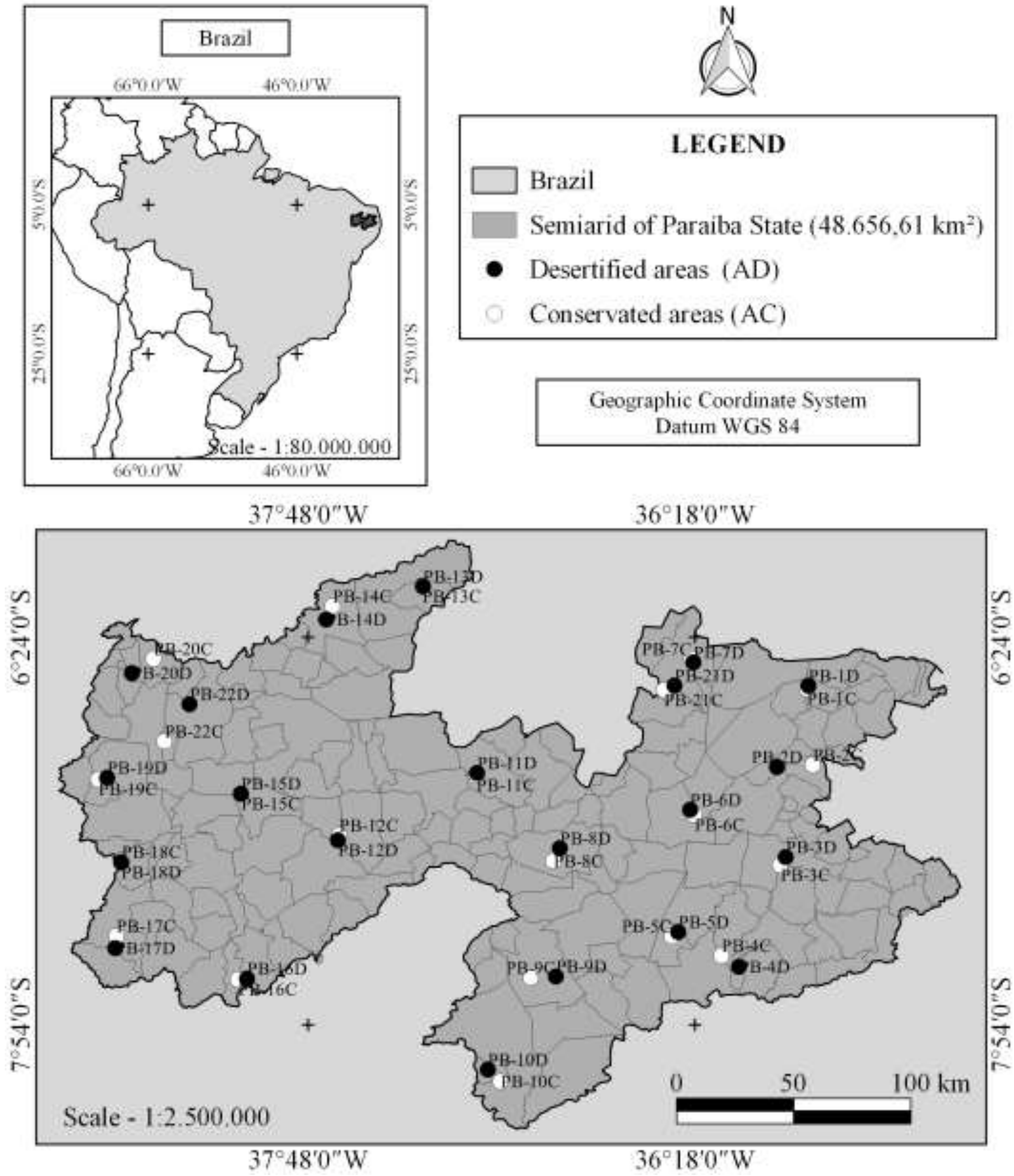

Figure 1. Geographic localization of the conserved (CA) and desertified areas (DA) in the semi-arid region of Paraíba State, Brazil.

TBA = is the sum of the basal areas of all species.

VIII - Importance Value Index (IVI): represents how well the species is established in the community. It is the result of the relative values already calculated for density, frequency and dominance, reaching, therefore, the maximum value of 300.

$$IVIi = RDi + RDoi + RFi \qquad (8)$$

IX -Value of Coverage Index (VCI): is the sum of relative values and dominance of each species, up to a maximum value of 200.

$$VCIi = RDi + RDoi + RFi \qquad (9)$$

RESULTS

The conserved areas had 5 to 17 species per plot, with an average value of 10 (±2.9), totaling 63 species (Table 1), while the desertified areas presented 1 to 4 species per plot, with an average value of 2 (±1.0), totaling 9 species (Table 2).

The most frequent species found in the conserved areas were *Caesalpinia pyramidalis* (77.3%), *Croton sonderianus* (77.3%), *Piptadenia stipulacea* (68.2%) and *Aspidosperma pyrifolium* (63.6%), while the remainder presented AF below 50% (Table 3). The most frequent species of trees found in the desertified areas were *Mimosa tenuiflora* (68.2%), *C. sonderianus* (31.8%), *C. pyramidalis* (31.8%), *Jatropha mollissima* (31.8%) and *A. pyrifolium* (18.8%) (Table 4).

The conserved areas presented a higher AD than the desertified areas, with 4,845 I ha^{-1} and 895 I ha^{-1} (Tables 3 and 4), respectively. *C. sonderianus* had the highest AD (1,345 I ha^{-1}) in the CA, followed by *C. pyramidalis* (573 I ha^{-1}). The highest AD the in DA were from *M. tenuiflora* (414 I ha^{-1}) and *C. sonderianus* (173 I ha^{-1}).

Regarding ADo, it was noted that *C. pyramidalis* (72.56 m^2 ha^{-1}), *Anadenanthera colubrina* (69.06 m^2 ha^{-1}), *Myracrodruon urundeuva* (49.06 m^2 ha^{-1}), *Schinopsis brasiliensis* (43.06 m^2 ha^{-1}), and *C. sonderianus* (21.56 m^2 ha^{-1}) showed the highest values in the conserved areas (Table 3). *M. tenuiflora* (9.87 m^2 ha^{-1}), *C. pyramidalis* (4.05 m^2 ha^{-1}), *A. pyrifolium* (2.52 m^2 ha^{-1}), *Prosopis juliflora* (2.43 m^2 ha^{-1}) and *J. mollissima* (0.92 m^2 ha^{-1}) (Table 4) had the highest ADo values in the desertified areas.

The species *C. sonderianus* (13.7%), *C. pyramidalis* (12.6%) and *A. colubrina* (8.0%) had the highest IVI in the CA, while *M. tenuiflora* (41.9%), *C. pyramidalis* (15.9%) and *C. sonderianus* (12.6%) showed the highest IVI in the AD (Tables 3 and 4, respectively).

The coverage value index (CVI) showed a pattern similar to IVI, with higher values for *C. sonderianus* (16.6%), *C. pyramidalis* (14.9%) and *A. colubrina* (9.7%) in AC, and *M. tenuiflora* (46.8%), *C. pyramidalis* (16.3%) and *C. sonderianus* (11.4%) in AD (Tables 3 and 4, respectively).

DISCUSSION

The diversity of species is the main feature that determines the ability of a system to survive during and after a period of adversity, that is, the resilience of the system (Salgado-Laboriau, 1994). In this context, we can say that the present anthropic activities promote the reduction of the arboreous diversity in the desertified areas, lowering, consequently, the environmental quality of the Caatinga biome in the semi-arid region of Paraíba State. This corroborates the work of Costa et al. (2009).

The anthropic action, in addition to reducing the number of species, also affects the distribution of those remaining in the desertified areas, affecting the emergence of those adapted to stricter requirements, such as *M. tenuiflora* (Lima, 1996), *J. molissima*, *A. pyrifolium* and *C. pyramidalis* (Silva et al., 2004). It is also noted that some characteristics of the former three species reduce the impacts of pressure of use by population and by domestic animals (Souza et al., 2015), showing low density for building and firewood usage, or toxicity to animal consumption (Souza, 2008; Lima and Soto-Blanco, 2010; Dantas et al., 2012).

The highest AD in conserved areas suggests a greater protection of the soil against erosion processes, especially by water, decreasing soil and nutrients losses (Martin Filho et al., 2009; Ramos et al., 2014), and consequently increasing the vegetation resilience. The highest density of species in conserved areas also increases the production of litter, levels of organic matter, infiltration capability and storage of water in the soil, thus reducing the susceptibility to water scarcity (Mendonça et al., 2009). The highest values of ADo of the species in CA relate to a number of factors, including the potential of some species, such as *M. urundeuva* and *A. colubrina*, which can reach 14 and 15 m in height in the Caatinga (Lorenzi, 1992). Other factors are better conditions for plant growth and development, as previously seen, and time to accumulate biomass, as these areas did not suffer clear cutting for at least 32 years. Although *C. pyramidalis* reaches only 10 m high, that is, 66% of *M. urundeuva*'s and *A. colubrina*'s height, it has characteristics that counterbalance that of the latter in biomass production, such as tolerance to periods of water stress (xerophile) and easy regeneration after cutting (Lorenzi, 2002; Lorenzi, 2009). In the DA, the best-adapted species to the water stress conditions reached the highest values of ADo. The species adapted to these conditions have some advantages in relation to those not adapted, which tend to face greater difficulties to getting established and disseminated. The IVI expresses numerically the importance of a given species amongst the trees of a community (Poggiani et al., 1996). Therefore, the maximum value of 13.7% (*C. sonderianus*) indicates a better distribution of the IVI amongst the species in the conserved areas, that is, a better balance between the species and, consequently, a higher quality of vegetation. Regarding DA, *M. tenuiflora*'s IVI of 41.9% points this species out as the most ecologically important for this environment, corroborating data from Freitas et al. (2007). According to this author, *M. tenuiflora*'s ability to dominate the environment is due to its high capacity to regrow, revealing a good adaptation to the degraded environments of the Caatinga.

The parameter CVI conveys the ecological importance of the species in horizontal distribution terms so that the maximum value of 16.6% (*C. sonderianus*) also gives evidence of a more balanced importance among the species in the CA than in the DA. As much as the IVI, this parameter reflects the effect of the anthropic action in the Caatinga biome, where the number of arboreous species is low and where there is an environmental imbalance, a more severe water scarcity and the predominance of species more adapted to these desertified conditions.

Conclusions

The process of desertification reduces the diversity of the arboreous species in the semi-arid region of Paraíba

Table 1. Number of species and plants from each species, in the conserved areas of the semi-arid region of Paraíba State.

No.	**Species**	**Plot - PB**																					
		1C	**2C**	**3C**	**4C**	**5C**	**6C**	**7C**	**8C**	**9C**	**10C**	**11C**	**12C**	**13C**	**14C**	**15C**	**16C**	**17C**	**18C**	**19C**	**20C**	**21C**	**22C**
1	*Amburana cearensis* (Fr. Al.) A. C. Smith	1	0	1	0	0	0	0	3	0	0	0	0	0	1	1	1	0	2	0	2	0	0
2	*Anadenanthera colubrina* (Vell) Brenan	0	0	1	0	0	0	0	0	2	4	0	0	3	1	2	0	6	3	0	2	0	1
3	*Annona leptopetala* (R.E.Fr.) H.Rainer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
4	*Aspidosperma pyrifolium* Mart.	0	6	2	11	10	2	1	0	7	7	24	9	3	0	0	0	0	0	0	1	1	3
5	*Astronium graveolens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
6	*Bauhinia cheilantha* (Bong.) Steud.	0	1	1	0	0	0	0	0	0	2	0	0	0	15	1	10	2	6	0	0	2	0
7	*Bauhinia forficata* Link	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
8	*Caesalpinia ferrea* Mart. ex Tul. var. ferrea	0	0	0	0	0	0	0	0	4	2	0	0	13	1	0	0	0	0	0	0	0	0
9	*Caesalpinia pyramidalis* Tul.	1	4	18	11	5	6	15	4	1	2	0	12	0	8	5	8	11	0	0	10	5	0
10	*Capparis flexuosa* L.	0	0	0	4	0	0	0	0	1	0	0	1	0	0	0	0	3	0	1	0	0	0
11	*Capparis yco*	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	*Cedrela odorata* L.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
13	*Chloroleucon dumosum* (Benth.) G.P.Lewis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
14	*Combretum glaucocarpum* Mart.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	16	4	2	0	0	0
15	*Combretum leprosum* Mart.	0	0	0	0	0	0	0	2	0	0	3	2	0	0	5	0	0	0	1	2	0	1
16	*Commiphoraâ leptophloeos*-(Mart.) J.B. Gillett	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	3	0
17	*Cordia trichotoma*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
18	*Coutarea hexandra* (Jacqu.) Schum.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
19	*Croton sp.*	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	*Croton nepetifolius* Baill.	0	0	0	0	0	14	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
21	*Croton rhamnifolioides* Pax & Hoffm	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0
22	*Croton sonderianus* Muell. Arg.	0	0	6	6	28	1	27	17	0	0	8	12	31	27	39	11	6	19	26	25	7	0
23	*Desmodium tortuosum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
24	*Eremanthus arboreus* (Gardner) MacLeis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
25	*Erythroxylum plungens*	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
26	*Erythroxylum sp. 1*	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	*Erythroxylum sp. 2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
28	*Fagara rhoifolia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
29	*Genipa americana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
30	*Guapira opposita* (Vell.) Reitz	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
31	*Jatropha mollissima* (Pohl.) Baill	4	0	0	1	1	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	4	0
32	*Libidibia ferrea* (Mart. ex Tul.) L.P.Queiroz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
33	*Luetzelburgia auriculata* Duck	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
34	*Manihot dichotoma* Ule	0	0	2	0	1	0	5	2	0	0	0	0	0	2	0	1	0	0	0	0	1	0
35	*Maytenus rigida*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. Contd.

36	*Mimosa arenosa* (Willd.) Poir	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	*Mimosa ophthalmocentra* Mart. ex Benth	0	0	1	0	0	18	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0
38	*Mimosa tenuiflora* (Willd.) Poir	0	0	0	0	0	0	0	2	0	0	14	2	3	0	0	0	0	0	0	0	0	0
39	*Myracrodruon urundeuva* Fr. All.	0	0	0	0	1	1	0	0	7	0	0	0	0	0	4	2	0	0	5	2	0	0
40	Not Identified 1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	Not Identified 2	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
42	Not Identified 3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	Not Identified 4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Not Identified 5	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
45	Not Identified 6	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0
46	Not Identified 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	13	0	0	0	0
47	Not Identified 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0
48	*Parapiptadenia zehntneri* (Harms)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
49	*Piptadenia stipulacea* (Benth.) Ducke	12	9	0	11	3	0	2	1	0	3	0	0	0	5	4	2	0	13	17	1	9	2
50	*Piptadenia viridiflora* (Benth.)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	*Pisonia tomentosa* Casar	0	1	10	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	*Pseudobombax marginatum* (A. St.-Hil., J. & C.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
53	*Randia armata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
54	*Sapium glandulatum* Pax	4	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	*Schinopsis brasiliensis* Engl.	3	2	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
56	*Senegalia tenuiflora* (L.) Britton & Rose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0
57	*Senna trachypus* (Benth.) H.S.Irwin & Barneby	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
58	*Sideroxylon obtusifolium* (H. ex. R. & S.)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
59	*Spondias tuberosa L.*	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	*Tabebuia impetiginosa*	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	*Tocoyena brasiliensis* Mart.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
62	*Ximenia americana* L.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	*Ziziphus joazeiro* Mart.	15	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	2	0	1
Total number of plants per plot		**41**	**26**	**65**	**48**	**49**	**45**	**71**	**33**	**45**	**31**	**52**	**38**	**53**	**71**	**63**	**43**	**49**	**73**	**58**	**49**	**32**	**25**
Total species in each plot		**8**	**9**	**17**	**8**	**7**	**9**	**13**	**9**	**12**	**13**	**5**	**6**	**5**	**10**	**10**	**12**	**9**	**13**	**10**	**11**	**8**	**12**

State. The most frequent species in the conserved areas are *Caesalpinia pyramidalis* (77.3%), *Croton sonderianus* (77.3%), *Piptadenia stipulacea* (68.2%) and *Aspidospermapyrifolium* (63.6%), while in the desertified areas *Mimosa tenuiflora* (68.2%), *C. sonderianus* (31.8%), *C. pyramidalis* (31.8%) and *Jatropha mollissima* (31.8%) are more frequent.*C. sonderianus, J. mollissima, Caesalpinia pyramidalis* and *Aspidosperma pyrifolium* both occur in conserved and desertified areas.

The absolute density (AD) in the conserved areas is higher than in the desertified, reaching 4,845 I ha^{-1} and 895 I ha^{-1}, respectively. The absolute dominance (ADo) followed the order

Table 2. Number of species and plants from each species, in the desertified areas of the semi-arid region of Paraíba State.

No.	Species	Plot - PB																					
		1D	2D	3D	4D	5D	6D	7D	8D	9D	10D	11D	12D	13D	14D	15D	16D	17D	18D	19D	20D	21D	22D
1	*Aspidosperma pyrifolium* Mart.	0	0	0	0	3	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2	*Caesalpinia pyramidalis* Tul.	0	2	0	9	6	1	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2
3	*Croton sonderianus* Muell. Arg.	0	25	0	1	0	0	0	0	2	0	0	0	0	0	0	0	4	1	0	2	0	3
4	*Jatropha mollissima* Muell. Arg.	0	1	0	3	3	2	2	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0
5	*Libidibia ferrea* (Mart. ex Tul.) L.P.Q.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0
6	*Mimosa tenuiflora* (Willd.) Poir	0	0	29	0	0	0	2	0	1	0	1	6	8	2	3	1	1	8	10	2	7	5
7	*Piptadenia viridiflora* (Benth.)	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	*Prosopis juliflora* (Sw.) DC.	0	0	0	0	0	1	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0
9	*Solanum paniculatum*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total number of plants per plot		**9**	**28**	**29**	**13**	**12**	**4**	**10**	**4**	**11**	**2**	**1**	**6**	**8**	**2**	**5**	**2**	**5**	**10**	**10**	**4**	**7**	**10**
Total species in each plot		**2**	**3**	**1**	**3**	**3**	**3**	**4**	**3**	**4**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**3**	**1**	**2**	**1**	**3**

Table 3. Phytosociologycal parameters of tree species in the conserved areas of the semi-arid region of Paraíba, Brazil.

No.	Scientific Name	Common Name	NPE	NP	AD (I ha^{-1})	RD (%)	AF (%)	RF (%)	ADo (m^2 ha^{-1})	RDo (%)	IVI	IVI (%)	CV	CV (%)
1	*Amburana cearensis* (Fr. Al.) A. C. Smith	Cumarú	8	12	55	1.1	36.4	3.7	11.96	3.0	7.79	2.6	4.09	2.0
2	*Anadenanthera colubrina* (Vell) Brenan	Angico	10	25	114	2.3	45.5	4.6	69.06	17.1	24.09	8.0	19.46	9.7
3	*Annona leptopetala* (R.E.Fr.) H.Rainer	Bananinha	1	1	5	0.1	4.5	0.5	0.05	0.0	0.57	0.2	0.11	0.1
4	*Aspidosperma pyrifolium* (Mart.)	Pereiro	14	87	395	8.2	63.6	6.5	20.39	5.1	19.70	6.6	13.22	6.6
5	*Astronium graveolens*	Gonçalo Alves	1	10	45	0.9	4.5	0.5	1.78	0.4	1.84	0.6	1.38	0.7
6	*Bauhinia cheilantha* (Bong.) Steud.	Mororó	9	40	182	3.8	40.9	4.2	3.92	1.0	8.89	3.0	4.72	2.4
7	*Bauhinia forficata* Link	Mororó de espinho	1	1	5	0.1	4.5	0.5	< 0.01	< 0.1	0.56	0.2	0.09	0.0
8	*Libidibia ferrea* (Mart. ex Tul.)	Jucá	4	20	91	1.9	18.2	1.9	8.43	2.1	5.82	1.9	3.96	2.0
9	*Caesalpinia pyramidalis* (Tul.)	Catingueira	17	126	573	11.8	77.3	7.9	72.56	18.0	37.68	12.6	29.81	14.9
10	*Capparis flexuosa* L.	Feijão bravo	5	10	45	0.9	22.7	2.3	0.51	0.1	3.38	1.1	1.06	0.5
11	*Capparis yco*	Icó	1	2	9	0.2	4.5	0.5	0.22	0.1	0.71	0.2	0.24	0.1
12	*Cedrela odorata* L.	Cedro	1	2	9	0.2	4.5	0.5	8.56	2.1	2.77	0.9	2.31	1.2
13	*Chloroleucon dumosum* (Benth.) G.P.Lewis	Arapiraca branca	2	2	9	0.2	9.1	0.9	0.28	0.1	1.18	0.4	0.26	0.1
14	*Combretum glaucocarpum* (Mart.)	Sipaúba	4	23	105	2.2	18.2	1.9	1.49	0.4	4.38	1.5	2.53	1.3
15	*Combretum leprosum* (Mart.)	Mofumbo	7	16	73	1.5	31.8	3.2	1.26	0.3	5.05	1.7	1.81	0.9
16	*Commiphora leptophloeos* (Mart.) J.B. G.	Imburana	5	8	36	0.8	22.7	2.3	4.82	1.2	4.26	1.4	1.95	1.0
17	*Cordia trichotoma*	Freijorge	2	3	14	0.3	9.1	0.9	0.91	0.2	1.43	0.5	0.51	0.3
18	*Coutarea hexandra* (Jacqu.) Schum.	Quina quina	1	1	5	0.1	4.5	0.5	< 0.01	< 0.1	0.56	0.2	0.09	0.0
19	*Croton nepetifolius* Baill.	Marmeleiro branco	2	24	109	2.3	9.1	0.9	0.43	0.1	3.28	1.1	2.36	1.2

Table 3. Contd.

20	*Croton rhamnifolioides* (Pax & Hoffm)	Catinga branca	1	8	36	0.8	4.5	0.5	0.56	0.1	1.35	0.5	0.89	0.4
21	*Croton sonderianus* (Muell. Arg.	Marmeleiro	17	296	1345	27.8	77.3	7.9	21.56	5.3	40.98	13.7	33.11	16.6
22	*Croton* sp.	Not identified	1	2	9	0.2	4.5	0.5	0.34	0.1	0.73	0.2	0.27	0.1
23	*Desmodium tortuosum*	Rapadura de cavalo	1	1	5	0.1	4.5	0.5	0.01	< 0.1	0.56	0.2	0.10	0.0
24	*Eremanthus arboreus* (Gardner) MacLeis	Candeeiro	1	1	5	0.1	4.5	0.5	0.08	< 0.1	0.58	0.2	0.11	0.1
25	*Erythroxylum* sp. 1	Not identified	1	5	23	0.5	4.5	0.5	0.29	0.1	1.00	0.3	0.54	0.3
26	*Erythroxylum* sp. 2	Not identified	1	4	18	0.4	4.5	0.5	0.09	< 0.1	0.86	0.3	0.40	0.2
27	*Erythroxylum plungens*	Rompe-gibão	1	3	14	0.3	4.5	0.5	0.20	< 0.1	0.79	0.3	0.33	0.2
28	*Fagara rhoifolia*	Limãozinho	1	1	5	0.1	4.5	0.5	0.04	< 0.1	0.57	0.2	0.10	0.1
29	*Genipa americana*	Genipapo	1	2	9	0.2	4.5	0.5	0.58	0.1	0.79	0.3	0.33	0.2
30	*Guapira opposita* (Vell.) Reitz	Pau piranha	2	3	14	0.3	9.1	0.9	1.08	0.3	1.48	0.5	0.55	0.3
31	*Jatropha mollissima* (Pohl.) Baill	Pinhão bravo	7	14	64	1.3	31.8	3.2	1.08	0.3	4.82	1.6	1.58	0.8
32	*Libidibia ferrea* (Mart. ex Tul.) L.P.Queiroz	Pau Ferro	2	2	9	0.2	9.1	0.9	0.83	0.2	1.32	0.4	0.39	0.2
33	*Luetzelburgia auriculata* (Duck)	Pau serrote	1	1	5	0.1	4.5	0.5	0.11	< 0.1	0.59	0.2	0.12	0.1
34	*Manihot dichotoma* Ule	Maniçoba	7	13	59	1.2	31.8	3.2	5.66	1.4	5.86	2.0	2.62	1.3
35	*Maytenus rigida*	Bom-nome	1	1	5	0.1	4.5	0.5	< 0.01	< 0.1	0.56	0.2	0.09	0.0
36	*Mimosa arenosa* (Willd.) Poir	Mimosa calumbi	2	2	9	0.2	9.1	0.9	1.98	0.5	1.60	0.5	0.68	0.3
37	*Mimosa ophthalmocentra* Mart. ex Benth	Jurema de imbira	5	25	114	2.3	22.7	2.3	1.40	0.3	5.01	1.7	2.69	1.3
38	*Mimosa tenuiflora* (Wild.) Poir	Jurema preta	4	21	95	2.0	18.2	1.9	15.86	3.9	7.75	2.6	5.90	3.0
39	*Myracrodruon urundeuva* Fr. All.	Aroeira	7	22	100	2.1	31.8	3.2	49.06	12.2	17.47	5.8	14.23	7.1
40	Not Identified 1	Papaconha	1	1	5	0.1	4.5	0.5	0.03	< 0.1	0.56	0.2	0.10	0.1
41	Not Identified 2	Quebra-faca 1	2	10	45	0.9	9.1	0.9	1.27	0.3	2.18	0.7	1.25	0.6
42	Not Identified 3	Not identified	1	3	14	0.3	4.5	0.5	0.05	< 0.1	0.76	0.3	0.29	0.1
43	Not Identified 4	Not identified	1	10	45	0.9	4.5	0.5	0.05	< 0.1	1.41	0.5	0.95	0.5
44	Not Identified 5	Goiabinha	2	2	9	0.2	9.1	0.9	0.08	< 0.1	1.13	0.4	0.21	0.1
45	Not Identified 6	Canela de veado	1	8	36	0.8	4.5	0.5	1.45	0.4	1.57	0.5	1.11	0.6
46	Not Identified 7	Quebra-faca 2	1	13	59	1.2	4.5	0.5	0.85	0.2	1.89	0.6	1.43	0.7
47	Not Identified 8	Casca de tatu	2	10	45	0.9	9.1	0.9	0.88	0.2	2.08	0.7	1.16	0.6
48	*Parapiptadenia zehntneri* (Harms)	Angico-monjolo	2	2	9	0.2	9.1	0.9	1.99	0.5	1.61	0.5	0.68	0.3
49	*Piptadenia stipulacea* (Benth.) Ducke	Jurema branca	15	95	432	8.9	68.2	6.9	16.66	4.1	19.99	6.7	13.04	6.5
50	*Piptadenia viridiflora* (Benth.)	Amorosa branca	1	1	5	0.1	4.5	0.5	0.08	< 0.1	0.58	0.2	0.11	0.1
51	*Pisonia tomentosa* (Casar)	João mole	3	12	55	1.1	13.6	1.4	1.83	0.5	2.97	1.0	1.58	0.8
52	*Pseudobombax marginatum* (J. & C.)	Embiratanha	1	1	5	0.1	4.5	0.5	0.21	0.1	0.61	0.2	0.15	0.1
53	*Randia armata*	Espinho de judeu	1	1	5	0.1	4.5	0.5	7.28	1.8	2.36	0.8	1.90	0.9
54	*Sapium glandulatum* (Pax)	Burra leiteira	5	8	36	0.8	22.7	2.3	6.13	1.5	4.58	1.5	2.27	1.1
55	*Schinopsis brasiliensis* (Engl.)	Baraúna	5	10	45	0.9	22.7	2.3	46.34	11.5	14.74	4.9	12.43	6.2
56	*Senegalia tenuiflora* (L.) B & R.	Unha de gato	2	5	23	0.5	9.1	0.9	0.07	< 0.1	1.41	0.5	0.49	0.2

Table 3. Contd

57	*Senna trachypus* (Benth.) H.S.I. & B.	Canafístula	1	1	5	0.1	4.5	0.5	< 0.01	< 0.1	0.56	0.2	0.09	0.0
58	*Sideroxylon obtusifolium* (H. ex. R. & S.)	Quixaba	1	1	5	0.1	4.5	0.5	0.11	< 0.1	0.58	0.2	0.12	0.1
59	*Spondias tuberosa* (L.)	Umbú	1	5	23	0.5	4.5	0.5	1.29	0.3	1.25	0.4	0.79	0.4
60	*Tabebuia impetiginosa*	Ipê roxo	1	2	9	0.2	4.5	0.5	0.16	< 0.1	0.69	0.2	0.23	0.1
61	*Tocoyena brasiliensis* (Mart.)	Genipapinho	1	1	5	0.1	4.5	0.5	0.00	< 0.1	0.56	0.2	0.09	0.0
62	*Ximenia americana* (L.)	Ameixa do mato	1	1	5	0.1	4.5	0.5	0.02	< 0.1	0.56	0.2	0.10	0.0
63	*Ziziphus joazeiro* (Mart.)	Juazeiro	5	23	105	2.2	22.7	2.3	9.18	2.3	6.75	2.2	4.43	2.2
Total sum				1066	4,845	100	981.8	100	403.42	100	300	100	200	100

NPIS = number of plots with the species; NPS = number of plants of the species i; AD = absolute density; RD = relative density; AF = absolute frequency; RF= relative frequency; ADo = absolute dominance; RDo = relative dominance; VI = value of importance; VI % = value of importance in percentage and VC = value of coverage; Total plot assessed= 22.

Table 4. Phytosociological survey of tree species in the conserved areas of the semi-arid region of Paraíba, Brazil.

No.	Scientific Name	Common Name	NPIS	NPS	AD (I ha^{-1})	RD (%)	AF (%)	RF (%)	ADo (m^2 ha^{-1})	RDo (%)	IVI	IVI (%)	CVI	CVI (%)
1	*Aspidosperma pyrifolium* (Mart.)	Pereiro	4	7	32	3.55	18.2	8.5	2.52	12.1	24.18	8.1	15.67	7.8
2	*Caesalpinia pyramidalis* (Tul.)	Catingueira	7	26	118	13.20	31.8	14.9	4.05	19.5	47.57	15.9	32.67	16.3
3	*Croton sonderianus* (Muell. Arg.)	Marmeleiro	7	38	173	19.29	31.8	14.9	0.73	3.5	37.69	12.6	22.79	11.4
4	*Jatropha mollissima* (Muell. Arg.)	Pinhão bravo	7	18	82	9.14	31.8	14.9	0.92	4.4	28.43	9.5	13.54	6.8
5	*Libidibia ferrea* (Mart. ex Tul.) L.P.Q.	Pau Ferro	2	3	14	1.52	9.1	4.3	0.16	0.8	6.53	2.2	2.27	1.1
6	*Mimosa tenuiflora* (Wild.) Poir	Jurema preta	15	91	414	46.19	68.2	31.9	9.87	47.5	125.59	41.9	93.68	46.8
7	*Piptadenia viridiflora* (Benth.)	Amorosa branca	1	8	36	4.06	4.5	2.1	0.12	0.6	6.76	2.3	4.63	2.3
8	*Prosopis juliflora* (Sw.) DC.	Algaroba	3	5	23	2.54	13.6	6.4	2.43	11.7	20.62	6.9	14.23	7.1
9	*Solanum paniculatum*	Jurubeba	1	1	5	0.51	4.5	2.1	< 0.01	< 0.1	2.64	0.9	0.51	0.3
Total sum				197	895	100	214	100	20.78	100	300	100	200	100

NPI = number of plots with the species; NPS = number of plants of the species i; AD = absolute density; RD = relative density; AF = absolute frequency; RF = relative frequency; ADo = absolute dominance; RDo = relative dominance; VI = value of importance; VI% = value of importance in percentage and VC = value of coverage; Total plot = 22.

C. pyramidalis (72.56 m^2 ha^{-1}) > *Anadenanthera colubrina* (69.06 m^2 ha^{-1}) > *Myracrodruon urundeuva* (49.06 m^2 ha^{-1}) in the conserved areas, and *Mimosa tenuiflora* (9.87 m^2 ha^{-1}) > *C. pyramidalis* (4.05 m^2 ha^{-1}) > and *A. pyrifolium* (2.52 m^2 ha^{-1}) in the desertified areas.

The highest importance value index (IVI) and coverage value index (CVI) were observed for *C. sonderianus* (13.7 and 16.6%) and *M. tenuiflora* (41.9 and 46.8%), in the conserved and desertified areas, respectively, indicating a more balanced importance between the species in the conserved areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessing rural farmers' perceptions and vulnerability to climate change in uMzinyathi District of Kwazulu-Natal, South Africa

Stephen Shisanya* and Paramu Mafongoya

Water Research Commission (WRC), University of KwaZulu-Natal (UKZN), South Africa.

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There is little awareness among rural farming communities on their vulnerability to climate change. This paper examined the vulnerabilities of the rural small scale farming communities in the uMzinyathi District of KwaZulu-Natal, South Africa to climate change. A survey among 200 households who were randomly chosen but who had lived in the community for over twenty years was conducted. Focus group discussions and key informant interviews were carried out to obtain qualitative data. Over the period 1993 to 2010, average annual temperature had increased by 1.5°C. Rainfall generally decreased over the period 1981 to 2010 with a range of 907 mm. Household perception on extreme climate conditions were a reflection of the quantitative climate data collected. Households were anxious (76%) that they will face negative impacts of climate change in future. Households were evenly distributed across the five vulnerability categories. Perceptions of communities to climate change should be considered by policy makers in advancing strategies to mitigate impacts of climate change. Vulnerability of farmers to climate change could be reduced by investing in early warning systems, providing farmers with information on climate change and farmers seeking alternative livelihood options rather than agriculture. Household specific interventions should be considered in mitigating climate change.

Key words: Local knowledge, adoptive capacity, early warning systems, agriculture, mitigation.

INTRODUCTION

Our climate is important because it determines our localities and in general our livelihoods and how we are organised in our societies. It has been shown that our climate will change over time and this may occur both naturally, as integral parts of how the global and regional climate systems function, as well as in response to additional influences due to human activity (Intergovernmental Panel on Climate change (IPCC), 2008). These changes that may occur over time may pause major challenges to humanity. The Fourth

*Corresponding author. E-mail: sshisanya@gmail.com.

Assessment Report of the IPCC has projected that even with immediate implementation of climate mitigation policies, the global climate system will continue to shift and change for decades (Fussel and Klein, 2006; IPCC, 2007a). It is predicted that in the tropics, temperature will continue to increase, rainfall will decrease and frequency of floods and droughts will increase over time (IPCC, 2001).

The state and dynamics of climate change processes differ from place to place and generate conditions that differ in character and degree to an extent that populations that are exposed to similar climatic phenomenon are not impacted the same (IPCC, 2001). Sub-populations or groups inhabiting a region, and even from household to household within a group may experience changes in climate differently. For household to react to a changing climate, it will require that household will have to notice that climate has changed. Local knowledge about climate change will become very important in determining the way in which households will respond to climate change. This knowledge will be used to shape the practices that communities will be engaged in. Local knowledge assists communities to make decisions on how to respond to changes in their environment and how they will act to minimise loses or take advantage of the change (Cabrera et al., 2006).

Limited studies have been done on the social aspects of vulnerability to climate change (Gbetibouo and Ringler, 2009). Available information on vulnerability of specific communities to climate change and potential adaptation measures is still insufficient (Chikozho, 2010; IPCC, 2007a). Such information is necessary to enable policy makers to tackle climate change with some level of accuracy.

There is at present scanty consensus on the conceptual framework on how to define and measure vulnerability (Scaramozzino, 2006). There is need for more comprehensive studies that reveal vulnerability of communities, in order to come up with timely information and options for adaptation.

Vulnerability is therefore a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (Adger, 1996; Aandahi and O'Brien, 2001). Vulnerability to climate change does not manifest due to climate alone, but rather arises in the presence of multiple stressors which include socio-economic factors and environmental factors (Deressa et al., 2008). The socioeconomic factors include the level of technological development, infrastructure, institutions and the political environment (McKenzie, 2003). The environmental factors cited in literature include climatic conditions, quality of soil and water availability (IPCC, 2007b). The variations of these socioeconomic and environmental factors across different social groups are responsible for the differences in their levels of vulnerability to climate change. Vulnerability is also mediated by institutional factors including rules, norms and policies (Gbetibouo and Ringler, 2009). However, vulnerability is still a contested concept, and there is little agreement about how to convert it into policy and relevant measures for priority setting (Nelson et al., 2010).

This paper attempts to analyse vulnerabilities of the rural small scale farming communities to climate change in the uMzinyathi District Municipality of South Africa with the aim of expanding the knowledge on vulnerability analysis through the lens of individual household perceptions. Factors that contribute to individual household vulnerability to climate change are also investigated.

LITERATURE REVIEW

Climate change will continue to be a major threat to rural livelihoods (Nhemachena, 2009). Southern Africa is widely recognised as one of the most vulnerable regions to climate change because of low levels of adaptive capacity (particularly among rural communities), combined with a high dependence on rain-fed agriculture (IPCC, 2007b). With a changing climate, it is predicted that by mid-21st century, South Africa will have a broad rainfall reduction in the range of 5 to 10% with adverse negative impacts on agriculture especially in the rural areas accompanied with droughts and floods (Gbetibouo and Ringler, 2009). Comprehensive studies have been done in South Africa on the impact of climate change on quantitative agricultural production and economic implications (Challinor et al., 2007). Limited studies have been done on the social aspects of climate change (Gbetibouo and Ringler, 2009).

Key for communities to adapt to a changing climate is their ability to perceive climate change (Gbetibouo, 2008). A number of studies have shown that communities' perception of climate change have matched quantitative data of climate elements. In a study conducted by Vedwan and Rhoades (2001) on the perception of apple farmers in the western Himalayas, they found that farmers' perceptions to climate change indeed corresponded to climatic data records. A similar study conducted by Hageback et al. (2005) on how small scale farmers of Danagou watershed in China perceived climate change also concluded that there was a strong correlation between farmers' perception and meteorological data. Slegers (2008) had similar findings in his study with farmers in semi-arid central Tanzania. However, other studies like the one carried out by Rao et al. (2011) in the semi-arid parts of Kenya showed that communities' perception of climate change did not match quantitative data collected for the area.

Adoptive capacity of rural communities can be enhanced if practices that are already being implemented by farmers are incorporated into national strategies on climate change. Many scholars have pointed out the importance of local knowledge in developing effective strategies to a changing climate (Newsham and Thomas, 2011; Mertz et al., 2009). Unfortunately, many development agencies including national governments, Non-governmental Organizations (NGOs), international donor communities do not consider rural communities' perceptions to climate change for inclusion in their interventions (FAO, 2011).

The IPCC's (2001) considers vulnerability to climate change to be the degree to which a system is susceptible or unable to cope with adverse effects of climate change, including climate variability and extremes. Climate change has been the subject of intense debate in the global environment with the need to understand communities' vulnerabilities arising from these debates. Whilst definitions of vulnerability are plentiful, the main area of contest has been finding a robust measurement of vulnerability that puts into account the basics of risk analysis. In general, Nelson et al. (2007) and IPCC (2001) looks at vulnerability as the susceptibility of a system to disturbances determined by exposure to perturbations, sensitivity to perturbations, and the capacity to adapt. Specific to climate change, IPCC (2001) defines vulnerability as "the degree to which a system is susceptible, or unable to cope with adverse effects of climate change, including climate variability and extremes". In addition to the challenge of defining vulnerability, it is also difficult to measure quantitatively (Schwarz et al., 2011; IPCC, 2007a). To a large extent, vulnerability concept remain largely academic and theoretical, and not of a great help in improving the way natural resources are managed or used in planning and management (Schwarz et al., 2011). Chambers (1989) has argued that the primary goal of applied vulnerability assessment should be to create contextually relevant measures of vulnerability that trigger action to reduce it. Scaramozzino (2006), Aandahi and O'Brien (2001), and Adger (1996) continue to emphasize that vulnerability is influenced by both physical and socioeconomic characteristics which are themselves not static, implying that vulnerability is context specific, and specific to place, time and the perspective of those assessing it. The context specific nature of vulnerability means that there can be no single, unified or general purpose approach to conceptualising it. Vulnerability analysis ranges from local or household Adger (1999) levels to the global level (Brooks et al., 2005).

IPCC (2001) and Deressa et al. (2008) observed that vulnerability can be conceptualized in many different ways along a continuum from outcome to contextual vulnerability. Outcome vulnerability is characterized by the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes i.e. existent state (Kelly and Adger, 2000). Contextual vulnerability assesses 'the susceptibility of a system to disturbances determined by exposure to perturbations, sensitivity to perturbations, and the capacity to adapt (Kelly and Adger, 2000). Schwarz et al. (2011) cautions of the importance of understanding people's perception about a particular climate event e.g. cyclone. It is important to note that communities are not homogenous in terms of exposure to the threat or resilience and will respond differently to different stimuli (Schwarz et al., 2011).

Deressa et al. (2008) identifies three major conceptual approaches to analysing vulnerability to climate change: the socioeconomic (focuses on socio-economic variations in the community, ignoring the environmental variation), the bio-physical (considers the level of damage from a given environmental stress, ignoring the individuals' capacity to adapt), and the integrated assessment approaches. Although, each has its strong points and weaknesses, the integrated approach has much to offer in terms of policy decisions (Nelson et al., 2010; Fussel, 2007). The integrated approach combines both socio-economic and bio-physical approaches to determine vulnerability. As regards IPCC (2001) definition of vulnerability, Deressa et al. (2008) cautions that although the integrated approach corrects the weaknesses of the other approaches, its limitation is that there is no standard method for combining the biophysical and socioeconomic indicators, requiring care in the ranking of variables. Luers (2003) observed that the use of indicators is limited by considerable subjectivity in variable selection and their weighting. However, Leichenko and O'Brien (2002) showed that composite indices method captures the multi-dimensionality of vulnerability comprehensively and has more to offer practical decision making processes in terms of policy. Thus, this study adopted this method to analyse the vulnerability of rural farming households of uMzinyathi District Municipality of KwaZulu-Natal.

Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adoptive capacity (IPCC, 2001). Since IPCC definition accommodates the integrated vulnerability assessment approach, this study is based on this approach that considers both biophysical and the socioeconomic indicators in assessing vulnerability of rural small-scale farming communities in uMzinyathi District Municipality to climate change.

Deressa et al. (2008) showed that sensitivity and adaptive capacity are linked. Given a fixed exposure, the adaptive capacity influences the level of sensitivity; higher adaptive capacity (socio-economic vulnerability) results in lower sensitivity (bio-physical vulnerability) and vice versa. Exposure relates to the degree of climate stress upon a particular unit of analysis which may be represented by frequency of climate extremes or predicted change in temperature or rainfall (Gbetibouo and Ringler 2009). Sensitivity is the degree to which a system is modified or affected by an internal or external disturbance or set of disturbances which reflects the responsiveness of a system to climatic influences, as shaped by both socio-economic and ecological conditions (Gallopín, 2003). Brooks (2003) and IPCC (2001) describe adaptive capacity as the potential or ability of a system, region, or community to adjust to the effects or impacts of climate change (including climate variability and extremes). Analysing vulnerability involves identifying not only the threat, but also the “resilience,” or the responsiveness of the system and its ability to exploit opportunities and resist or recover from the negative effects of a changing environment (Gbetibouo and Ringler, 2009).

MATERIALS AND METHODS

Data collection

Meteorological data was collected from the meteorological department of South Africa for the nearest weather station, Greytown station (0270155 9 – GREYTOWN) with latitude and longitude of -29.0830 and 30.6000, respectively and an altitude of 1029 m above sea level. Meteorological data for the different weather elements was available only over the indicated periods; rainfall (1981 to 2010), temperature (1993 to 2010). This data was analysed for trends and variability. A survey was conducted among 200 households purposively sampled to have respondents of 40 years old or more and who have lived in the area for at least 20 years and participating in agricultural activities. A questionnaire was used to seek quantitative information while qualitative information was collected through focus group discussions and key informant interviews. Topics of inquiry included in the interviews were: (a) crop production involvement; (b) means of coping with past and current climatic conditions; (c) foresight into future climatic conditions; (d) direction of future adaptive strategies; (e) aids and constraints to adaptation, and (f) access to information. Quantitative data was captured and analysed using SPSS.

Analysis of the weather elements and community responses to their perceptions on changes in climate was then analysed using the SPSS programme. A comparison was then made between the actual changes in weather patterns and the communities’ perception on climate change. Further analysis was also done on the characteristics of households who perceived climate had changed compared to those who did not perceive that climate had changed.

Construction of vulnerability indices

From our conceptual framework, vulnerability indexwas calculated using the formula:

V = f (I - AC)

(-) or (+)

where V is vulnerability index, I is potential impact and AC is adaptive capacity. In the calculation, both exposure and sensitivity were given negative signs. The justification is that areas that are exposed to damaging climate are more sensitive to damages given that the livelihoods of the community is agriculture based, assuming constant adaptive capacity (Deressaet al., 2008). In this relationship, the higher the net value indicates lesser vulnerability and vice versa. The methodology used in UNDP’s Human Development Index (HDI) (UNDP, 2006) is followed for normalization. Indicators that have positive (↑) functional relationship with vulnerability e.g. variance in rainfall, their index values are calculated using the formula:

$$x = \frac{xi - Min(xi)}{Max(xi) - Min(xi)}$$

Indicators with negative (↓) functional relationship with vulnerability, e.g. adult literacy, their index value is calculated using the formula:

$$y = \frac{max(xi) - xi}{Max(xi) - Min\ (xi)}$$

After standardization of the indicators, weights were assigned to the indicators using the Principal Component Analysis (PCA) technique (Filmer and Pritchett, 2001; McKenzie, 2003). PCA technique was used to develop principle components that will account for most of the variance in the observed variables which were then used as predictor or criterion variables in subsequent analyses (McKenzie, 2003). The PCA is a multivariate statistical technique used to reduce the number of variables without losing too much information in the process (Sarbu and Pop, 2005). The PCA technique achieves this by creating a fewer number of variables which explain most of the variation in the original variables (Giri, 2004). The new variables which are created are linear combinations of the original variables. Those Principle Components (PCs) with Eigen values greater than one were selected as proposed by (Jeffers, 1967). Rousson and Gasser (2003) cautions that in some cases, principal components often lack interpretability and may define some abstract scores which often are not meaningful, or not well interpretable in practice. However, in order to enhance interpretability, principal components are often rotated according to the varimax criterion of Kaiser (1958).

For classificatory purposes, Iyengar and Sudarshan (1982) showed the suitability of the beta distribution in classifying levels of vulnerabilities characterized into the following fractile intervals:

(1) Very highly vulnerable if $0 < y_i < z_1$
(2) Highly vulnerable if $z_1 < y_i < z_2$
(3) Vulnerable if $z_2 < y_i < z_3$
(4) Moderately vulnerable if $z_3 < y_i < z_4$
(5) Less vulnerable if $z_4 < y_i < 1$

where y_i is the normalised vulnerability index and $(0,z_1)$, (z_1,z_2), (z_2,z_2), (z_3,z_4) and $(z_4,1)$ are the linear intervals such that each interval has the same probability weight of 20%.

RESULTS

Rainfall pattern in uMzinyathi District (1981 – 2010)

uMzinyathi District received an average annual rainfall of 784.29 mm (Average 1981 to 2010) but with quite large differences between years of low and high rainfall (Figure 1). Over the period (1981 to 2010), there was a generally decreasing rainfall in the study area.

The year 1987 registered the highest amount of rainfall (539 mm above average), while the year 2003 recorded the least volume of rainfall (368 mm below average). The years 1985, 1987 and 1988 had generally high rainfall records, 296, 538 and 395 mm above average,

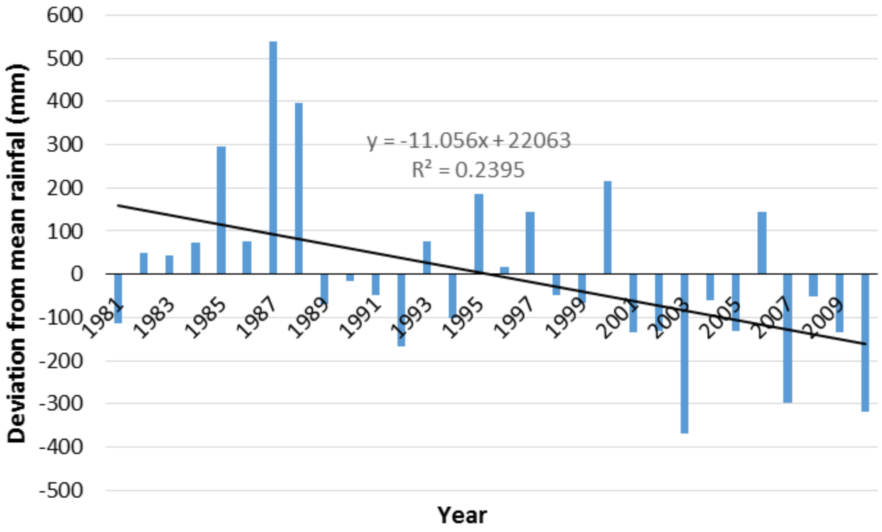

Figure 1. Annual deviation of rainfall from the mean (1981-2010).

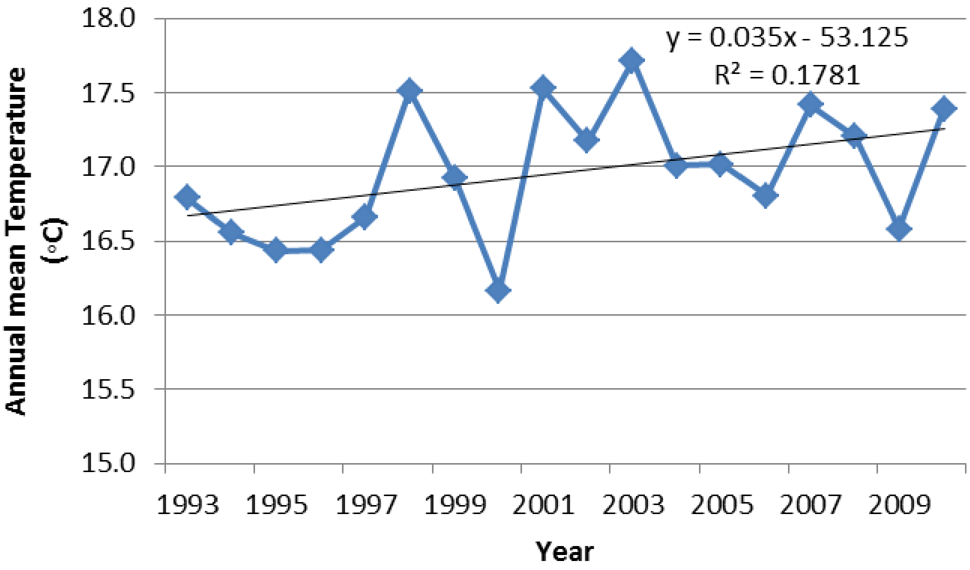

Figure 2. Annual average temperature (1993-2010).

respectively. The years 2004, 2007 and 2010 recorded the least rainfall with amounts of 368, 296 and 319 mm below average rainfall, respectively. The average annual rainfall over the period was 784.29 mm.

Temperature pattern of uMzinyathi District (1993 – 2010)

Over the period of 1993 to 2010, uMzinyathi District Municipality experienced annual average temperature range of between 16.2 and 17.7°C, with a period average annual temperature of 17.0°C. Generally, annual temperature increased over the period under review (Figure 2).

The year 2003 registered the highest temperature of 17.7°C and the year 2000 registered the least temperature of 16.2°C. Over the 17 years under review, temperature had increased by 1.5°C.

Community perceptions of climate change

Through focus group discussions and interviewing key informants, the local community was able to recollect precisely the years that had extreme events that affected their agricultural activities and this was compared to the meteorological data of the area (Table 1).

Table 1. Years of extreme climate conditions of relevance to agricultural production in UMzinyathi District Municipality.

Year	Observation by local community	Official records of annual rainfall (Data Source: SA Weather- Station [0270155 9] - GREYTOWN -29.0830 30.6000 1029 m)
1981-1982	Drought	1981 rainfall was below average with 1982 having slightly above average rainfall (Average rainfall = 784.29)
1985-1988	Intensive rains with floods during the summer cropping seasons	1985-1988 were all above average rainfall period. Most of the rains in 1985 and 1988 intensified over the period December - February. In 1986 most of the rain was received in January (234 mm) and in September for 1987 (385 mm)
1992	Drought	1989- 1994 were dry years with below minimum rainfall. 1992 was most severe (619 mm)
2003	Drought	2003 was a dry year(416 mm), the driest since 1981
2007-2010	Dry years	The periods 1998-2010 experienced below average rainfall except for years 2000 (1000 mm) and 2006 (929 mm) that received above average rainfall
2007	Drought	2007 was a dry year (488 mm) and most of the rain was received in October and November (288 mm)
2010	Drought	2010 was a dry year (465 mm) with only January receiving most rain (140 mm)

Table 2. Percentage of households' perceptions of climate change parameters in uMzinyathi District Municipality over the last 20 years (n=200).

Climate change parameters		Increase	Decrease	No change	Don't know
Noticed long term changes in the temperature in the last 20 years	Summer season temperature	78.0	11.0	5.0	6.0
	Winter season temperature	70.0	16.0	3.0	11.0
	Length of cold periods	19.0	55.0	23.0	3.0
	Length of hot periods	62.0	15.0	20.0	3.0
Noticed long term changes in rainfall in the last 20 years	Summer season rainfall	13.0	84.0	2.0	1.0
	Winter season rainfall	17.0	76.0	3.0	4.0
	Length of summer season rainfall	10.0	74.0	12.0	4.0
	Length of winter season rainfall	16.0	69.0	1.0	4.0
	Fluctuation in timing of rains	53.0	26.0	16.0	5.0
	Frequency of droughts	73.0	8.0	14.0	5.0
	Frequency of floods	39.0	52.0	8.0	1.0

Community observations did match the data that was recorded from the meteorological station. Community members were able to recollect the periods of extreme events of droughts and floods. Though some years were indicated as having exhibited extreme condition, in some instances these were carryover effects of the previous year.

From Table 2, households (78.0%) indicated that summer temperatures had generally increased and 62.0% said that hot periods had also increased.

A majority (70.0%) of households indicated that winter temperatures were becoming warmer and 55.0% indicated that the length of cold season was getting shorter. Most of the households (84.0%) indicated that summer season rainfall had decreased and so was the rains received during the winter season (76.0%).

Table 3. Results of unrelated probit model of households' perception of change in the climate, uMzinyathi District (n = 200).

Household characteristic	Perceive change in temperature	Perceive change in rainfall
Age	0.321**	0.5365**
Sex of household head	0.587	0.452
Education	0.369	-0.257**
Years of farming experience	0.213	0.118***
Access of information on climate change	0.025*	0.348**
Irrigation	-0.258**	0.310**
Visited by extension officer	0.756**	0.467**
Received training on climate change	0.015**	0.384***
Intercept	2.333**	1.798**
Log likelihood: -178.352	-	-
Athrho: 0.453***	-	-
Rho: 0.687	-	-

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level.

Households indicated that both the summer and winter rainfall periods had decreased over time (74.0 and 69.0%) respectively. Households (53.0%) also indicated that there was an increased fluctuation in timing of rains and that there was increased frequency (73.0%) of droughts while incidences of floods had decreased over time (52.0%).

Further analysis was carried out to characterise households that were likely to notice climate change (temperature and/or rainfall changes) compared to those who were not likely to notice climate change by running a probit model.The independent variables used in this study included age, sex of household head, education, years of farming experience, access to information on climate, irrigation, visited by extension officers, received training on climate change. The results presented in Table 3 shows that age of household heads seemed to increase the probability that households were more likely to perceive long term changes in both rainfall and temperature.

Households who had access to irrigation water were also more unlikely to perceive changes in both rainfall and temperature. Households with longer farming experience were more likely to perceive long term changes in rainfall. On the other hand household who had received training on climate change were more likely to perceive changes in climate whether in temperature or on rainfall. Households who received extension services were likely to perceive changes in rainfall and temperature.

Categories of vulnerability indicators

The conceptual framework for this study was used to categorise the bio-physical and the socio-economic vulnerabilities into vulnerability indicators (Table 4) showing the selected indicators for the study, how they impact on community vulnerability and their units of measurement.

Community exposure was determined by the indicators, change in temperature and change in precipitation and these were measured by community perceptions. Community sensitivity was determined by frequency of droughts and floods and similarly measured by community perceptions. On the other hand, adoptive capacity was considered to include two of the livelihood assets, human and social capital.

Household anxiety to climate change

When asked about the feeling about future climate (Table 5), most households indicated that they were worried that they will face droughts and floods (78.0 and 64.0%, respectively). Interestingly most households (71.0%) indicated that they may not face crop failure.

Most households (69.0%) were not anxious that they may face price decline of their farm products. Household were not concerned about soil fertility decline (69.0%) and increase in cost of farm inputs (74.0%). Households were also anxious that they could face crop and animal disease outbreaks (58.0 and 56.5% respectively) with the anticipated future change in climate. Overall, households (76.0%) were anxious that they will face adverse change in climate in future.

Principal component analysis

The result of the Principal Component Analysis (Table 6) shows that 14 components with Eigen value of 1 or greater accounted for 67.5% of the total variance.

The first component has an Eigen value of 6.818 and

Table 4. Vulnerability indicators and possible impact on level of vulnerability of rural farming community in uMzinyathi District Municipality.

Determinants of vulnerability	Vulnerability indicators	Indicator description	Unit of measurement	Relationship between indicator and vulnerability
Exposure	Change in climate	Change in temperature	Community perception	The higher the change from normal the higher the vulnerability level
		Change in precipitation	Community perception	The higher the change from normal the higher the vulnerability level
Sensitivity	Extreme climate *(Land degradation index)*	Frequency of droughts and floods	Community perception	The higher the frequency, the higher the vulnerability level
Adoptive capacity	**Human capital** Literacy level Knowledge on Crop and water management	Quality of education	% of population	The higher the literacy level the lesser the vulnerability
	Irrigation potential **Social capital**	-	% of population in community relationships	The more a household is involved in community relationships the lesser the vulnerability

Table 5. Percentage of households response to anxiety on future climate change (n=200).

Household worry to:	Never	Rarely	Sometimes	Often
Recurrent droughts	15.5	6.0	38.5	39.5
Recurrent flood	12.0	24.0	38.5	25.5
Crop failure	25.0	46.0	12.5	16.5
Crop diseases	17.0	25.00	39.0	19.0
Livestock diseases	19.0	24.5	33.5	23.0
Price decline of farm products	51.0	18.0	20.5	10.5
Soil fertility decline	49.5	20.0	17.0	13.5
Price increase of inputs	51.50	22.5	18.5	7.5
Late on-set of rains	18.0	32.5	32.5	17.0
Shorter rainy seasons	17.5	22.5	38.0	22.0
Climate variability	19.0	5.0	35.5	40.5

explains 15.4% of the variation in the original variables and each subsequent component explains a decreasing proportion of variance. The screen plot test (Cattell, 1966) in Figure 3, shows a plot of the Eigen values associated with each component and indicates a "break" between the components with relatively large Eigen values and those with small Eigen values.

The components that appear before the break are assumed to be meaningful and are retained for rotation; those appearing after the break are assumed to be unimportant and are not retained (Cattell, 1966). In this case only components 1, 2 and 3 were used in the computation of household vulnerability indices. The component scores are shown in Table 7. Component 1 has got four component indicators; component 2 has eight indicators while component 3 has two indicators.

Household vulnerability index

Figure 4 shows the computed household vulnerability index. Fewer households, 40 (20%) had positive

Table 6. Total variance explained on the coping strategies to climate change (n = 200).

Component	Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.818	15.496	15.496	3.531	8.025	8.025
2	4.814	10.940	26.436	3.444	7.828	15.854
3	2.635	5.988	32.424	3.271	7.433	23.287
4	2.022	4.594	37.019	2.444	5.554	28.840
5	1.853	4.211	41.230	2.428	5.518	34.358
6	1.626	3.695	44.925	2.035	4.625	38.983
7	1.525	3.466	48.392	1.918	4.358	43.341
8	1.424	3.235	51.627	1.690	3.841	47.183
9	1.337	3.040	54.667	1.645	3.738	50.921
10	1.254	2.849	57.516	1.586	3.604	54.525
11	1.175	2.671	60.188	1.563	3.553	58.078
12	1.133	2.575	62.762	1.508	3.426	61.505
13	1.067	2.425	65.188	1.438	3.269	64.773
14	1.028	2.335	67.523	1.210	2.750	67.523

Extraction Method: Principal Component Analysis.

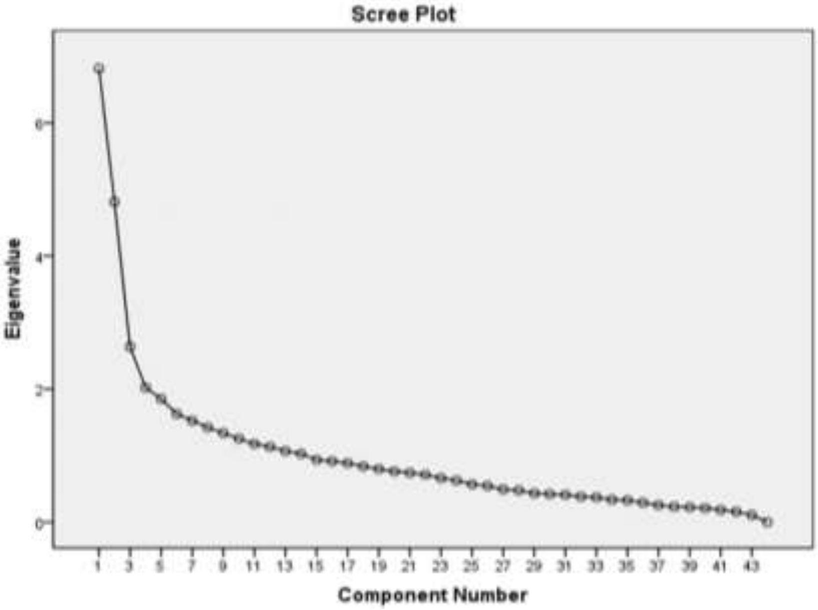

Figure 3. Screen plot showing the proportion of variance explained by each principal component.

household vulnerability index indicating that they were relatively not vulnerable to climate change while the rest 160 (80%) had negative household vulnerability index implying that they were relatively vulnerable to climate change.

Household vulnerability categories

Table 8 shows household vulnerabilities distributed across the five categories. There seem to be an even distribution of households among the different levels of vulnerability.

Category 3 (vulnerable) had the least number of households (17.0%), while category 4 (moderately vulnerable) had the most households (23%). 18.5% of households were very highly vulnerable, while 20% were less vulnerable.

A Chi-square test was carried out between household vulnerability categories and nominal household

Table 7. Rotated component matrix.

Component indicators	1	2	3
Rain water harvesting for irrigation	0.797	-	-
Crop diversification	0.699	-	-
Cover cropping	0.490	-	-
Across slope cultivation	0.468	-	-
Minimum tillage	-	0.680	-
Crop residue management	-	0.672	-
Tree planting alongside crops	-	0.596	-
Intercropping	-	0.557	-
Mixed farming	-	0.544	-
Diversifying to non-farming activities	-	0.488	-
Using organic manure	-	0.448	-
Using moist valley bottoms	-	0.347	-
Out migration	-	-	0.742
Leasing out land	-	-	0.698

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 14 iterations.

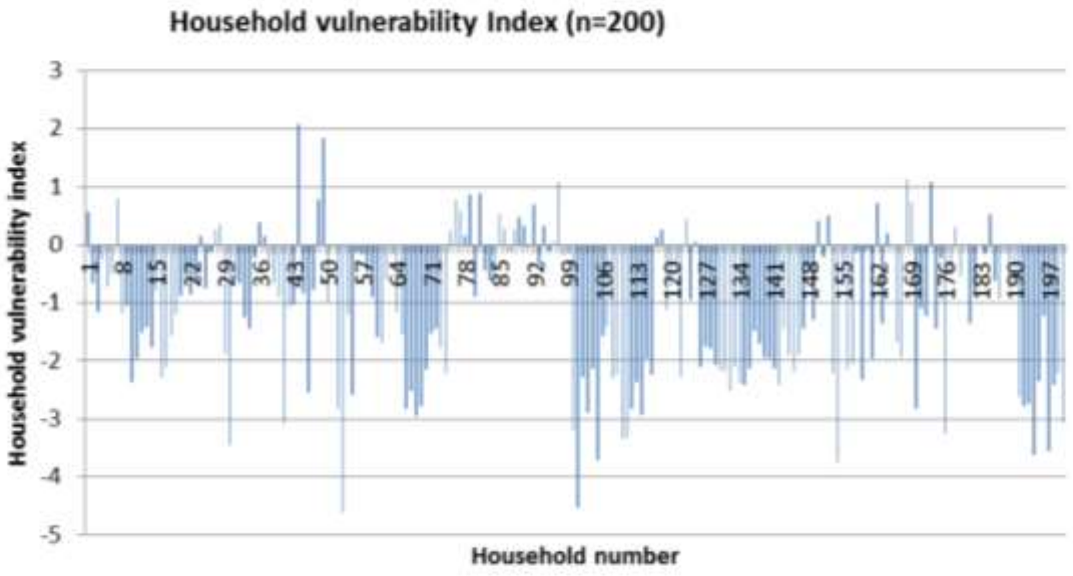

Figure 4. Individual household vulnerability index.

characteristics (Table 9). Level of education of household head and households owning a radio had significant ($p < 0.05$) relationships to vulnerability to climate change. Other household characteristics considered did not have a significant relationship to household vulnerability.

A Pearson's correlation was carried out to establish if there existed any relationship between household ordinal characteristics and household vulnerability (Table 10). There was a negative and significant relationship between household vulnerability and old age and disability grants (-0.155* and -0.185**), respectively. Other household characteristics considered in the study did not have significant relationships to household vulnerability.

DISCUSSION

Analysis of temperature (1993 to 2010) showed an annual increase by 1.5°C. Rainfall records showed generally decreasing levels of precipitation over the period of 1981 to 2010. The results are in agreement with

Table 8. Household vulnerability categories (normalized).

Statistics		Value	
A		3.2801	
B		3.09	
Mean		0.5173	
STD DEV		0.1926	
Median		0.5225	
LQUARTILE		0.3727	
UQUARTILE		0.6650	
Vulnerability categories		**n=200**	**Percentage**
Very highly vulnerable	0.00 <yi< 0.34	37	18.50
Highly vulnerable	0.34 <yi< 0.46	43	21.50
Vulnerable	0.46 <yi< 0.56	34	17.00
Moderately vulnerable	0.56 <yi< 0.68	46	23.00
Less vulnerable	0.68 <yi< 1.00	40	20.00

Table 9. A Chi-square test of household vulnerability and nominal household characteristics (n = 200).

Nominal household characteristic	Vulnerability index		
	Chi-square	Degrees of freedom	Asymp. Sig (2 sided) (*p* – value)
Sex of household head	200	199	0.467
Highest level of education of household head	600	597	0.042**
Household head can read and write	200	199	0.467
Household owns TV	235	230	0.467
Household owns radio	200	199	0.026**
Household owns mobile set	200	199	0.467
Anxiety over climate change	5200	5174	0.397

Table 10. Pearson's correlation between ordinal household characteristics and household vulnerability (n = 200).

Ordinal household characteristic	Household vulnerability
Total number of household members	0.064
Income per month from old age grant	-0.155*
Income per month from disability grant	-0.185**
Total Household income per month	0.020
Total area cultivated in square metres	0.420
Total money spent on food purchase in a month	-0.091
Value of inputs used in agricultural production	0.040
Value of livestock owned by household	-0.108
Number of children in household	0.027
Number of adults in household	0.039

**Significant at 5% level; *Significant at 10% level.

(IPCC, 2001) indication that with climate change, temperatures will increase while total rainfall will generally decrease. Communities of uMzinyathi District are very much aware of what climate is and they are able to share their experiences on a changing climate. From both the focus group discussions and the household surveys, temperature and rainfall seemed to be the main climate elements of concern. Relative humidity was not of critical concern among the respondents. The overall results showed that communities of uMzinyathi District recognise that climate has changed over the past 20 years. The perceived climate change does correspond to the meteorological data of the study area. These findings are in agreement with similar studies including Vedwan and Rhoades (2001) who examined how apple farmers in the western Himalayas of India perceive climatic change and Hageback et al. (2005) who assessed small-scale farmers' perceptions of climate change in the Danagou watershed in China. Other studies that are in agreement with this finding include Slegers (2008), working with semi-arid communities in Central Tanzania.

The results show that uMzinyathi communities perceive that climate has become hotter and drier. This confirms the meteorological data presented earlier for the study area and (Hanjra and Qureshi, 2010) observations that climate change will increase water scarcity. The implications could be decreased stream flow and groundwater recharge (IPCC, 2001; Blignaut and van der Elst, 2009) and generally insufficient water to sustain both crop and animal production consequently leading to high levels of food insecurity. Having access to water for irrigation provided a back-up system for households as such fluctuation in temperature and rainfall is not of concern. A similar observation was made by Gbetibouo (2008) among a farming community in the Limpopo River Basin. Households who received extension services were likely to perceive climate change since they were exposed to information about climate. Experienced farmers in farming were more likely to perceive changes in climate because of the sensitivity they may have developed over time.

Increasing temperatures may lead to increased levels of pest and disease manifestation, further diminishing the already precarious household food levels. This result confirms (Hunter, 2011) fears that with rural households relying heavily on climate-sensitive resources such as local water supplies and agricultural land, climate-sensitive activities such as rain-fed agriculture and livestock husbandry, and natural resources, the impact of climate change will be profound among these households.

Households' fear that in future floods and droughts will negatively impact on their livelihoods confirming Trobe (2002) and United Nations Environmental Programme (UNEP, 1999) observations that climate change will negatively impact on rural farming communities who rely largely on climate sensitive resources. Floods will wipe away crops and animal investments with direct consequence on decreasing household food security. Floods may be accompanied with waterborne diseases and this will further exacerbate household food insecurity.

Three components were found to significantly influence household vulnerability. In the case of the first component which explained 15.4% of the whole dataset, has strong positive loadings on adapting to climate variability through coping strategies including rain water harvesting for irrigation, growing different crop varieties, crop diversification, praying for rainfall, cover cropping and across slope cultivation. This component may be described as crop management coping strategies. The second component that explains 10.9% of the dataset has a positive loading on adapting to climate change through eight factors that can similarly be categorised as crop management coping strategies. Among other component factors included are minimum tillage, crop residue management, tree planting alongside crops etc. The third component accounting for 5.9% of the dataset is composed of two factors that can be categorised as farm management coping strategies. Component factors included out-migration, leasing out land and buying of insurance.

In considering household characteristics and household vulnerability to climate change, households with household heads who had higher level of education were less vulnerable to climate change, confirming (International Food Policy Research Institute (IFPRI) 2006) observation that better access to information by households will contribute to reduced vulnerability. It was observed that increased household incomes reduced household vulnerability. Incomes diminish dependency on climate sensitive resources like agriculture thus reducing household vulnerability to climate change as observed by IFPRI (2006).

It was observed that households are nearly evenly distributed in all the five vulnerability categories. The indication is that even within the same locality vulnerability to climate change will vary significantly. This may imply that blanket recommendations on dealing with vulnerabilities to climate change may not be effective even at household level. This confirms Kristie and Semenza (2008) observation that addressing vulnerability need to be context specific even at household level. Households may need tailor made interventions to address their vulnerability situation.

Conclusion

This paper has attempted to look at how household perceptions to climate change in relation to quantitative meteorological data and the impacts on household vulnerabilities. Climate data analysed for uMzinyathi District shows a general warming trend with a 1.5°C annual temperature increase over the period 1993 to 2010. The area is becoming drier with a general trend of decreasing rainfall over the period 1981 to 2010. Households' perceptions to climate change were a reflection of climatic data records. Households were able to recognise that temperature had indeed increased while there was a reduction in the volumes of rainfall received.

There is urgent need to incorporate indigenous knowledge in formulating climate change mitigation policies to further support communities' response to climate change. Due to the heterogeneity of climate factors for different areas, local knowledge will become more important for development agencies hence the need for such agencies to incorporate such knowledge in their interventions.

Although, farmers were well aware of climatic changes and the different crop management practices to adapt to the changing climate, the famers remained very vulnerable to climate change in future. Farmers vulnerability could be drastically reduced if there were mechanisms in place to forewarn famers of impending climate changes. This could allow them to take the necessary measures. The main coping strategies of farmers in the uMzinyathi District Municipality included growing of different crop varieties, planting different fields at different times, use of organic fertilizers, leaving some of their fields fallow, practice of minimum tillage, planting trees alongside slopes, cropping of valley bottoms and carrying out mixed cropping. It is one thing for farmers knowing about the different mitigating practices and it is another to effectively practice them. Further research is required to investigate to what extend farmers are effectively undertaking the different mitigating practices.

Technology will play a greater role in reducing farmers' vulnerability to climate change. Selection of varieties and crops that can cope with the changing crops growing environment may significantly reduce households' vulnerability. Support to the farming communities through appropriate and effective extension services were necessary to deal with the new crop growing conditions arising among the agricultural community. Possibilities of utilizing the Tugela River for crops irrigation need to be investigated in order to compensate for the generally decreasing levels of rainfall in the region.

The analysis revealed a rural community that is vulnerable at different levels to climate change now and in the future. The results indicated that vulnerability to climate change is highly masked by the fact that the community rely on government grants for their livelihoods and that agricultural activities are generally shrinking and becoming unimportant to the communities. This situation makes poor households vulnerable to national policy choices and politics. It is essential that creative and meaningful solutions are found to enable the rural community in the uMzinyathi District Municipality become self-reliant and look beyond government grants that can be abolished by a simple change in government policy. These results do not tell policy makers how to design adaptation interventions. The results do suggest, though, that activities other than agricultural might usefully form part of overall adaptation strategies including engaging in alternative income generating activities to compensate for the delicate agricultural activities that are totally reliant on the decreasing levels of rainfall. Other mitigation strategies might include water harvesting, resource conservation and management of especially land, irrigation systems, provision of agro-ecological extension packages, supporting social networks already existing in the areas in form of self-help groups and a system of drought early warning systems.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Upland rice growth and yield response to weed management practices under rainfed conditions in Morogoro, Tanzania

David S. Kolleh[1], Kallunde P. Sibuga[2]* and Charles F. King[3]

[1]Central Agriculture Research Institute (CARI), P. O. Box 3929, Suakoko, Bong County, Liberia.
[2]Deparment of Crop Science and Horticulture, College of Agriculture, Sokoine University of Agriculture, P. O. Box 3005, Morogoro, Tanzania.
[3]Research Associate, Crops Program, Central Agriculture Research Institute (CARI), P. O. Box 3929, Suakoko, Bong County, Liberia.

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Field experiments were conducted in two seasons at the farm of Sokoine University of Agriculture in Morogoro, Tanzania (6.85°S; 37.64°E and 568 m.a.s.l.) during the short rain (November 2014 to January 2015) and the long rain (March to June 2015). The experiment was a split plot in randomized complete block design (RCBD) with 4 replicates. Weed management practices (herbicides, hoe weeding (3x) and weedy) were the main plot treatments; four rice genotypes (NERICA-1, NERICA-4, NERICA-7 and Mwangaza) were the subplots. Significant differences ($P<0.05$) were recorded on weed counts. Dominant weed groups as determined by Summed Dominance Ratio (SDR) in both experiments were broadleaf species (50.8%), sedges (25.2%) and grasses (24.0%). Post-emergence (8.6%) and hoe weeding (12.3%) significantly reduced weed dry biomass as compared to pre-emergence (17.8%) and weedy (61.3%) treatments in both experiments, respectively. Significant differences ($P<0.05$) were recorded among the rice variables. Data showed that Mwangaza and NERICA-1 had the tallest and shortest plant height (129.8 and 39.1 cm), respectively in both experiments. The highest and lowest tiller (35.3 and 7.5 m^2) count was recorded for both these genotypes, respectively. The lowest and highest LAI (2.5 and 4.5) were recorded on Mwangaza and NERICA-7 respectively; and NERICA-7 had the highest and lowest straw biomass (1603 and 305.1 g/m^2) in both experiments. The highest rice grain yield were recorded for NERICA-1 on hoe weeded plots and plots applied with post-emergence herbicide (2187.5 and 1562.5; 4176.1 and 4630.6 kg/ha) as compared to plots applied pre-emergence herbicide and weedy plots (965.9 and 0.0; 3323.8 and 0.78 kg/ha) in 2014/2015 and 2015 experiments, respectively. The highest return on investment, 3 352 846 Tanzanian shillings (Tshs) was obtained on NERICA-1 in post-emergence herbicide plots, and this was also similar ($P<0.05$) to hoe weeded plots. Post-emergence herbicide was also effective in weed control and had significant effect on profit analysis. This treatment/practice should be used in combination with hoe weeding under integrated weed management for better weed control.

Key words: Weeds, management, upland rice, yields, growth, profitability.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important cereal crop in agriculture and the economy of the world (MOAC, 2007). According to FAO (2008), one third of the world's population depends on rice for 50% of their daily caloric intake. Tanzania is the second largest producer of rice in Southern Africa after Madagascar with a production level of 1.1 million tons. In Tanzania, rice is the second most important food and commercial crop after maize and among the major sources of employment, income and food security for farming households (FAOSTAT, 2010). The rice cultivated area by 2012 was 720 000 hectares with a very low 10-year (2003-2012) average yield estimated at 1.8 tons per ha as compared to Madagascar where production is 2.5 tons per hectare (FAO, 2014). However, imported rice is considered inferior in quality as compared to local rice by consumers; therefore, imported rice is sold at lower prices as compared to domestic rice (Minot, 2010). Agriculture is the backbone of the Tanzania's economy through employment, food production and export (MAFC, 2011). Upland rice is an important cash crop in many areas of eastern and southern Tanzania; including Morogoro (Kinyau et al., 2013). Morogoro is one of the major rice producing regions in Tanzania and rice production in Morogoro accounts for 45.6% of the total rice produced in Tanzania (RLDC, 2009).

There are many environmental effects and practices to increase the plant products such as irrigation (Yazici and Babalik, 2016), weeds and fertilization. Weeds are a major constraint in rice production and cause huge yield reductions in rice, millet, sorghum, maize and cowpea (Maiti and Singh, 2004). Globally, 9 to 32% yield losses in rice is attributed to weeds (Oerke and Dehne, 2004). Weeds are among the greatest yield-limiting constraints to rice production in Africa (WARDA, 1996) including Tanzania (Anwar et al., 2011). In irrigated production systems where rice is directly seeded, weeds are the major yield constraints (Becker et al., 2003). Ramzan (2003) reported yield reduction due to weed infestation up to 48 and 53% in transplanted and direct seeded-flooded rice, respectively. Sunil et al. (2010) also reported that season-long weed competition in direct seeded rice may cause yield reductions of up to 80%.

Weed infestation has been mentioned as a major cause of the yield gap under rain fed agriculture in the tropics, thus contributing to about 25% yield losses in cereal crops according to Affholder et al. (2013). Inappropriate weed management practices have been highlighted as constraints in rice producing regions in Tanzania including Bagamoyo and Morogoro where hoe weeding was found to be the most preferred management option for small holder farmers due to cost and the lack of basic knowledge on the use of modern agricultural technologies (Mkanthama, 2012). Weed control is important to prevent losses in yield and production costs and to preserve good grain quality (Zhang, 2001). It is important to develop effective weed management strategies to control the damage of weeds in rice fields. Effective control and management of weeds in upland rice farming will enable farmers to maximize and enhance sustainable rice production. This study seeks to identify appropriate and effective weed management strategies to help reduce losses caused by weeds and thereby optimize yield and profitability.

MATERIALS AND METHODS

Field experiments were conducted over two seasons at the farm of Sokoine University of Agriculture in Morogoro, Tanzania (6.85°S; 37.64°E and 568 m.a.s.l.) during the short rain (November 2014 to January 2015) and the long rain (March to June 2015). The experiment was a split plot in a randomized complete block design (RCBD) with 4 replicates. Weed management practices (pre-emergence 2, 4-D 720 EC, post-emergence Hansunil 600 EC, hoe weeding (3x) and weedy) were the main plot treatments and four rice genotypes (NERICA-1, NERICA-4, NERICA-7 and Mwangaza) were the subplots.

Fertilizer applications were done according to current agronomic practices. Nitrogen was applied at the recommended rate of 100 kg/ha, namely 50% (50 kg N/ha) of the recommended N was applied 21 DAS as a basal application and the remaining 50 kg N/ha was applied as a topdressing 35 DAS using urea (46% N). All fertilizer application was done using the broadcasting method (Kanyeka et al., 2007).

Weed counts were done 20 days after sowing using a 0.5 x 0.5 m quadrat placed randomly in the net harvest area (3.52 m^2) in each subplot. Two counts were made in each subplot and the calculated average was recorded. Weed counts from each quadrat were summed to find a total number of weeds by plant group (broad leaves, grasses and sedges species). This was done before and after application of treatments. Six weeks after sowing or 42 days after sowing, weed counts was also done by using 0.5 x 0.5 m quadrat. This was done before the second hoe weeding. Sampled weeds were classified according to species. Weed dry biomass was determined at 63 DAS by throwing 0.5 m quadrat at either ends of each subplot. The weeds inside the two measured 0.5 m quadrat areas were uprooted and arranged by weed group and weed species. This was oven dried for 72 h at 70°C. The 0.5 x 0.5 m quadrat was preferred in order to get the full representation of weeds density within a given measured area considering 1 m^2 quadrat as the measurement for the determination of the size of weed populations. The contribution of individual weed species to the weed community was determined by the summed dominance

*Corresponding author. E-mail: davidkolleh29@gmail.com or kollehd@ymail.com. Tel: +231 777 061 345 or +231 886 232 692

Table 1. Production cost.

Item/variable	Unit	Qty. applied L/ha	Unit price	Total (Tshs)
Ultra 2, 4-D 720 EC	Litre	2.8	12 000 Tshs/Lit	205 809
Hansunil 600 EC	Litre	4.8	25 000 Tshs/Lit	291 249
Hoe weeding	Man day	113	3 225 Tshs/day	640 174
Herbicide application	Man day	2	5 000 Tshs/day	10 000
Labour for management	Manday/month	210	3 225 Tshs/day	257 140.7

The exchange rate for Tanzanian shillings (Tshs) to US$ during the experiment: Tanzanian shillings 2000 to US$ 1, Qty = quantity.

ratio (SDR) calculated using relative density (RD) and relative dry mass (RDM) (Janiya and Moody, 1989) as follows:

$$\text{SDR} = \frac{\text{RD+RDM}}{2} \quad (1)$$

Where

$$\text{RD (\%)} = \frac{\text{Density of a given species}}{\text{Total density of all species}} \text{x } 100 \quad (2)$$

And

$$\text{RDM (\%)} = \frac{\text{Dry weight of a given species}}{\text{Total density of all species}} \text{ x } 100 \quad (3)$$

Five plants from the net harvest area (3.52 m^2) of each subplot were randomly selected and tagged. The height of each tagged plant was taken at three intervals: 39, 62 and 83 days after sowing using a 200 cm ruler. Plant height was determined by placing a meter ruler at the soil surface to the tip of the flag leaf of each tagged plant and the mean calculated and recorded. The five plants selected were used to record all other rice variable data such as tillers, panicle, and leaf area index and spikelet fertility. Grain straw was determined as the ratio of dry grain yield to dry straw mass and this was measured by the given ratio:

$$\frac{\text{Dry grain yield}}{\text{Dry straw weight}} \quad (4)$$

Rice yield was harvested from 3.52 m^2 in the middle of each subplot sun dried, weighed and recorded as grain yield. The profit margin was determined by subtracting the cost of production (which includes cost of seed, land preparation, herbicide application and labour for planting, hoe weeding, bird scaring, harvesting and processing) from the revenue derived from the sale of paddy rice. Net profit was calculated by subtracting the cost of production from the gross return. Return on investment was calculated as described by Jolly and Clonts (1993) as stated below:

$$\text{Return on Investment (\%)} = \frac{\text{Net profit}}{\text{Investment}} \text{ x } 100 \quad (5)$$

The inputs or variable costs are shown in Table 1.

Statistical analysis

Data obtained from the experiments were subjected to statistical analysis of variance (ANOVA) using the computer programme GENTSAT statistical package 14th edition (Payne et al., 2009). The treatments mean separation were done using Tukey's honestly significant test (Abdi et al., 2009). Daily data for rainfall (mm), minimum and maximum temperature (°C) and % relative humidity (RH %) were collected from Tanzania Meteorological Agency (TMA), at SUA station in Morogoro.

RESULTS AND DISCUSSION

Rainfall (mm)

The total rainfall during the growing seasons is indicated in Figure 1. The highest rainfall during the first experiment was 155.5 and 84.6 mm in the month of December 2014 and January 2015, respectively. The repeated experiment started with a high rainfall of 144.3 mm in the month of March 2015 (Figure 1).

Temperature (°C) and relative humidity (%)

The recorded mean maximum temperature during the growing season was 30.7°C while the mean minimum temperature during the period was 22.1°C, respectively. Relative humidity ranged from 74.4 to 84.6% for December 2014 to January 2015 as shown in Figure 2. The mean RH during the growing season was 90.4% Figure 3.

In the study conducted during the short rain of 2014/15 and long rain of 2015, weeds observed in the experimental plots were composed of broadleaf, grasses and sedges as listed. Significant differences ($P<0.05$) were recorded for weed counts among weed management practices. *Cyperus rotundus, Echinochloa colona* and *Cyperus eculentus* were the most prevalent weed species in the 2014/15 experiment (39.7, 33.9 and 26.4%) respectively and *Amaranthus retroflexus, Panicum maximum* and *Cyperus eculentus* were recorded as the most prevalent weed species in 2015 experiment in species (37.6, 34.7 and 27.7%), respectively (Tables 4 and 5).

Broad leave weeds were the most dominant group and grass species, the least dominant in both experiments. In the 2014/15 experiment, sedges were recorded in pre-emergence plots as the second most dominant group of weeds and grasses were recorded in post-emergence treatments; hoe weeding and weedy plots as well. In the 2015 experiment, plots unto which pre-emergence, post-

Figure 1. The mean monthly values for maximum and minimum temperature, and rainfall for the growing season of 2014/2015 in Morogoro, Tanzanian.

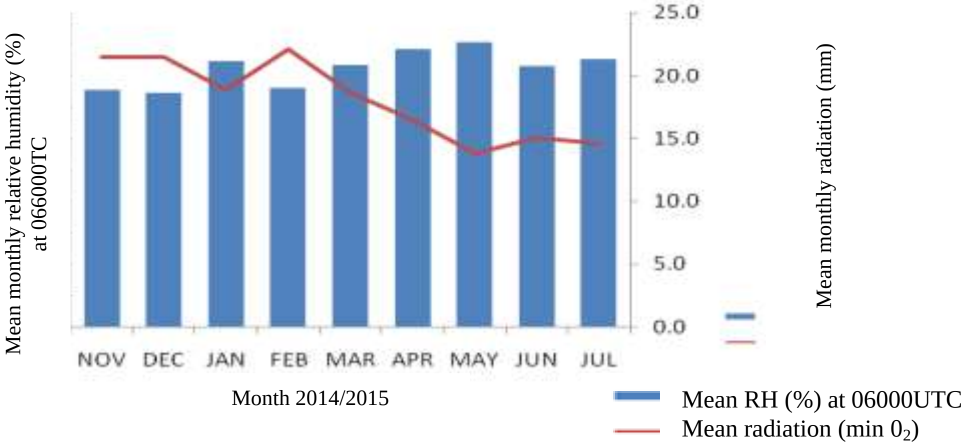

Figure 2. The mean monthly values for relative humidity and radiation for the growing season of 2014/2015 in Morogoro, Tanzanian.

emergence and hoe weeded were applied, showed sedges as the second most dominant weed group recorded, while grasses were the second highest in weedy plots (Figures 4 and 5).

The weed free treatment produced maximum rice yield in both years but 2015 was greater as compared to 2014/15 (4630.6 vs. 2272.7 kg/ha). This might be attributed to better growth of plants on account of reduced weed competition at critical crop growth stages resulting in increased availability of nutrients, water and light. All the weed control treatments in 2014/15 experiment significantly ($P \le 0.05$) increased tiller numbers, LAI, straw dry biomass, panicles, spikelets and filled grains and ultimately the yield over weedy plots; but in 2015 experiment, tiller count, LAI, straw dry biomass, panicle count, spikelet count and filled grains were non-significant. In both years, the weed management practices significantly ($P \le 0.05$) produced maximum tiller number (35.3 and 13.7/m^2), LAI (0.072, 0.89), straw dry biomass (950.4, 1603 g/m^2), panicle counts (109.2, 68.7/m^2), spikelet counts (29.5, 13.8/m^2), filled grains (98.0, 92.8/m^2) and yield (2187.5 and 4630.6 kg/ha) respectively (Tables 6 and 7). Singh et al. (2005) reported similar results with the use of pre-emergence herbicide in rain fed direct seeded rice.

The highest grain yield (2187.5 kg/ha in 2014/15 and 4630.6 kg/ha in 2015) was recorded for NERICA-1 in both years, whereas, NERICA-4and Mwangaza were also statistically similar (Figure 3). This was perhaps due to high weed control efficiency of the treatments except weedy plots with low yield (Figure 3). Hansunil 600 EC had a significant influence on weed management practices and was closely followed by hoe weeding. In each case, the use of Hansunil 600 EC followed by (3x) hoe weeding or other herbicides indicates that Hansunil seems to be an effective post-emergence herbicide for weed control in upland rice. The high efficacy of Hansunil 600 EC as post-emergence herbicide was reported by several authors (Moody, 1991; Valverde et al., 2001). In combination with hand weeding, it was reported to be effective in controlling weeds in rain fed direct seeded rice (Ramamoorthy et al., 1998 and Singh et al., 2005).

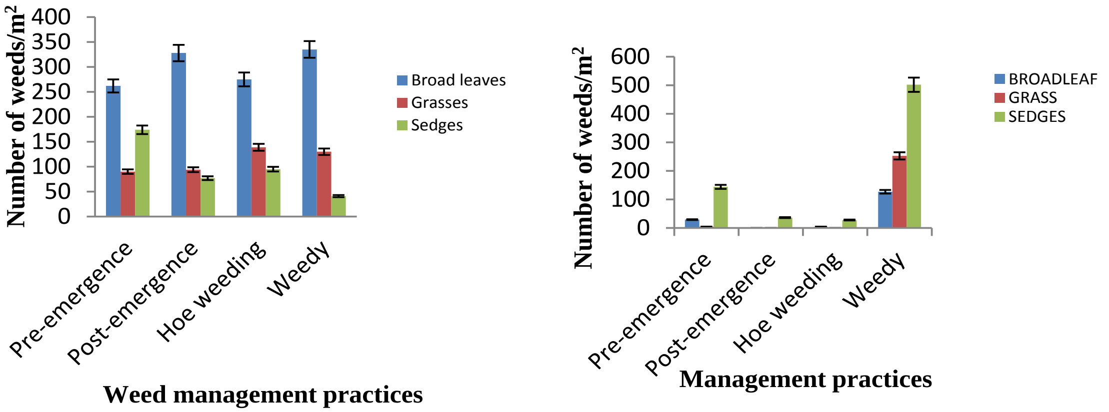

Figure 3. Weed counts before and after the application of treatments during 2014/15 experiment. Bars denote standard errors.

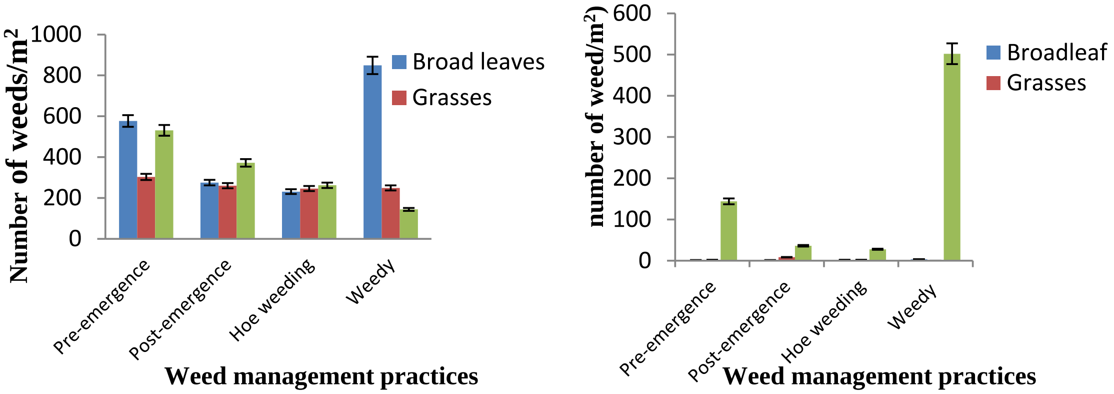

Figure 4. Weed counts before and after the application of treatments during 2015 experiment. Bars denote standard errors.

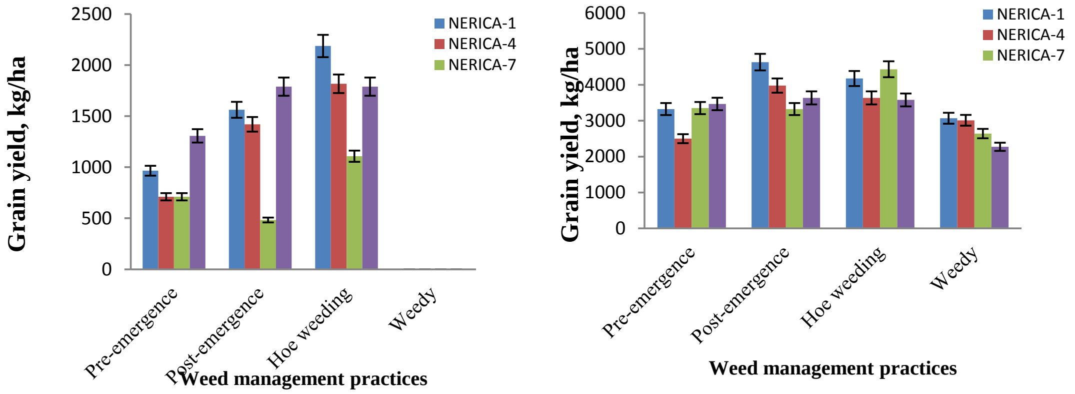

Figure 5. Mean grain yield during 2014/15 and 2015 experiments in Morogoro, Tanzanian. Bars denote standard errors.

Rainfall pattern in the second experiment was well distributed during the crop growth period and resulted to better crop performance. The experimental plots were heavily infested with *Cyperus* species which subsequently reduced yield in 2014/15 experiment (Tables 2 and 3).

Table 2. Weed species recorded, total number, and summed dominant ratio during the 2014/15 experiments in Morogoro, Tanzanian.

Treatment	Weed group	Weed species	Family name	Total number/m^2	SDR (%)
Pre-emergence	Broad leaves	*Mimosa pudica* L.	Mimosaceae	64	24.4
		Amaranthus retroflexus	Amaranthaceae	61	23.3
		Commenlina benghalensis L.	Commelinaceae	49	18.7
		Launaea spp.	Asteraceae	43	17.2
		Richadria	Rubiaceae	45	16.4
	Grasses	*Echinochloa colona*	Poaceae	47	52.2
		Sorghum halepensea	Poaceae	27	30.0
		Cynodon dactylon	Poaceae	16	17.8
		Panicum maximum	Poaceae	-	-
	Sedges	*Cyperus rotundus*	Cyperaceae	106	60.9
		Cyperus esculentus	Cyperaceae	68	39.1
Post-emergence	Broad leaves	*Mimosa pudica* L.	Mimosaceae	77	23.4
		Amaranthus retroflexus	Amaranthaceae	75	22.9
		Commenlina benghalensis L.	Commelinaceae	62	18.9
		Spelling	Rubiaceae	58	17.7
		Launaea sp.	Asteraceae	56	17.1
	Grasses	*Echinochloa colona*	Poaceae	51	54.2
		Panicum maximum	Poaceae	28	29.8
		Cynodon dactylon	Poaceae	9	9.6
		Sorghum halepensea	Poaceae	6	6.4
	Sedges	*Cyperus rotundus*	Cyperaceae	48	62.3
		Cyperus esculentus	Cyperaceae	29	37.7
Hoe weeding	Broad leaves	*Mimosa pudica* L.	Mimosaceae	68	24.7
		Amaranthus retroflexus	Amaranthaceae	64	23.3
		Commenlina benghalensis L.	Commelinaceae	51	18.5
		Richadria?	Rubiaceae	47	17.1
		Launaea spp.	Asteraceae	45	16.4
	Grasses	*Echinochloa colona*	Poaceae	62	44.6
		Panicum maximum	Poaceae	58	41.7
		Cynodon dactylon	Poaceae	12	8.6
		Sorghum halepensea	Poaceae	7	5.0
	Sedges	*Cyperus rotundus*	Cyperaceae	55	57.9
		Cyperus esculentus	Cyperaceae	40	42.1
Weedy	Broad leaves	*Mimosa pudica* L.	Mimosaceae	79	23.6
		Amaranthus retroflexus	Amaranthaceae	76	22.7
		Commenlina benghalensis L.	Commelinaceae	64	19.1
		Richadria ?	Rubiaceae	59	17.6
		Launaea spp.	Asteraceae	57	17.0
	Grasses	*Echinochloa colona*	Poaceae	60	46.2
		Panicum maximum	Poaceae	56	43.1
		Cynodon dactylon	Poaceae	9	6.9
		Sorghum halepensea	Poaceae	5	3.8
	Sedges	*Cyperus rotundus*	Cyperaceae	26	63.4
		Cyperus esculentus	Cyperaceae	15	36.6

SDR = Summed dominant ratio.

Table 3. Weed species recorded, total number, and summed dominant ratio during the 2015 experiments in Morogoro, Tanzanian.

Treatment	Weed group	Weed species	Family name	Total Number/m^2	SDR % 2015
Pre-emergence	Broad leaves	*Mimosa pudica* L.	Mimosaceae	181	31.4
		Amaranthus retroflexus	Amaranthaceae	135	23.4
		Launaea spp.	Asteraceae	98	17.0
		Richadria	Rubiaceae	85	14.7
		Commenlina benghalensis L.	Commelinaceae	78	13.5
	Grasses	*Panicum Maximum*	Poaceae	202	66.7
		Echinochloa colona	Poaceae	57	18.8
		Sorghum halepensea	Poaceae	23	7.6
		Cynodon dactylon	Poaceae	21	6.9
	Sedges	*Cyperus rotundus*	Cyperaceae	276	52.0
		Cyperus esculentus	Cyperaceae	255	48.0
Post-emergence	Broad leaves	*Mimosa pudica* L.	Mimosaceae	66	24.0
		Amaranthus retroflexus	Amaranthaceae	64	23.3
		Commenlina benghalensis L.	Commelinaceae	51	18.5
		Richadria	Rubiaceae	48	17.5
		Launaea spp.	Asteraceae	46	16.7
	Grasses	*Echinochloa colona*	Poaceae	93	35.8
		Panicum Maximum	Poaceae	69	26.5
		Sorghum halepensea	Poaceae	50	19.2
		Cynodon dactylon	Poaceae	48	18.5
	Sedges	*Cyperus esculentus*	Cyperaceae	197	53.0
		Cyperus rotundus	Cyperaceae	175	47.0
Hoe weeding	Broad leaves	*Mimosa pudica L.*	Mimosaceae	59	25.5
		Amaranthus retroflexus	Amaranthaceae	56	24.2
		Commenlina benghalensis L.	Commelinaceae	42	18.2
		Richadria ?	Rubiaceae	38	16.5
		Launaea spp	Asteraceae	36	15.2
	Grasses	*Echinochloa colona*	Poaceae	91	37.0
		Panicum Maximum	Poaceae	84	34.1
		Cynodon dactylon	Poaceae	38	15.4
		Sorghum halepensea	Poaceae	33	13.4
	Sedges	*Cyperus esculentus*	Cyperaceae	140	53.4
		Cyperus rotundus	Cyperaceae	122	46.6
Weedy	Broad leaves	*Mimosa pudica L.*	Mimosaceae	182	21.4
		Amaranthus retroflexus	Amaranthaceae	179	21.1
		Commenlina benghalensis L.	Commelinaceae	167	19.7
		Richadria	Rubiaceae	162	19.1
		Launaea spp.	Asteraceae	159	18.7
	Grasses	*Echinochloa colona*	Poaceae	89	35.7
		Panicum maximum	Poaceae	85	34.1
		Cynodon dactylon	Poaceae	39	15.6
		Sorghum halepensea	Poaceae	36	14.5
	Sedges	*Cyperus esculentus*	Cyperaceae	75	52.1
		Cyperus rotundus	Cyperaceae	69	47.9

SDR = Summed dominant ratio.

Table 4. The mean of broadleaf, grass and sedges number weeds/m^2 during 2014/15 and 2015 experiments in Morogoro, Tanzanian.

Treatment	2014/15			2015		
	Broadleaf number	Grass number	Sedges number	Broadleaf number	Grass number	Sedges number
(A x B) interaction						
Pre × N-1	84^{de}	22^{a-c}	27^{e-g}	145	614	79^{cd}
Pre × N-4	55^{ab}	24^{a-c}	51^{i}	149	65^{f}	174^{g}
Pre × N-7	72^{b-e}	26^{a-c}	49^{i}	144	61^{ef}	131^{ef}
Pre × MWG	51^{a}	18^{ab}	47^{i}	139	74^{g}	147^{fg}
Post × N-1	81^{de}	21^{a-c}	17^{cd}	71	76^{g}	58^{bc}
Post × N-4	81^{de}	27^{a-c}	32^{gh}	69	65^{f}	53^{a-c}
Post × N-7	82^{de}	16^{a}	24^{e-g}	66	21^{a}	150^{fg}
Post MWG	84^{de}	30^{a-d}	4^{ab}	69	98^{h}	111^{d-f}
Hoe × N-1	60^{abc}	35^{a-d}	27^{fg}	63	34^{b}	75^{cd}
Hoe × N-4	73^{b-e}	48^{d}	21^{d-f}	60	60^{e}	48^{a-c}
Hoe × N-7	69^{a-d}	26^{a-c}	37^{h}	41	54^{d}	99^{de}
H. × MWG	73^{b-e}	30^{a-d}	10^{bc}	67	98^{h}	40^{a-c}
Weedy × N-1	76^{cde}	36^{b-d}	20^{de}	204	30^{b}	52^{a-c}
Weedy × N-4	83^{de}	41^{cd}	0^{a}	225	45^{c}	18^{a}
Weedy × N-7	86^{de}	24^{a-c}	6^{ab}	229	100^{hi}	16^{a}
Weedy × MWG	90^{e}	29^{a-d}	15^{cd}	191	74^{g}	28^{ab}
Mean	75	30.8	24.2	120.7	98.1	79.9
CV (%)	6.8	28.3	11.1	17.0	2.5	19.5
SE +	5.3	8.7	2.7	20.7	1.6	15.6

Figures followed by the same letter (s) in the marginal and interaction means are not significantly different at P< 0.05 according to Turkey's test.

Table 5. The mean of broadleaf, grass and sedges weed dry biomass (g/m^2) during 2014/15 and 2015 experiments in Morogoro, Tanzanian.

Treatment	2014/15			2015		
	Broadleaf dry weight	Grass dry weight	Sedgesdry weight	Broadleaf dry weight	Grassdry weight	Sedgesdry weight
(A × B) Interaction						
Pre × N-1	9.0^{ab}	0.7^{a}	151.1^{cd}	1.5^{a-c}	0.0^{a}	0.0^{a}
Pre × N-4	63.6^{c}	4.7^{a}	120.8^{b-d}	1.0^{a}	1.4^{b}	9.6^{c}
Pre × N-7	16.3^{ab}	5.9^{a}	206.6^{d}	1.5^{a-c}	5.6^{c}	10.3^{c}
Pre × MWG	28.0^{b}	7.4^{a}	97.5^{a-c}	1.7^{a-c}	0.0^{a}	16.9^{d}
Post × N-1	0.0^{a}	0.1^{a}	25.6^{a}	1.2^{ab}	0.0^{a}	0.0^{a}
Post × N-4	0.1^{a}	0.0^{a}	77.1^{a-c}	1.5^{a-c}	34.0^{e}	0.0^{a}
Post × N-7	0.0^{a}	0.1^{a}	33.7^{ab}	1.7^{a-c}	0.0^{a}	0.0^{a}
Post MWG	0.0^{a}	0.1^{a}	8.2^{a}	1.2^{ab}	0.0^{a}	0.0^{a}
Hoe × N-1	1.5^{a}	0.0^{a}	11.9^{a}	1.5^{a-c}	8.6^{d}	0.0^{a}
Hoe × N-4	5.0^{a}	0.1^{a}	22.3^{a}	2.5^{bc}	0.0^{a}	0.0^{a}
Hoe × N-7	4.3^{a}	0.2^{a}	38.1^{ab}	1.5^{a-c}	0.0^{a}	0.0^{a}
H × MWG	4.3^{a}	0.2^{a}	39.1^{ab}	2.0^{a-c}	0.0^{a}	0.0^{a}
Weedy × N-1	143.9^{e}	201.2^{b}	592.9^{e}	2.7^{c}	0.0^{a}	1.8^{a}
Weedy × N-4	146.7^{e}	244.5^{c}	611.8^{e}	5.0^{d}	0.0^{a}	4.4^{b}
Weedy × N-7	101.0^{d}	310.2^{d}	155.9^{cd}	1.7^{a-c}	0.0^{a}	36.0^{e}
Weedy × MWG	116.0^{d}	254.8^{c}	647.2^{e}	4.5^{d}	0.0^{a}	0.0^{a}
Mean	39.9	64.4	177.5	2.0	3.1	4.9

Table 5. Contd.

CV (%)	23.2	14.8	19.1	27.3	7.4	14.4
SE +	9.3	9.5	33.95	0.6	0.2	0.7

Figures followed by the same letter (s) in the marginal and interaction means are not significantly different at P< 0.05 according to Turkey's test.

Table 6. Mean tiller number /m^2, leaf area index and straw dry biomass (g/m^2) during 2014/15 and 2015 experiments in Morogoro, Tanzanian.

Treatment	2014/15			2015		
	Tiller number	Leaf area index	Straw dry biomass	Tiller number	Leaf area index	Straw dry biomass
A x B Interaction						
Pre × N-1	16.9^{b}	1.25^{b}	549.8^{c-e}	10.5	3.14	753
Pre × N-4	16.3^{b}	1.31^{bc}	384.0^{b}	9.8	2.83	736
Pre × N-7	14.4^{b}	1.81^{c}	305.1^{b}	10.8	4.48	1181
Pre × MWG	17.9^{bc}	1.31^{bc}	579.8^{d-f}	8.3	3.10	724
Post × N-1	22.8^{d}	1.06^{b}	434.2^{bc}	11.7	2.98	1448
Post × N-4	27.9^{d}	1.38^{bc}	680.6^{e-g}	10.5	2.79	1288
Post × N-7	16.9^{b}	1.44^{bc}	617.$^{4d-g}$	10.4	4.39	1282
Post MWG	22.5^{cd}	1.19^{b}	749.4^{gh}	7.5	3.39	912
Hoe × N-1	35.1^{fg}	1.06^{b}	701.1^{f-h}	12	2.53	1441
Hoe × N-4	30.5^{ef}	1.25^{b}	528.7^{cd}	10.7	2.60	1490
Hoe × N-7	35.2^{g}	1.50^{bc}	761.1^{h}	13.7	3.71	1603
H. × MWG	35.3^{g}	1.04^{b}	950.4^{i}	10.7	2.76	1309
Weedy × N-1	0.0^{a}	0.0^{a}	0.0^{a}	11.4	2.84	744
Weedy × N-4	0.0^{a}	0.0^{a}	0.0^{a}	10.1	2.64	877
Weedy × N-7	0.0^{a}	0.0^{a}	0.0^{a}	11.4	3.13	899
Weedy × MWG	0.0^{a}	0.0^{a}	0.0^{a}	8.1	2.85	846
Mean	18.2		452.6	10.5	1.13	1095.8
CV (%)	9.6	0.0	12.0	8.3	4.3	21.7
SE +	1.8	18.8	54.4	0.9	0.13	238.1

Figures followed by the same letter (s) in the marginal and interaction means are not significantly different at P< 0.05 according to Turkey's test.

Economic analysis

Different weed control practices involved different costs which affected total production costs. Hansunil 600 EC post-emergence herbicide was effective in weeds control with the cost of Tshs (291 249 ha^{-1}). Hoe weeding was laborious and more expensive; however, hoe weeding three times gave maximum weed control cost of Tshs 640 174 ha^{-1} (Table 8). All the herbicide treatments gave lower cost of weed control; but pre-emergence of 2,4-D herbicide gave lowest weed control cost of Tshs 205,809 ha^{-1} for the experiments but recorded the lowest profit (Table 8). The benefit of post-emergence (37.7%) and hoe weeding treatments (33.9%) increased grain yield, reflecting a good level of control over weeds growing in the experimental plots. The pre-emergence herbicide performed less well, achieving (28.3%) greater yield over the weed control. These results are in line with findings by Mirza et al. (2007) who reported that hand weeding is laborious and gave higher weed control cost while the use of herbicide gave the lower cost of weed control. The highest revenue (2 505 580 Tsh and 6 482 840Tsh) for both experiments was obtained with post emergence plots due to higher grain yields (1789.7 and 4630.6 kg/ha^{-1}), respectively and lesser cost of production (291 249 Tshs) as compared to three times hoe weeding with highest grain yield (2187.5 and 4431.8 kg/ha^{-1}) and cost (640 174 Tshs) of production for the experiments, respectively.

Pre-emergence 2,4-D herbicide was applied once given low weed control cost (205 809), but this was not profitable as the grain yield (1306.8 and 3465.9 kg/ha)

Table 7. The mean of panicle number, spikelet number and percent filled grain/m^{2} during 2014/15 and 2015 experiments in Morogoro, Tanzanian.

Treatment	2014/15			2015		
	Panicle number	Spikelet number	Filled grain	Panicle number	Spikelet number	Filled grain
(A x B) Interaction						
Pre × N-1	46.7^{b}	9.2^{b}	96.1^{cd}	68.2	13.6	92.8
Pre × N-4	68.2^{cd}	14.0^{bc}	94.55^{cd}	65.2	13	84.1
Pre × N-7	46.7^{b}	9.3^{b}	91.05^{cd}	59	11.8	88.4
Pre × MWG	64.2^{bc}	8.8^{b}	78.2^{b}	53	10.6	89.8
Post × N-1	84.0^{de}	16.1^{cd}	95.1^{cd}	68.7	13.8	86.4
Post × N-4	70.5^{cd}	14.0^{bc}	96.1^{d}	66.7	13.3	80.9
Post × N-7	64.7^{bc}	13.4^{bc}	87.4^{b-d}	65.2	12.7	85
Post MWG	85.7^{def}	16.8^{cd}	95.3^{cd}	56.2	11.2	81.4
Hoe × N-1	99.0^{efg}	21.3^{d}	87.3^{b-d}	64.2	12.8	91.4
Hoe × N-4	109.2^{g}	21.6^{d}	90.0^{cd}	68	13.6	79.8
Hoe × N-7	94.7^{ef}	16.5^{cd}	98.0^{d}	60.7	12.1	85.4
H. × MWG	103.7^{fg}	29.5^{e}	85.6^{bc}	52.2	10.4	83.3
Weedy × N-1	0.0^{a}	0.0^{a}	0.0^{a}	56.5	11.3	92.2
Weedy × N-4	0.0^{a}	0.0^{a}	0.0^{a}	58.7	11.7	86.5
Weedy × N-7	0.0^{a}	0.0^{a}	0.0^{a}	61	12.2	88.1
Weedy × MWG	0.0^{a}	0.0^{a}	0.0^{a}	43	8.6	87.8
Mean	58.6	11.9	68.4	60.4	12.0	86.5
CV (%)	11.4	20.0	14.5	13.9	9.4	7.2
SE +	6.7	2.5	13.5	8.32	1.1	6.2

Figures followed by the same letter(s) in the marginal and interaction means are not significantly different at P< 0.05 according to Turkey's test.

Table 8. Grain yield and net return as influenced by different weed management practices at SUA, Morogoro, Tanzania.

Treatment	Rate kg ai. /ha	Grain yield (kg/ha)		Total variable cost (Tshs/ha)		Net revenue (Tshs/ha)		Net rate of return (%/ha)	
		2014/15	2015	2014/15	2015	2014/15	2015	2014/15	2015
Pre × N-1	2.88	965.9	3323.8	205 809	205 809	1 352 260	4 653 320	5.6	21.6
Pre × N-4	2.88	710.2	2500	205 809	205 809	994 280	3 500 000	3.8	16.0
Pre × N-7	2.88	710.2	3352.2	205 809	205 809	994 280	4 693 080	3.8	21.8
Pre × MWG	2.88	1306.8	3465.9	205 809	205 809	1 829 520	4 852 260	7.9	22.6
Post × N-1	4.8	1562.5	4630.6	291 249	291 249	2 187 500	6 482 840	6.5	21.3
Post × N-4	4.8	1420.4	3977.2	291 249	291 249	1 988 560	5 568 080	5.8	18.1
Post × N-7	4.8	482.9	3323.8	291 249	291 249	676 060	4 653 320	1.3	15.0
Post MWG	4.8	1789.7	3636.3	291 249	291 249	2 505 580	5 090 820	7.6	16.5
Hoe × N-1	-	2187.5	4176.1	640 174	640 174	3 062 500	5 846 540	11.0	8.1
Hoe × N-4	-	1818.1	3636.3	640 174	640 174	2 545 340	5 090 820	9.0	7.0
Hoe × N-7	-	1107.9	4431.8	640 174	640 174	1 551 060	6 204 520	5.1	8.7
H. × MWG	-	1789.7	3579.5	640 174	640 174	2 505 580	5 011 300	8.8	6.8
Weedy × N-1	-	0	0.78	128 999	257 140.7	0	1100	-1.0	-10.12
Weedy × N-4	-	0	0.76	128 999	257 140.7	0	1060	-1.0	-99.6
Weedy × N-7	-	0	0.67	128 999	257 140.7	0	940	-1.0	-99.6
Weedy × MWG	-	0	0.57	128 999	257 140.7	0	800	-1.0	-99.6

The yield was yield obtained (kg/ha), Pre x N-1=pre-emergence and NERICA, MWG = Mwangaza, post x NERICA=post-emergence and NERICA, hoe weeding x NERICA= hoe weeding and NERICA and cont x NERICA=control and NERICA and Mwangaza.

was lower than post emergence herbicide and hoe weeding for both experiments (Table 8). These results are supported by works of Upadhyay and Chaudhary (1979) who reported that hand weeding and hoe weeding was three times more economical than applying herbicide only. Average return on investment for both experiments ranged from 7.5 to 12.9% with the highest benefit cost ratio observed in pre emergence herbicide, (2,4-D). This finding is in line with reports by Chakraborty and Majumdar (1973) who obtained best economic return with 2,4-D. Sabio and Pastories, (1981) also reported that application of herbicides was more economical than manual or hand weeding alone.

Conclusion

Weeds are a major constraint of the yield of upland rice. The present study revealed that Hansunil 600 EC post-emergence herbicide, hoe weeding and pre-emergence 2,4-D 720 EC herbicide treatments provided a level of control as compared to the weedy plots (37.8, 33.9 and 28.3%), respectively. Although, hoe weeding was an effective means of control, Hansunil post-emergence herbicide was more economical, delivering a return on investment of 37.8%. Weeds can be effectively and economically controlled in upland rice using Hansunil 600 EC post-emergence herbicide. The most effective weed management practices were hoe weeding and post-emergence herbicide treatments which resulted in the attainment of high grain yield and subsequent high returns on investment. These treatments offer alternatives to both resource-poor and large-scale producers, respectively.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Analysis of wheat commercialization in Ethiopia: The case of SARD-SC wheat project innovation platform sites

Tadele Mamo[1]*, Wudineh Getahun[1], Agajie Tesfaye[1], Ali Chebil[2], Tesfaye Solomon[1], Aden Aw-Hassan[2], Tolessa Debele[1] and Solomon Assefa[2]

[1]Ethiopian Institute of Agricultural Research (EIAR), Ethiopia.
[2]International Center for Agricultural Research in the Dry Areas (ICARDA).

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In Ethiopia, wheat is becoming an essential source of income for farmers even though it is still a fundamental food crop. While the major proportion is kept for consumption, farmers sell part of their wheat produce. The main objectives of this paper are to assess the level of commercialization and its determinants of wheat producers in the four major producing regions. Quantitative primary data was collected from December 2013 to January 2014. The structured questionnaire was used to help collect quantifiable data from wheat producer households. Econometric tools were employed for the analysis of wheat producers' commercialization and its determinants. The findings indicate that about 27% of the wheat produced is being used for sale with the highest and lowest in Oromia (41%) and Tigray (17%) innovation platform sites, respectively. The results also reveal that most of the commercialization index falls within 25 and 50%. This indicates that wheat is becoming an essential cash crop to supplement household incomes. The empirical results of Tobit model show that educational level of head household, livestock size expressed in Tropical Livestock Unit (TLU), amount of wheat produced, and credit access, affect wheat commercialization positively and significantly while distance to the market and family size affect commercialization of farmers negatively. Finally, based on the findings of the research, some technical, institutional and policy that empower farmers through organizing in groups, training, and contractual arrangement with millers are needed to improve wheat productivity and linkage of wheat farmers to market.

Key words: Commercialization, Tobit model, SARD-SC project, IP, wheat, Ethiopia.

INTRODUCTION

Ethiopia has already implemented its first Growth and Transformation Plan (GTP-I) that had a five years span (2010/11-2014/15) and has just started a second five years plan (GTP-II) 2015/16-2019/20. Both the past and

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*Corresponding author. E-mail: mtadeleb@gmail.com.

the current plans focused on agricultural commercialization (MoFED, 2010, 2015). Ethiopia is one of the fast growing counties in Africa. Literatures have revealed that in such fast growing economy, what emerges is a gradual but definite movement out of subsistence food crop production towards a diversified market-oriented production system (Delgado, 1995; Panashat, 2011). Agricultural commercialization, which is stated as a process involving transformation of agriculture to market oriented production, tends to have a positive impact on income, consumption and nutritional setup of the farm households. It also has a significant effect on the level of household food security (Braun, 1995).

The level of commercialization for staple food crops is usually less as compared to the high value cash crops. Some of the staple food crops are also used for industrial purposes which increases their level of commercialization. Wheat has a dual purpose that categorizes it both as a staple food crop as well as in industrial crop that is used in flour, pasta, macaroni and other related industries. However, the government of Ethiopia is currently categorizing wheat as an industrial crop rather than staple food crop due to its high demand in food industries. Therefore, wheat producing farmers are expected to be market oriented and supply it to market for agro-industrial purpose. Ethiopia is the second largest wheat producer in sub-Saharan Africa (SSA) next to South Africa (Abu, 2012; Demeke and Marcantonio, 2013). The crop ranked 4th after teff, maize and sorghum both in terms of area coverage (1.7 million ha) and quantity of production (4.2million tons) in 2014/15 cropping season in Ethiopia (CSA, 2015). The same source indicated that four major wheat producing regions in Ethiopia, namely Oromia, Amhara, SNNP and Tigray account for about 99% of national wheat production sharing 58, 28, 8 and 5% in 2014/15 cropping season, respectively.

The domestic production of wheat increased from 2.2 million tons in 2004/05 to 4.2 million tons ten years later (2014/15). Similarly, productivity has increased from 1.56 tons/ha in 2004/5 to 2.54 tons/ha in 2014/15, which is a growth by 63%. This swift growth of productivity could largely be attributed to the use of improved technologies of wheat. Within the same period of time, the area coverage for wheat has also increased from 1.4 million hectares in 2004/5 to 1.6 million hectares in 2014/15, which is a growth by 14% (CSA, 2005, 2015).

Wheat research has got a great focus both from national and international research centers funded from the Ethiopian government and external sources. One of the externally funded wheat project is the Support to Agricultural Research for Development of Strategic Crops (SARD-SC) wheat project operating in four major wheat producing regions of a country specified already was launched in Ethiopia in 2013. The project has four main components: 1) technology generation; 2) technology dissemination and adoption; 3) capacity building and 4) project management. The SARD-SC wheat project follows the innovation platform (IP) approach which brings all stakeholders together to achieve its broad objectives.

As the production and productivity of wheat increases, the level of commercialization of wheat producing farmers becomes a crucial aspect in the wheat sector. However, due to the fact that the crop was categorized as a staple food crop in the past, there has been a little information on the commercialization status as well as factors that either enhance or hinder the commercialization process of wheat in the country in general and in the SARD-SC wheat project IP sites in particular. Therefore, this paper aims to fill this gap having the following objectives.

Objectives

1. To assess the level of commercialization of wheat producers in four major wheat producing regions.
2. To assess the determinants of commercialization of wheat producers in these areas.

METHODOLOGY AND THE STUDY APPROACHES

The study area

The study was conducted in six districts of SARD-SC IP sites selected from four major wheat producing regions of Ethiopia. Two districts each from East Gojjam zone of Amhara region and Bale zone of Oromia regions, and one district each from South Tigray zone of Tigray region and Gurage zone of SNNP region were purposively selected for the following reasons: First, these districts were selected by each of the regions themselves as sites for the SARD-SC wheat project Innovation Platform (IP) to demonstrate wheat technologies. Second, the districts did not receive enough attentions and supports from other development projects to enhance wheat production and productivity; thus making these areas good cases for showing technology impacts. Third, the districts have a high potential of wheat production with the exception of Enemay and Shebel Berenta districts. The selected sites represent the African Highlands hub of the SARD-SC wheat project of Ethiopia (Figure 1).

Data collection techniques and target groups

Quantitative primary data was used for this study. Quantitative method was used to gather quantifiable data from wheat producers using a structured questionnaire. The structured questionnaire was used to help collect quantifiable data especially from wheat producer households. Data from wheat producer households was collected from December 2013 to January 2014. The data is a comprehensive baseline data collected through trained enumerators and supervisors using structured questionnaire in Computer Aided Personal Interview (CAPI).

Sampling frame and sampling procedure

The sampling frame of the study is the list of wheat producer

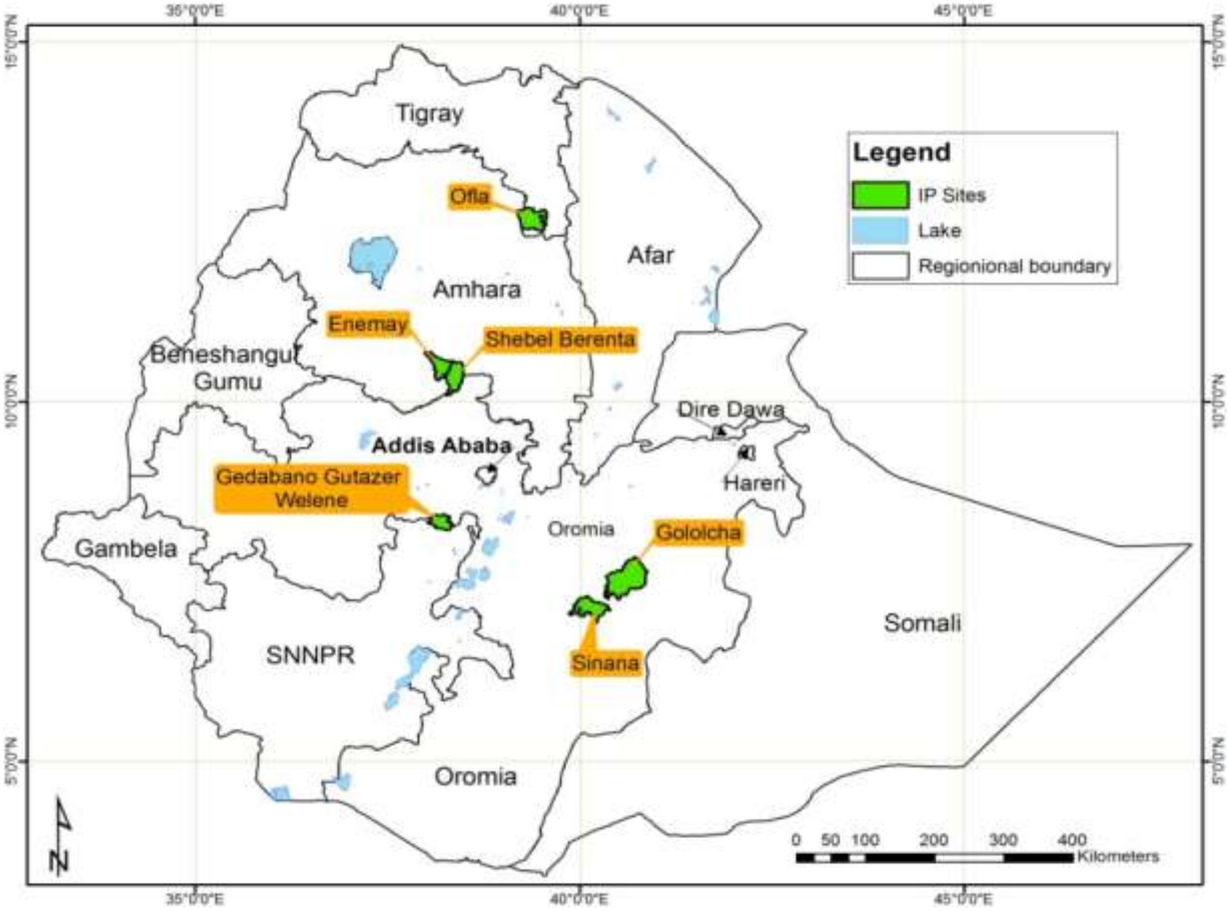

Figure 1. Wheat value chain analysis study districts, Ethiopia, 2014.

Table 1. Distribution of sample sizes by IP districts and region.

Region	Zone	District of IP sites	Sample size
Tigray	South Tigray	Ofla	128
SNNP	Gurage	Gedebano-Gutazer-Wolene	100
Amhara		Enemay	218
	East Gojjam	Shebel Berenta	189
Oromia		Sinana	166
	Bale	Gololcha	145
Total			946

households. A stratified multistage sampling technique was employed to select the required samples of households. First, four wheat growing regions were identified purposively to represent the diverse socio-economic and biophysical environment of wheat producers in Ethiopia. Second, in the stakeholder consultation workshop in each region, six districts which are considered representatives of the respective regions were selected based on wheat growing potential, and status of previous wheat research and development interventions. Then, three kebeles (note that kebele is the lowest administrative level in Ethiopia which is an equivalent to village in most countries) from each of the districts were selected based on their level of participation in SARD-SC wheat project. These are intervention kebeles (where the project has been implemented), spillover (neighbor to those intervention kebeles), and control kebeles (situated at remote distance to the intervention ones). Finally, from the household list available at each kebele, a total of 946 sample households were drawn randomly for interview using a structured questionnaire (Table 1).

Methods of data analysis and synthesis

Information and dataset collected was analyzed and synthesized using different statistical and econometric tools. Descriptive statistics was largely utilized to analyze the data and summarize the information. Tobit model was also employed for the analysis of wheat producers' commercialization status and its determinants.

Specification of commercialization index and the Tobit model

Following Govereh et al. (1999) and Strasberg et al. (1999), the household commercialization index can be defined as the ratio of the value of crop sold to the value of produced. Several authors adopted this definition and used it to calculate commercialization index of different crops (Aderemi et al., 2014; Agwu et al., 2013; Gebremedhin and Jaleta, 2010; Hichaambwa and Jayne, 2012; Jaleta et al., 2009; Kirui and Njiraini, 2013; Leavy and Poulton, 2007; Mutabazi et al., 2013; Osmani et al., 2014; Rahut et al., 2010). In a similar fashion, the commercialization index of wheat producers is given as:

$$CI_i = \frac{Vsold}{Vproduced} x100\% \tag{1}$$

Where: V sold and V produced are the value of wheat sold and produced by the i^{th} farmer, respectively; CI_i = commercialization index of i^{th} farmer having a value of zero to one with zero and one indicating totally subsistent and fully commercialized farmers, respectively.

Specification of the Tobit model

To analyze the wheat producers' level of commercialization and its determinants, the Tobit model was used. According to Tobin (1958), the Tobit model can be specified as:

$$y_i^* = \beta_0 + \beta_i X_i + \mu_i \tag{2}$$

$$y_i = w_i^* \ if \ \beta_0 + \beta_i X_i + \mu_i > 0 \quad = 0 \text{ if } \beta_0 + \beta_i X_i + \mu_i \leq 0$$

Where: y_i = is observed index of the i^{th} farmer; y_i^* = is the latent variable and the solution to utility maximization problem, subjected to classical linear assumptions; [$Ui \sim N(0, \sigma^2)$]. X_i = is vector of explanatory variables affecting level of commercialization; β_i = is vector of unknown parameters to be estimated; μ_i = is the error term, assumed to be normally distributed with mean 0 and constant variance, σ^2.

According to Maddala (1992) and Amemiya (1985), the estimates of the Tobit model is based on the maximum likelihood estimation (ML) by maximizing the Tobit likelihood function. Based on Sigelman and Zeng (1999), if density function and cumulative density functions of *y** are denoted by *f (.)* and *F (.)*, respectively, then the Tobit model implies that the probabilities of observing a non-zero y and a zero y are f(*y*) and p(y*<0) =F (0), respectively. Therefore, the log likelihood (LL) of the model can be:

$$\ln L = \ln\left(\prod_{y_i>o} f(y_i) \prod_{y_i=0} F(0)\right) = \sum_{y_i>0} \ln f(y_i) + \sum_{y_i=0} \ln F(0) \tag{3}$$

Since y* is assumed to be normally distributed as error terms are assumed to be normally distributed, f(.), F(.) and hence LL functions can be written in the form of density function and cumulative density function of the standard normal distribution as: $\phi(.)$ and $\Phi(.)$, and the LL function can be rewritten in the usual form as:

$$\ln L = \sum_{y_i>0}\left(-\ln\sigma + \ln\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right) + \sum_{y_i=0}\ln\left(1 - \Phi\left(\frac{x_i\beta}{\sigma}\right)\right) \tag{4}$$

Unlike the case of ordinary least square (OLS) coefficients, it is difficult to interpret the estimated coefficients of the Tobit as a marginal effect because there are three main conditional expectations of interest in the Tobit model. These are: 1) the conditional expectation of the underlying latent variable (y*); 2) the conditional expectation of the observed dependent variable (*y)*; and the conditional expectations of the uncensored observed dependent variable (*y*|*y*>0). Following Greene (1997), Johnston and Dinardo (1997), McDonald and Moffitt (1980), the marginal effects of these conditional expectations, respectively are given as:

$$\frac{\partial E(y^*|x)}{\partial x} = \beta \tag{5}$$

$$\frac{\partial E(y|x)}{\partial x} = \beta\Phi\left(\frac{x\beta}{\sigma}\right) \tag{6}$$

$$\frac{\partial \Pr(y > 0|x)}{\partial x} = \phi\left(\frac{x\beta}{\sigma}\right)\frac{\beta}{\sigma} \tag{7}$$

The interpretations of these marginal effects depend on the point of interest based on the focus of the study. For instance, if the interest is to make statements about the conditional mean function in the population despite the censoring, Equation 5 is used for the censored data. If a researcher is interested on average value of the population of study, and how those values vary with covariates, Equation 6 is used and finally, if one wants to interpret, for example, about the determinants of average values of the dependent variable among those who have already participated in a program, Equation 7 is used. However, in literature, all the three marginal effects are interpreted to show the change in the probability of participation, intensity of dependent variable among the whole population and intensity of use among the participants only, respectively.

RESULTS AND DISCUSSION

Descriptive analysis of wheat commercialization status

Table 2 reveals the descriptive statistics of the variables included in the Tobit model. It shows that 95% of the sample households are male headed households. The mean age, education level and family size of the sample households are about 44 years, grade 3 and 6 persons of family member. The average livestock owned is about 5.5

Table 2. Descriptive analysis of variables included Tobit model for wheat commercialization analysis.

Variable	Mean	Std. Dev.	Min	Max
Sex of the HHH is 1 (1=Male; 0=female)	0.95	0.216	0	1
Age of the HHH (years)	44.42	11.725	18	100
Education of the HHH (completed grade)	2.96	3.329	0	16
Family size (numbers)	6.41	2.398	1	18
Livestock owned (TLU)	5.54	3.614	0	28.56
Access to extension service is 1 (1=Yes; 0=No)	0.94	0.240	0	1
Access to credit is 1 (1=Yes; 0=No)	0.59	0.492	0	1
Wheat area (ha)	0.85	1.153	0.0313	19
Annual wheat production (Kg)	2224.03	4008.216	25	59000
Wheat price (Birr/Kg)	7.99	2.171	3.5	14
Distance to market (minutes of walk)	55.36	43.003	0	240
Commercialization index (0 to 1)	0.27	0.238	0	1
Tigray Dummy (1=Yes; 0=otherwise)	0.13	0.337	0	1
Amhara Dummy (1=Yes; 0=otherwise)	0.43	0.496	0	1
Oromia Dummy (1=Yes; 0=otherwise)	0.33	0.472	0	1
SNNP Dummy (1=Yes; 0=otherwise)	0.10	0.301	0	1

HHH=Household head, SNNP= South Nations, nationalities and people.

Table 3. Distribution of extent of wheat commercialization of wheat producers in SARD-SC IP sites in 2012/13 cropping season.

Extent of commercialization	Tigray	SNNP	Amhara	Oromia	Overall
0% (totally subsistent farmers)	38	32	45	9	31
1- 25% commercialized	28	15	20	14	18
25.1- 50% commercialized	29	33	29	43	34
50.1 -75% commercialization	5	18	5	28	24
>75% commercialized	0	2	1	6	3
Minimum commercialization index	0	0	0	0	0
Maximum commercialization index	0.61	0.8	1	1	1
Mean commercialization index	0.17	0.29	0.19	0.41	0.27

TLU. Most of the sample households (94%) had access to extension services while about 60% of them have access to credit in 2012/13 cropping season. The average area allocated for wheat, annual wheat produced per household and selling price of wheat were 0.85 hectares, 2224 kg and 8 Birr/Kg. On average, the sample households walk about 55 min (nearly one hour) to reach the market of input and output in the study area.

Table 3 demonstrates the descriptive statistics of wheat commercialization by IP site region. The result shows that the average value of the overall sample household commercialization index of wheat producers is 0.27 (or 27%) with the highest and lowest in Oromia (0.41) and Tigray (0.17) IP sites, respectively. Although, wheat is a staple food crop, it is also equally important for industrial purpose in flour factories. This result clearly indicated that in IP sites where wheat production is adequate like in the case of Oromia IP site, the level of commercialization is also relatively high. Therefore, increasing wheat productivity leads to higher level of commercialization which in turn has a positive effect on flour factories that use wheat as a raw material. The result also indicates that 31% of the overall sample households have commercialization index of zero value indicating that they are fully subsistent in terms of wheat farm. However, there is a great variation in the proportion of subsistent farmers in terms of wheat among IP sites with the highest and lowest in Amhara (45%) and Oromia (9%), respectively. That is, only 9% of Oromia IP site wheat farmers are totally subsistent in terms of wheat, while 45% of them are subsistent in the Amhara IP site. The result also reveals that most of the commercialization index (34%) falls within 25 to 50% while the least (3%) falls above 75% commercialization index.

Table 4. Tobit estimates and marginal effects of determinants of wheat commercialization.

Variables	Std. Err.	P>t	Marginal effects		
			$\frac{\partial E(y^*\|x)}{\partial x}=\beta$	$\frac{\partial E(y\|x)}{\partial x}=\beta\Phi\left(\frac{x\beta}{\sigma}\right)$	$\frac{\partial \Pr(y>0\|x)}{\partial x}=\phi\left(\frac{x\beta}{\sigma}\right)\frac{\beta}{\sigma}$
Constant	0.325	0.000***			
Sex of head	0.024	0.580	0.04910	0.02339	0.03348
Age of head	-0.001	0.549	0.00089	0.00047	0.00067
Education of head	0.006	0.075*	0.00336	0.00177	0.00252
Family size	-0.014	0.001***	0.00463	0.00244	0.00347
Livestock owned	0.009	0.005***	0.00319	0.00168	0.00239
Extension access	-0.030	0.421	0.03606	0.02184	0.03077
Credit access	0.036	0.058*	0.02038	0.01043	0.01486
Wheat area (ha)	0.007	0.754	0.02227	0.01177	0.01674
Wheat production	0.0000169	0.006***	0.00001	0.000005	0.000004
Average Price	0.005	0.420	0.00604	0.00319	0.00454
Market distance	-0.000914	0.000***	0.00027	0.00014	0.0002
Tigray Dummy	-0.230	0.000***	0.05972	0.01714	0.02397
Amhara Dummy	-0.159	0.000***	0.03790	0.01843	0.02602
Oromia Dummy	-0.011	0.783	0.04266	0.02215	0.03154
/sigma	0.271				

Number of observations = 996; Uncensored obs.= 687
Left-censored obs.=306; Right-censored obs.=3
Log likelihood = -348.29093; Pseudo R^2 = 0.3035
LR chi2(14) = 303.49; Prob > chi2 = 0.000

Y=pr(0<y<1) = 0.78666966;
Y = E(y|0<y<1)= 0.31447635;
Y = E(y*|0<y<1) = 0.24930193

* and *** means significant at 10 and 1% level of significance, respectively.

Determinants of wheat commercialization in the SARD-SC IP sites

As shown in Table 4, the likelihood function of the Tobit model for wheat commercialization index is highly significant (LR chi^2 (14) =259.74 with Prob > Chi^2 = 0.0000) indicating a strong explanatory powers of the independent variables. Out of the 14 explanatory variables included in the model, eight variables, namely education of household head, family size, livestock ownership, access to credit, wheat production, market distance, region dummy (Tigray and Amhara) were found to significantly influence the commercialization level of wheat producers in the study area. However, sex and age of household head, access to extension services, area allocated to wheat, price of wheat and being Oromia IP sites variables were not significant in the model.

As expected, education of household head was found to have a positive and significant effect on the level of wheat commercialization at 10%. Previous findings (Omiti et al., 2009; Tufa et al., 2014) are also in line with this finding. The marginal effect result indicated that as the level of formal education of the household head increased by one grade, the decision to participate in wheat marketing would be increased by 0.34% while it increases the level of commercialization by 0.00177 and 0.00252 for the whole sample and for those who have already started wheat marketing, respectively. Therefore, improving access to education of wheat farmers would have a positive effect on wheat commercialization.

Number of livestock owned in TLU was found to positively contribute to the level of wheat commercialization at 1%. This result has been supported by the finding of Tufa et al. (2014). Livestock and crop production is usually considered as complementary enterprises in that livestock can positively contribute to crop production by providing natural fertilizer, oxen used for traction power and source of cash to finance purchased inputs such as seed and fertilizer. As the level of wheat production increased, the amount of marketable surplus supplied to market is also increased. Therefore, livestock ownership has a positive effect on wheat production explicitly and on commercialization implicitly. The marginal effect results show that increasing the number of livestock by one TLU would increase the probability of participating in wheat selling by 0.32%, whereas it increases the level of wheat commercialization by 0.00168 and 0.00239 for the whole population of the study and for those who have already started wheat selling, respectively.

Access to credit was found to have a positive effect on wheat commercialization at 10% level of significance.

Credit plays an important role in solving cash constraints needed in wheat production used to purchase inputs such as fertilizer, improved seed, crop protection chemicals that used to enhance wheat production and productivity which in turn has a positive effect on marketable surplus. Therefore, improving access to rural credit would have a positive effect on the level of wheat commercialization. The marginal effects show that the probability of wheat producers who have access to credit increases by 2.04% as compared to those who do not have access to credit while level of commercialization increases by 0.01043 and 0.01486 for the whole population and for the participants of wheat marketing, respectively.

Another explanatory variable that influenced the commercialization of wheat producers was the amount of annual wheat production. The findings of Gebremedhin and Jaleta (2012), Gebreselassie and Sharp (2008), Goitom (2009), and Omiti et al. (2009) also support this finding. The marginal effects show that an additional kilogram wheat production increases the level of wheat commercialization by 0.001% which means one additional ton annual wheat production increases the commercialization index by 1% while it increases the level of commercialization index by about 0.000005 and 0.000004 for the population of study and for those who have already started selling wheat, respectively. The result implies that increasing wheat production plays a great role for its commercialization in the study area. Therefore, generating and disseminating improved wheat technologies would bring a positive effect in wheat sector not only at the production sector but also at the marketing and processing sector as the level of wheat commercialization directly related to these two sectors.

The estimation result of Tobit model has also demonstrated that family size was found to influence the level of wheat commercialization at 1% level of significance carrying a negative sign. This result agrees with the findings of Gebremedhin and Jaleta (2012) and Tufa et al. (2014). The marginal effect shows that as the number of family member increased by one person, the probability of participating in wheat selling is decreased by 0.463 while it decreases the level of wheat commercialization by 0.00244 and 0.00347 for the whole population of the study and for those who have already practiced wheat selling, respectively. The result is expected because large family needs more wheat to consume and less to sell as compared to the small one.

Distance to market of selling wheat in minutes of walk from wheat producers homestead influenced the level of commercialization negatively and significantly as expected. This result is in line with the findings of Gebremedhin and Jaleta (2012), Omiti et al. (2009), Tufa et al. (2014). The marginal effects show that as the market distance decreases by one minute of walk, the probability of participation in wheat marketing increases by 0.027%, whereas it increases the commercialization index of the population of study and of those who have already started selling wheat by about 0.00014 and 0.0002, respectively. Therefore, improving marketing infrastructure at the lowest kebele level or strengthening marketing cooperatives to collect wheat at farm gate would have a positive impact on wheat commercialization.

Being both Tigray and Amhara region IP sites were found to be negatively related to the level of commercialization at 1%. The marginal effects show that Tigray and Amhara region IP sites of the SARD-SC wheat project hinder the probability of participating in wheat marketing by 5.97 and 3.79% in Tigray and Amhara IP sites, respectively. Gebreselassie and Sharp (2008) have shown that difference in location led to difference in level of commercialization. The marginal effect also indicated that Tigray and Amhara IP site decreases the level of wheat commercialization for the total population and for those who have already practiced wheat marketing by 0.01714 and 0.02397 in Tigray IP site and by 0.018 and 0.026 in Amhara IP site, respectively. The explanation for this relationship might be due to the fact that there is low level of production of wheat in both IP sites as compared to Oromia IP site. The result implies that, to raise the level of commercialization in these areas, improving the level of wheat production is an important task.

Conclusions

In this paper, the commercialization status along with factors affecting wheat producers commercialization level was assessed using a primary data collected from 946 sample households in four major wheat producing regions of Ethiopia where the SARD-SC wheat project has been implemented using the innovation platform (IP) approach. The result reveals that the level of commercialization of the overall sample is 0.27 but varies from region to region with the highest (0.41) in Oromia and lowest (0.17) in Tigray. The result also shows that education level of the household head, livestock ownership, annual wheat production and access to credit were found to positively contribute to the commercialization of wheat while number of family member and the distance of market (distant market) were found to have a negative effect on it. Hence, improving access to education and credit should be focused on to increase level of wheat commercialization. Similarly, increasing annual wheat production and improving level of livestock ownership that have multi purposes such as source of traction power, source of manure for fertilizer, and source of cash to buy inputs should be a focus area to improve wheat commercialization. Improving market access like farm gate market such as contractual farm would also be arranged to improve level of commercialization of wheat producers.

Finally, this paper is limited to analyzing wheat commercialization focusing on the domestic production. However, Ethiopia is currently importing wheat and distributes to millers in subsidized form so as to stabilize the wheat price. One of the future research agenda is therefore to evaluate the effect of imported wheat on smallholder commercialization and the wheat sector in general. This will pave the way to evaluate if subsidizing farmers to produce and sell more so that the import wheat and distributed through subsidy finally ceased. A couple of other future research agendas are: one is a study on the impact of collective action (cooperative marketing along with their limitations to foster wheat commercialization and enable farmers to earn fair price) and the second is a study on the impact of wheat quality enhancing commercialization.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

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Coffee pruning: Importance of diversity among genotypes of *Coffea arabica*

Wagner Nunes Rodrigues*, Lima Deleon Martins, Márcio Antonio Apostólico, Tafarel Victor Colodetti, Sebastião Vinícius Batista Brinate, Bruno Fardim Christo and Marcelo Antonio Tomaz

Centro de Ciências Agrárias, Universidade Federal do Espírito Santo. Alto Universitário, Postal Box 16, 29500-000, Guararema, Alegre, Espirito Santo, Brazil.

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The renovation of Arabica coffee crops located in mountain regions should be based on the use of new improved genotypes and increased plant density, which require the establishment of an adequate pruning system. Little is known about the response of improved genotypes to pruning, therefore this study was done to evaluate the vegetative and reproductive recovery after pruning of genotypes of Arabica coffee cultivated in environment with high plant density, in order to identify how the different patterns of recovery may influence the crop after pruning. The experiment was developed in Espírito Santo state (Brazil), where 16 genotypes of Arabica coffee were cultivated in a randomized block design, with four repetitions (six plants per plot) and pruned after their fourth harvest. The 2-years period after pruning was evaluated to quantify the potential recovery and variability of behavior were found, making it possible to identify groups of genotypes of different behavior regarding the green coffee yield, grain size, growth rate and formation of new vegetative structures. The results show that not all genotypes recovered in the same speed after pruning, being possible to highlight some genotypes with better performance post-pruning. This fact shows the importance of genetic factors; more specifically the recovery, growth and coffee yield after the intervention; should not be ignored when deciding on the best method to renew the plantation. The decision on which cultivar and which pruning method to use should be a rational choice, based on the possible synergy between those technologies.

Key words: *Coffea arabica*, crop yield, growth, recovery.

INTRODUCTION

A considerable part of the coffee plantations in Brazil was or is still undergoing a process of renovation. This process is being supported by government programs based on the strategic plan for agriculture development, which stimulate the evaluation and planting of new coffee cultivars for renewal of the older crops (Seag, 2010).

*Corresponding author. E-mail: rodrigues@phytotechnics.com.

The promotion of new genotypes is from the scenario of cultivation in Brazil, which for decades was based on the cultivation of a very few number of cultivars (Matiello et al., 2005). Currently, several new improved cultivars are available for cultivation in Brazil, and the new genotypes used in these cultivars associate high crop yield with new agronomic traits, such as resistance to pests, diseases, drought and higher beverage quality, creating an advantageous option for the formation of more profitable and sustainable coffee plantations (Oliveira and Pereira, 2008).

Since some of the main regions where Arabica coffee (*Coffea arabica* Lineu) is cultivated in Brazil mountain regions, the use of improved genotypes should be associated with their adaptation for farming systems where the mechanization of the processes is not fully possible. The mountain plantations also require additional concern with soil conservation to make the agricultural activity sustainable in these conditions. For these conditions, the cultivation with high plant density is recommended, allowing a higher efficiency of land use, protecting the soil and bringing benefits in crop yield and efficiency of manpower to the process (Paulo et al., 2005; Oliveira et al., 2007).

However, the narrow spacing used in plantation with high plant density make the canopies to start overlapping each other with the plant aging, therefore, it is necessary to establish an adequate pruning management to mitigate the effects of an early excessive narrowing in the plantation. Pruning is a technology that has been associated with higher yield due to its promotion of reproductive output in different plant species (Bilir et al., 2006; Dutkuner et al., 2008). For coffee plants, there are several pruning managements that are recommended to be used when the canopies start overlapping and causing detrimental effects (normally after 4-6 years of cultivation, depending on the spacing, environment and growth), between the recommended pruning for *C. arabica* in Brazil, there are: “recepa” (high or low cut of orthotropic stems), “decote” (high cut above to control the plant height), “desponte” (cut of plagiotropic branches at a determined length), “esqueletamento” (association of orthotropic and plagiotropic cutting to control the shape of the canopy), and selective pruning (cutting varies per plant), as described by Cunha et al. (2011).

The differences of growth rates and patterns that exist among genotypes of *C. arabica* indicate that not all genotypes respond equally to pruning, as genotypes with vigorous growth may recover more promptly, while genotypes of slower or restrict growth may not recover satisfactory after cutting. Thus, due to the existence of diversity in canopy architecture and growth patterns, studies to characterize the adaptation and recovery capacity of cultivars become necessary to support a better recommendation cultivars and techniques for these conditions.

Little is known about the response of improved genotypes to pruning, with no conclusive scientific information about the quantification of the recovery potential of different genetic materials after pruning. Thus, it is necessary to study the existence of diversity of response among genotypes to improve the recommendation or even define groups which respond positively to the technique.

The objective of this study was to evaluate the vegetative and reproductive recovery after pruning of genotypes of Arabica coffee cultivated in environment with high plant density, in order to identify how the different patterns of recovery may influence the crop after pruning.

MATERIALS AND METHODS

Experimental design

The experiment was developed in Alegre municipality, Espírito Santo state, Brazil (20°45′S, 41°33′W), the local presents altitude of 690 m above sea level, in the mountains of the Caparaó Region, the soil is classified as oxisol. Sixteen genotypes of Arabica coffee (*C. arabica* Lineu), chosen from previews studies that affirmed their potential to be cultivated in this region (Rodrigues et al., 2016), were cultivated in a randomized block design, with four repetitions (six plants per plot). Plant spacing was 2.00 x 0.60 m, representing a high-density cultivation (Androcioli Filho and Androcioli, 2011), which was grown following the agricultural practices currently recommended for the region (Prezotti et al., 2007; Reis and Cunha, 2010, Reis et al., 2011). After the fourth harvest (5 years of cultivation), the canopies were subjected to pruning, cutting orthotropic stems at 1.60 m above soil level (horizontal cut) and plagiotropic branches at near 20 cm of canopy radius (vertical cut).

Growth, production and classification

The vegetative and reproductive recovery of the plants was evaluated, from pruning to the first reproductive cycle after recovery (2 years after pruning). The canopy growth rates were calculated based on the temporal variation of length of orthotropic and plagiotropic stems (from insertion to the apex), expressed in number of days required to grow 1 cm, resulting in the orthotropic growth rate (OGR, days cm^{-1}) and plagiotropic growth rate (PGR, days cm^{-1}). The emission of new branches from the orthotropic stem above the pruning cut was monitored and the temporal variation of number of new branches was used to calculate the branch emission rate (BER, days $branch^{-1}$). Similarly, the emission of new nodes on plagiotropic branches was monitored to determine the node emission rate (NER, days $nodes^{-1}$). After ripening, all fruits from each plant were harvested and weighted; consecutively dried, processed and reweighed to determine the mass of green coffee yielded by each plant (GCP, kg $plant^{-1}$). The ratio between mass of processed grains and original mass of coffee beans was then calculated to evaluate the mass return ratio (MRR, %). Triplicate samples of green coffee were used to classify the grain size in commercial sieves, establishing the proportion of fruits classified in larger classes of each grain shape. For large flat-shaped grains (standard), the mass graded over a 17 screen (over 6.74 mm of diameter) were determined (LFG, %); and for large egg-shaped grains (mocha), the mass graded over a 11 screen (over 4.36 mm of diameter) were determined (LMG, %).

Data analyses

The collected data was investigated using univariate variance analyses ($p<0.01$ and $p<0.05$), using the model $Y_{ijk} = \mu + B_j + G_i + \varepsilon_{ij}$, where Y_{ijk} represents the phenotypic value of the ijkth observation, B_j represents the effect of the jth block, G_i is the fixed effect of the ith genotype, and ε_{ij} is the random error related to the ijth observation. The genetic parameters were estimated following the methodology described by Cruz and Carneiro (2003): mean phenotypic variance as $\hat{\sigma}_p^2$; quadratic component as $\hat{\Phi}_g$; mean environmental variance as $\hat{\sigma}_e^2$; coefficient of genotypic determination as H^2; coefficient of genetic variation as CV_g; variation index as θ (Vencovsky, 1978; Cruz and Carneiro, 2003). The means of each variable were compared ($p<0.05$) using the Scott-Knott criteria (Scott & Knott, 1974). Sequentially, the data was explored by multivariate analyses, the generalized distance of Mahalanobis was estimated for all pairing of genotypes and the relative importance of each trait was estimated from the standardized means (Singh, 1981). From the distance matrix, the genotypes were clustered using the simple link criteria through the Tocher optimization method. The statistical analyses were performed using the statistical software "GENES" (Cruz, 2013).

RESULTS AND DISCUSSION

The results show existence of considerable variability among genotypes for most traits of recovery after pruning, only not significant differences for the orthotropic growth rate occurred (Table 1). As the cutting of the upper part of orthotropic branches promotes the break of apical dominance, it is possible that the metabolic investment in plagiotropic branches made the growth of orthotropic stems to be slower (Cline, 1996; Dun et al., 2006) and hid possible differences between growth patterns of genotypes. For all others traits, significant differences (as observed for Ms_g in Table 1) can be identified among genotypes, and this heterogeneity of behavior regarding vegetative and reproductive recovery can be linked to genetic variability existing among this group of genotypes, as indicated by the genetic parameters (Table 1).

Since the estimative of quadratic components were higher than environmental variances (Table 1) in the determination of phenotypic variances for all characteristics (except OGR), it is possible to relate major influence of genetic than environmental variances in the determination of these traits. For the species, *C. arabica*, the expression of several agronomic traits have been reported to be highly related to the expression of genetic diversity among cultivars (Carvalho et al., 2012; DaMatta, 2004; Del Grossi et al., 2013; Martinez et al., 2011; Martins et al., 2015; Rodrigues et al., 2014, 2015; Shigueoka et al., 2014). Additionally, the estimative of coefficient of genotypic determinations were higher than 90% for MRR, LFG and BER (Table 1), showing that these traits are especially valuable in the genetic study of the recovery, since genetic factors seems to have major contribution in the determination of the phenotypic values of these traits. The variation indexes for GCP, MRR, LFG, PGR and BER (Table 1) also indicate favorability for a possible genotype selection, since it seems that genetic variation surpassed environmental.

Regarding the difference of means among genotypes, Table 1 shows that it is possible to distinguish up to four different homogeneous groups for LFG and BER, three groups for MRR, and two homogeneous groups for GCP, LMG, PGR and NER. No differentiation was observed for OGR.

Paraíso MG H419-1, H419-3-3-7-16-4-1-1, Araponga MG1, Catucaí 24/137, Catiguá MG2, Sacramento MG1, Pau-Brasil MG1, and Catiguá MG3 yielded over 510 kg of green coffee per plant, which shows the potential of these genotypes for narrow cultivations and how their reproductive recovery was vigorous enough to allow a production that represents values 168% over the average crop yield for Arabica coffee in Brazil (Conab, 2016). This behavior for some genotypes, such as Araponga MG1 and Pau-Brasil MG1, may be related to a higher degree of adaptation for systems with high plant density, as also observed by Rodrigues et al. (2016).

The pruning seems to stimulate the production of plants of the genotype Sacramento MG1, since this genotype tend to develop vigorous vegetative growth when cultivated with high plant density, but overall yield with less fruits in several others genotypes Rodrigues et al. (2016). After pruning however, the intervention in canopy seems to promote the production to the point of the genotype to achieve similar yield than other highly productive cultivars, this fact may be a response to the enhanced light penetration in the canopies favoring the blossoming and development of reproductive structures (DaMatta et al., 2007).

The genotype Catuaí IAC 81 presented 36.94% of mass return, showing that is possible to achieve larger mass of green coffee from the same mass of coffee beans than the other genotypes. This results are evidences of a complete recovery of grain filling from this genotype, since its higher processing ratio was also observed in plants without intervention by pruning (Rodrigues et al., 2016).

Regarding the grain size, larger proportion of flat-shaped grains screened in sieves above 17 were observed from the genotypes Katipó, Araponga MG1 and Catucaí 24/137, which presented over 32% of grains classified as large. Considering mocha grains, the genotypes Iapar 59, Acauã, Araponga MG1, Catucaí 24/137, Catiguá MG3, Oeiras MG 6851 and Catuaí IAC 44 presented over 91% of their grains screened over sieve 11 (large grains).

H419-3-3-7-16-4-1-1, Araponga MG1, Sacramento MG1 and Pau-Brasil MG1 presented slower horizontal growth, requiring over 38 days to gain an average of 1 cm

Table 1. Descriptive analyses, genetic parameters and means of eight variables obtained by evaluating the vegetative and reproductive recovery of 16 genotypes of Arabica coffee after pruning (Alegre, Espírito Santo, Brazil, 2014-2016).

Parameter	GCP(9)	MRR(10)	LFG(11)	LMG(12)	OGR(13)	PGR(14)	BER(15)	NER(16)
	(g)	(%)	(%)	(%)	(days)	(days)	(days)	(days)
				Descriptive analysis				
Minimum	253.87	17.01	8.38	80.30	5.08	24.80	15.26	17.70
Maximum	775.56	39.41	45.97	97.50	19.10	55.18	65.32	33.19
Mean	476.36	23.87	24.30	90.79	7.76	35.35	26.47	24.28
CV (%)(1)	17.40	9.18	18.77	3.66	27.94	13.83	14.74	12.34
Genetic parameters								
MS_{G}(2)	$41.481.35^{**}$	71.33^{**}	305.87^{**}	23.79^{*}	7.17^{ns}	91.21^{**}	294.10^{**}	19.65^{*}
$\hat{\sigma}^{2}_{p}$(3)	10.370.34	17.83	76.47	5.95	1.79	22.80	73.52	4.91
$\hat{\sigma}^{2}_{e}$(4)	1.717.82	1.20	5.20	2.76	1.17	5.98	3.81	2.24
$\hat{\Phi}_{g}$(5)	8.652.52	16.63	71.27	3.18	0.62	16.82	69.72	2.67
H^{2}(6)	83.44	93.27	93.20	53.52	34.49	73.78	94.82	54.34
CV_{g} (%)(7)	19.53	17.08	34.74	1.97	10.14	11.60	31.54	6.73
θ(8)	1.12	1.86	1.85	0.53	0.36	0.83	2.14	0.54
Genotype means(17)								
Iapar 59	314.94^{b}	27.21^{b}	16.28^{c}	93.50^{a}	7.61^{a}	37.12^{b}	19.12^{d}	23.36^{b}
Katipó	433.83^{b}	22.31^{c}	33.88^{a}	86.40^{b}	7.69^{a}	34.04^{b}	27.63^{c}	23.37^{b}
Acauã	430.02^{b}	21.55^{c}	31.38^{b}	92.60^{a}	6.90^{a}	34.44^{b}	22.35^{d}	25.11^{b}
Paraíso MG H419-1	546.45^{a}	23.53^{b}	19.20^{c}	90.68^{b}	8.63^{a}	32.76^{b}	35.90^{b}	27.38^{a}
H419-3-3-7-16-4-1-1	629.45^{a}	19.42^{c}	28.35^{b}	90.60^{b}	7.27^{a}	39.42^{a}	25.89^{c}	28.30^{a}
Araponga MG1	510.51^{a}	24.10^{b}	32.80^{a}	95.53^{a}	8.43^{a}	38.97^{a}	24.18^{c}	23.95^{b}
Catucaí 24/137	614.25^{a}	22.06^{c}	38.28^{a}	92.75^{a}	9.14^{a}	31.66^{b}	25.97^{c}	24.30^{b}
Catiguá MG2	535.67^{a}	21.20^{c}	10.50^{d}	89.33^{b}	6.07^{a}	36.22^{b}	18.65^{d}	24.45^{b}
Sacramento MG1	564.15^{a}	21.74^{c}	10.65^{d}	89.60^{b}	6.94^{a}	42.82^{a}	21.28^{d}	21.51^{b}
Pau-Brasil MG1	569.65^{a}	20.24^{c}	17.30^{c}	87.28^{b}	10.76^{a}	46.26^{a}	50.52^{a}	24.33^{b}
Catiguá MG3	568.98^{a}	23.50^{b}	27.15^{b}	92.40^{a}	7.07^{a}	34.64^{b}	22.55^{d}	23.29^{b}
Oeiras MG 6851	398.36^{b}	20.03^{c}	29.38^{b}	91.43^{a}	9.31^{a}	31.16^{b}	37.51^{b}	27.38^{a}
Tupi	372.97^{b}	25.98^{b}	13.65^{d}	89.38^{b}	9.07^{a}	27.29^{b}	30.51^{c}	26.28^{a}
Catuaí IAC 44	417.58^{b}	26.62^{b}	29.78^{b}	92.78^{a}	6.10^{a}	30.67^{b}	20.71^{d}	23.53^{b}
Catuaí IAC 81	354.91^{b}	36.94^{a}	21.50c	90.48^{b}	6.66^{a}	35.17^{b}	22.53^{d}	21.26^{b}
Catuaí IAC 144	360.04^{b}	25.51^{b}	28.75^{b}	87.95^{b}	6.45^{a}	32.96^{b}	18.28^{d}	20.61^{b}

**Significant at 1% probability; *Significant at 5% probability; nsNon-significant at 5% probability; (1)Coefficient of variation; (2)Mean square of genotypes; (3)Mean phenotypic variance; (4)Mean environmental variance; (5)Quadratic component; (6)Coefficient of genotypic determination; (7)Coefficient of genetic variation; (8)Variation index; (9)Green coffee yielded per plant; (10)Mass return ratio; (11)Proportion of large flat-shaped grains; (12)Proportion of large egg-shaped grains; (13)Orthotropic growth rate; (14)Plagiotropic growth rate; (15)Branch emission rate; (16)Node emission rate; (17)Means followed by the same letter do not differ by the Scott-Knott test, at 5% probability.

in their plagiotropic branches. Additionally, the slow recovery of plagiotropic branches from the genotype Pau-Brasil MG1 is also highlighted for requiring 50 days to grow a new branch. Paraíso MG H419-1, H419-3-3-7-16-4-1-1, Oeiras MG 6851 and Tupi presented slower emission of new nodes, requiring over 26 days to develop an average of one new node in their plagiotropic branches.

Based on the Mahalanobis distances, the relative contribution of the variables was estimated. OGR was discarded due to its low contribution and the order of traits that contributed the most were: BER (31.54%) > LFG (23.42%) > MRR (23.39%) > GCP (10.50%) > PGR (6.43%) > NER (2.43%) > LMG (2.29%). By the Tocher method, the genotypes were clustered in seven groups. The group I clustered genotypes which presented high fruit production, exclusively genotypes among the ones with higher green coffee yield, being composed by H419-3-3-7-16-4-1-1, Catiguá MG2, and Araponga MG1.

Group II formed Catucaí 24/137, Catuaí IAC 81, and Catiguá MG3; and was characterized by genotypes with fast recovery of plagiotropic branches, presenting fast emission of nodes in the branches and a higher growth rate of branches, which made it possible to develop a larger number of nodes that could sustain a larger number of new structures, such as secondary branches, leaves and reproductive buds.

The group III clustered Oeiras MG 6851, Catuaí IAC 44 and Paraíso MG H419-1; which are genotypes of different behaviors, but all with high growth rate of plagiotropic branches, and overall longer internodes in their plagiotropic branches. Group IV clustered genotypes of lower mass return ratio, being formed by Katipó and Pau-Brasil MG1, which require a larger mass of coffee beans to produce the same mass of green coffee due to their fruit intrinsic characteristics. These genotypes also presented a smaller proportion of mocha grains screened as large. Moreover, this group of genotypes presented fast emission of new nodes on their plagiotropic branches. Similarly, the group V, composed of Acauã and Sacramento MG1, also presented low mass return ratio and fast node recovery rate. However, this group of genotypes associated these traits to a fast emission of new plagiotropic branches. Group VI clustered genotypes of lower yield and fast plagiotropic growth, being formed by Iapar 59 and Tupi.

The group VII was formed by a single genotype, Catuaí IAC 144, which associate low fruit yield, low proportion of grains classified as large mocha, fast growth and emission of plagiotropic branches and fast emission of nodes.

Conclusion

Since the genotypes with lower means of green coffee per plant still achieved high enough yield to surpass the average yield of the region, the pruning used in this experiment is a valuable technique for renovation and for handling the density of canopies in the system. But the various growth patterns and the different characteristic of the grains found in the results, associated with the high estimate genetic parameters is a proof that some genotypes are more suitable for plantations with high plant density, but not all genotypes recover after pruning in the same speed, which is possible to highlight some genotypes with better performance post-pruning. This fact shows the importance of developing more studies in this subject, since the genetic factors; more specifically the recovery, growth and coffee yield after the intervention; should not be ignored when deciding on the best method to renew the plantation. The decision on which cultivar and pruning method to use should be a rational choice, based on the possible synergy between these technologies.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interest.

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Full Length Research Paper

Artificial neural networks in predicting energy density of *Bambusa vulgaris* in Brazil

Ailton Teixeira do Vale, Eder Pereira Miguel*, Alessandro Cézar de Oliveira Moreira, Clarissa Melo Lima, Bruna Bárbara Maciel Amoras Orellana, Myla Medeiros Fortes, Mayara Paula Oliveira Machado, Joaquim Carlos Gonçalez and Ildeu Soares Martins

University of Brasilia (UnB), Brazil.

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In this study, the physical and chemical characteristics of *Bambusa vulgaris* ex J.C. Wendl. var.*vulgaris* (*Bambusa vulgaris*) aged 1, 2 and 3 years were evaluated. The objective was to train, validate and evaluate the efficiency of artificial neural networks (ANNs) as predictive tools to estimate bamboo stem energy density grown commercially in northeastern Brazil. For that, samples were collected in a commercial plantation and managed for energy production, determining the energy properties. Among all the characteristics analyzed, basic apparent density was the one with major correlation with bamboo stem energy density. This factor has a great advantage because it is easy to estimate, determined both by dry mass at 0% moisture, and at saturated mass. Also, the precision of ANNs was verified when associated with basic density, as a predictor of bamboo stem energy density, showing low standard error (Syx%, 1.52) and high coefficient of determination (R^2 = 0.98). ANN-estimated values had no statistical difference (t_{cal} 0.58 ≤ t_{tab} 2.08) with energy density estimated in the laboratory. Therefore, this tool was efficient, being recommended to predict the energetic density of the species under study, with basic density as the only predictive variable.

Key words: Bamboo, biomass, energy, artificial intelligence.

INTRODUCTION

Biomass converted into biofuels fits into the concept of sustainable development. Thus, bamboo, as a source of biomass, is an alternative to being, among other factors, a perennial grass, with good productivity without the need for being replanted (Guarnetti, 2013).

There are about 1439 species of bamboo worldwide, being distributed into 116 genera (Bamboo Phylogeny Group, 2012). Over 4000 uses are registered for this species (Kuehl and Yiping, 2012). Brazil owns the greatest diversity of species among the Latin American countries (Grombone-Buaratini et al., 2011). Over time, bamboo use has benefited man in several generations

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*Corresponding author. E-mail: miguelederpereira@gmail.com. Tel: + 55 61 3107-5637.

both as a source of work and income (Almeida, 2010). In East Asia, this plant is employed in the manufacturing of houses, agricultural tools, handicrafts and furniture (Negi and Saxena, 2011). Currently, other uses have been researched, such as activated charcoal (Liu et al., 2010) and other energy sources.

Wood energy potential should be evaluated by means of energy density, which is the product between calorific value and apparent density, whose IS unit is $kj.m^{-3}$. It is an important property because, in addition to encompassing density and calorific value, it encompasses wood chemical and physical characteristics for energy production through heat form. Moreira (2012) stated the energy density as an excellent indicator of energy potential for *Bambusa vulgaris*.

Nevertheless, these variables must be carefully defined, whereas both wood density and calorific value can be obtained under different conditions, generating different values for energy density. In general, this variable must be determined under conditions where calorific value and density are estimated with the same moisture content. But, the exception to this rule would be by the existence of basic density. In this case, the higher calorific value is used in calculations of the energy density.

For companies that use biomass as fuel, the energy density is fundamental as an indicator of its energy potential. In this sense, it becomes imperative to use techniques or tools that enable estimations of such energy potential. Among them are the artificial intelligence (AI) tools. The use of AI tools for estimations of growth and production in the forest science field is a new subject, which is rarely explored. In contrast, efforts have been made towards this approach, showing promising results for eucalyptus and pines species (Castro et al., 2013; Diamantopoulou, 2005; Gorgens et al., 2009; Miguel et al., 2015); yet, there are no studies on assessment for bamboos, mainly for energy density prediction.

Among the available AI techniques, artificial neural networks (ANNs) have gained prominence (Binoti et al., 2013; Miguel et al., 2015). The use of ANNs in modeling allows greater accuracy in production estimates and improved decision-making (Angel et al., 2007).

ANNs are mathematical models making use of artificial intelligence to solve certain complex problems. These nets are formed by simple processing elements- artificial neurons, which are activated by a function, known as the activation function. The neurons are bound to each other by connections, mostly coefficients or weights, which are adjusted by training algorithms. An artificial neuron is a simplified and related model of a real neuron, whose basic properties are information adequacy and reproduction based on connections, being thus an information-processing unit within a neural network (Wang et al., 2010).

According to Kuvendziev et al. (2014), these networks have as basic characteristics an adaptive learning, self-organization ability, robust and parallel-distributed structure (layers), learning efficiency and generalization. They are also tolerant to divergent data, being able to model several variables and respective non-linear relationships. Besides that, the use of this tool enables modeling with quantitative and qualitative variables.

Given the above, this study aimed to train, validate and evaluate the efficiency of artificial neural networks (ANN) as predictor tool of energy density estimators in bamboo stems (B. vulgaris), grown and exploited commercially in northeastern Brazil.

MATERIALS AND METHODS

Nine stems of *Bambusa vulgaris*, aged between 1 and 3 years, were collected from commercial areas in the city of Santo Amaro - Ba, Brazil. The selected stems were naturally dried inside a shed, with good air circulation, which belongs to the Laboratory Forestry Products (LPF), Brazilian Forest Service. If necessary, they were left in a forced-air circulation oven for drying at 105 ± 3°C until constant weight. Stems were chopped and ground in a Willey type mill, being later classified in a 0.250-mm sieve system for use in tests. The immediate analysis was performed based on the NBR 8112 standard (ABNT, 1986), with some adaptations: triplicate tests, a material with a particle size below 0.250 mm, use of ceramic crucibles, and for ashes 2 g sample for volatiles.

Samples were prepared for chemical analyses using the methods T 257 cm-85 (TAPPI, 2012) and T 264 om-88 (TAPPI, 1996). For evaluation of the extractive contents in ethanol (toluene), T 204 om-88 (TAPPI, 2007) was used. For ashes without extractives at 525°C, the method T 211 om-93 (TAPPI, 2002) was used. The laboratory analysis procedures LAP-003 and LAP-004, from the National Renewable Energy Laboratory - NREL (Templeton and Ehrman, 1995), were used to determine the contents of lignin. Equation 1 was used for holocellulose content (HC) determination.

$$HC = 100\% - TLign - AC_{525°C} \qquad (1)$$

Where HC = holocellulose content (%); TLign = total lignin (%); $AC_{525°C}$ = extractive free ash content at 525°C.

Basic density (ρ_b) of *B. vulgaris* stems was estimated according to NBR 7190 standard (ABNT, 1997), by relating the dry mass at 0% moisture and the sample saturated volume. Superior calorific value (SCV) was determined for 0.7000 g samples at 0% moisture and grain size under 0.250 mm. Trials were performed in triplicate with the aid of an isoperibolic calorimeter (Parr 1261, USA), following ABNT NBR 8633 protocol (ABNT, 1984). Equation 2 was used for energy density (ρE) determination.

$$\rho E = SCV.\ \rho b.k \qquad (2)$$

Where ρE = energy density ($MJ.m^{-3}$); SCV = superior calorific value ($kJ.kg^{-1}$); ρ_b = basic density ($kg.m^{-3}$); k = $10^{-3}.kJ^{-1}.MJ$ (conversion factor from kJ to MJ).

ANN adjustments

The networks were developed and trained through Pearson correlation between bamboo stem physical and chemical properties against its energy density. Hereafter, delay and burden for estimation of such variables was analyzed. According to Draper and Smith (1998), this type of modeling is justified when, instead of using difficult-to-obtain variables, estimates can be attained by easily accessible variables and under the pre-established requisites.

By adjusting ANNs, the numerical variables were linearly normalized within a range of 0 to 1 (Heaton, 2011). Input layer consisted of a single neuron (1), which stands for the basic density of the species as a function of the output variable. As an output, bamboo energy density was used.

Besides, the networks had one hidden layer. In fact, most of the time networks require at least one hidden layer to solve non-linearly separable problems (Oliveira-Esquerre et al., 2002). The number of neurons in this layer was optimized by the Intelligent Problem Solver (IPS) tool of Statistica 7.0 software (StaSoft Inc., 2005), using a sigmoidal activation function.

This sigmoid activation function is the most usual in ANN training, being differentiable if compared to the others. In a well-drawn network layout, any continuous function could be approximated with precision (Ismailov, 2014). It is mathematically expressed as:

$$\varphi(v) = \frac{1}{1 + \exp^{\beta u}} \tag{3}$$

Where φ = sigmoid activation function; β = estimate of the parameter for the sigmoidal function inclination; u = function activation potential.

The ANN key element is an artificial neuron. It is responsible for information processing after receiving values of operating parameters as input (basic density), returning the desired results as output (energy density). According to Wang et al. (2010), this neuron is a simplification of a biological neuron, and its basic properties consist of connection-based information matching and reproduction. Such connections may be composed of "n" inputs x1, x2, ..., xn (dendrites) and an output y (axon). The inputs receive weights w1, w2, ..., wn, which represent the synapses that might be negative or positive. Mathematically, this artificial neuron is represented by:

$$Y_k = \varphi(V_k) \tag{4}$$

Where Y_k = artificial neuron output; φ = activation function; V_k= linear combiner output, in other words:

$$V_k = \sum_{o}^{m} x_m . w_m \tag{5}$$

Where V_k= linear combiner.

Nevertheless, when working with ANN modeling, there is a potential problem of overfitting, which consists of an exaggerated learning of information from the database provided to the network. This way, the ANN becomes extremely trained on this information set and it starts to capture noise (errors) instead of the underlying relationships. Shortly, this overfitted network will not be able to be used in the entire sample data, since its generalization capacity was affected.

Another consideration to be taken is regarding the selection of the training algorithm. This factor interferes particularly with the move out of local minimum. A good algorithm should have a high capability for local search and global search (scanning). A training algorithm is defined as a set of well-defined rules for solving a learning problem. In the present study, the training algorithm was resilient propagation, as proposed by Riedmiller and Braun (1993), being one of the most efficient and recommended for Multilayer Perceptron ANNs (MLP-ANNs).

In this type of algorithm, weights are based on information contained in the current data. For this, an individual updating value is entered for each weight. Initially, weights of all networks were randomly generated (Heaton, 2011). Then, this individual updating value evolves during the learning process, based on the error function. Therefore, training persists until the error rate is shortened to an acceptable rate or until the maximum number of times or cycles are reached (Shiblee et al., 2010).

Network learning was of the supervised type since two sets of values were given to the network: a set of input values (basic density) and another of output values (energy density). The training consisted of an optimization of a problem related to the network parameters (synaptic weights), which aimed to respond to the inputs as expected, as well as extrapolating the same behavior to other unpredicted inputs until the error between the output patterns reaches the desired minimum values (Haykin, 2001).

ANN training

One hundred multilayer perceptron ANNs (MLPs) were trained. In this type of ANN, there are at least two different layers (Serpen and Gao, 2014). There are several procedures to determine the stopping point of a training process. Parallel to this, certain cares must be taken, once an excessive number of cycles can lead to network loss of generalization power (overfitting). Also, with a small number of cycles, the network may not reach its best performance (underfitting). These problems were eliminated by adopting an average quadratic error below 1% as training stopping criterion or, when the root mean square error (RMSE) increased again as suggested by Chen et al. (2014). Therefore, the training was finalized when one of the criteria was reached, and the best network to estimating bamboo energy density was then selected. The ANN adjustments were made using the Statistica 7.0 software (StaSoft Inc, 2005).

ANN validation

Eighty-one samples were tested to validate the neural network efficacy in predicting bamboo energy density as a function of basic density. These samples were collected in different stem positions (base, middle and top) of several plants, and for plants of different ages. From them, 60 samples (85%) were randomly selected to make part of adjustments; however, only 21 of them (25%) were used for validations. It is noteworthy that the same drawing of lots selected plants for both data adjustment and validation for the various stems, positions and ages. The 21 sample units described above were not part of the adjustment database, as suggested by Zucchini (2000). This author commented that validation samples must be independent. Moreover, Gujarati and Porter (2011) recommended that these samples should meet the modeling precepts, wherein nearly 10 to 30% of the samples composing the database should be directed to validation of the adjusted equations.

For ANN selection, traditional criteria were adopted to verify the goodness of fit, such as coefficient of determination (R2), estimate standard error (Syx%), and graphical analysis of residues. For validation, criteria consisted of t-test for pairwise data, estimate standard error (Syx%), aggregate difference (Da%), and absolute mean error (Ei).

RESULTS AND DISCUSSION

Table 1 shows the correlation values between physical and chemical properties of bamboo, as well as their

Table 1. Correlation between physical and chemical variables of bamboo.

Parameter	ρe (MJ.m^{-3})	ρb (kg.m^{-3})	MV (%)	Cz (%)	CF (%)	PCS (kj.kg^{-1})	Ext (%)	Ho (%)	LT
ρe (MJ.m^{-3})	1.00								
ρb (kg. m^{-3})	0.97**	1.00							
MV (%)	0.04	-0.09	1.00						
Cz (%)	0.36**	0.57**	-0.56**	1.00					
CF (%)	-0.46**	-0.57**	-0.29**	-0.62**	1.00				
PCS (kj.kg^{-1})	-0.29*	-0.52**	0.47**	-0.93**	0.64**	1.00			
Ext. (%)	-0.26	-0.33**	0.29**	-0.52**	0.33**	0.39**	1.00		
Ho (%)	0.16	0.04	0.47	-0.43**	0.06	0.37**	-0.14	1.00	
LT (%)	-0.58**	-0.68**	0.03	-0.56**	0.62**	0.64**	0.17	-0.18	1.00

De: Energy density; Db: basic density; MV: volatile material; FC: fixed carbon; Ext: extractives; Ho: holocellulose; TL: total lignin; **: significant at 1%; *: significant at 5%.

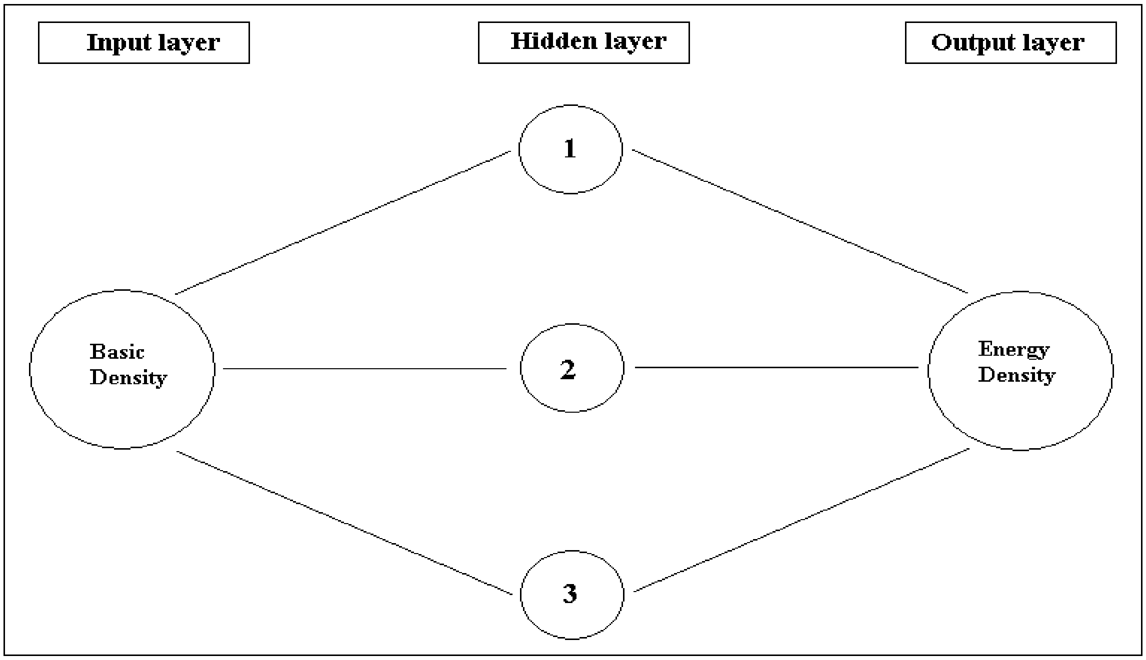

Figure 1. Architecture of the ANN selected for prediction of the bamboo energy density.

significance. Although, the variables such as ash content, fixed carbon, superior calorific value, and total lignin show significant correlations to energy density, only basic density was used as a predictive variable. This fact is justified by its high correlation with the energy density (Table 1), besides being more easily estimated as compared to the other variables.

After training 100 ANNs, the one with the best performance was selected, which showed a 1-3-1 architecture, that is, a network with three layers and five neurons (Figure 1). It was also noticed that good fits were achieved for ANNs predicting the bamboo energy density with low standard errors (absolute Syx = 159.68 and Syx% = 1.52) and high coefficients of determination (R^2 = 0.98).

Even though all adjustment estimators were good for selecting models, the graphical analysis of residues was fundamental for choosing an equation applied in the forest sciences. This is because trend errors are to occur within a certain amplitude of a variable of interest, without being detected by statistics measuring accuracy. Figure 2 displays the behavior of the ANN in predicting values of bamboo energy density as a function of basic density as compared to actual energy density and residual distribution.

Figure 2 highlights that the ANN was able to predict

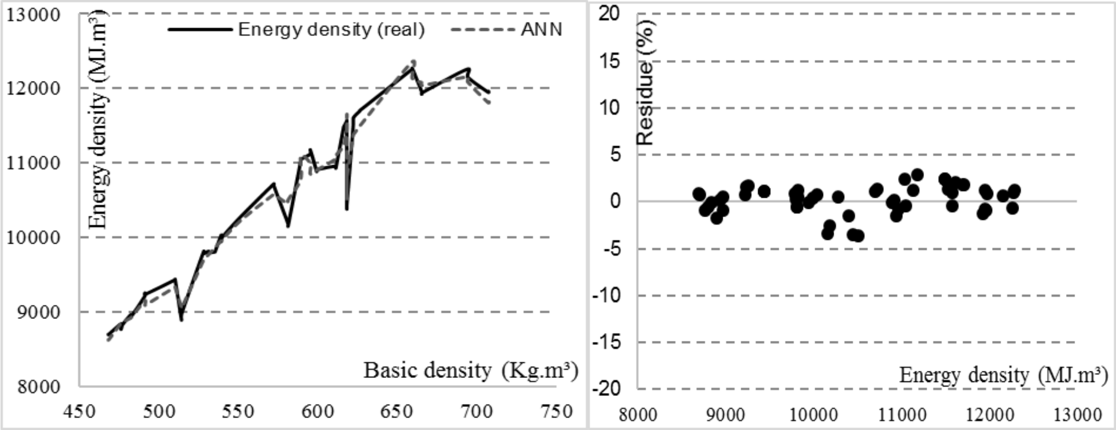

Figure 2. Behavior of the ANN in estimating bamboo energy density as compared to actual values, and residual distribution graph.

Table 2. Real and ANN-estimated values (average, minimum and maximum) for the variable bamboo energy density.

Variable	Statistics						Student t-test	
	Average	**Minimum**	**Maximum**	**Syx (%)**	**Da(%)**	**Ei**	**t_{cal}**	**t_{tab} (95%, DF: 20)**
Energy density								
Real	10805	8689	14055	-	-	-	0.58	2.08
ANN-estimated	10790	8681	14108	1.10	0.14	15.00		

Syx(%): Estimate standard error; Da (%): aggregate difference; Ei: mean absolute error; t_{cal}: t-statistics calculated values; $t_{tab:}$ t-statistics tabulated values; 95%: probability; DF: degree of freedom.

reliably the energy density with residual errors below 5%. Along with accuracy statistics (Syx: 1.45% and R^2: 0.98), we may infer that using basic density as the predictor variable and ANNs as modeling tools, an effective estimate of bamboo energy density was obtained.

ANN reliability was tested by comparing the values of energy density estimated by them with real values obtained in the laboratory. Of the total sample units (81), 25% (21) were randomly separated for this validation. Validation criteria for ANN adherence to the dataset were t-test for pairwise data, estimate standard error (Syx%), aggregate difference (Da) and absolute mean error (Ei), as seen in Table 2.

When set against the tabulated values, t-statistics showed no significance at 95% probability (Table 2), leading to the acceptance of the null hypothesis, therefore, using the ANN to estimate bamboo energy density, with basic density as a predictor variable, was valid and reliable. For a thorough analysis, other statistical parameters, related to the behavior of ANN against the validation sample, were gathered in Table 2.

It is noteworthy mention that the ANN previously selected during the fitting to predict bamboo energy density values presented the same behavior for estimate standard error (Syx%). Thus, this result corroborates the statements of Serpen and Gao (2014) who mentioned the efficiency of ANNs in learning and generalizing data and forms. These authors claimed that ANNs could extract standards from a given database and reapply then in others with great precision.

The aggregate difference (Da) is a statistic value used as a model fit index and corresponds to the difference between the sum of observed values and the sum of estimated ones. This index acts as an indicating criterion for sub or overestimations, and here expressed in percentage for a better visualization. The ANN developed to predict energy density showed values of 0.13%, characterizing thus an underestimation of this variable. However, it is evidenced, the adaptability of the ANN in predicting such property of bamboo, since the value of the aggregate difference was very low.

The mean errors (Ei) generated by the ANN were also analyzed. Values close to zero are desirable, whenever possible, as they show the ability of the network in estimating the variables of interest with accuracy. The mean error (Ei) generated by the ANN was 62.70 MJ.m^{-3}, in percentage, and it corresponds to 0.14%. Again, we may state that low mean errors evidence the potential of an ANN in the learning and predictability of a variable.

Seeking greater accuracy and precision, a most

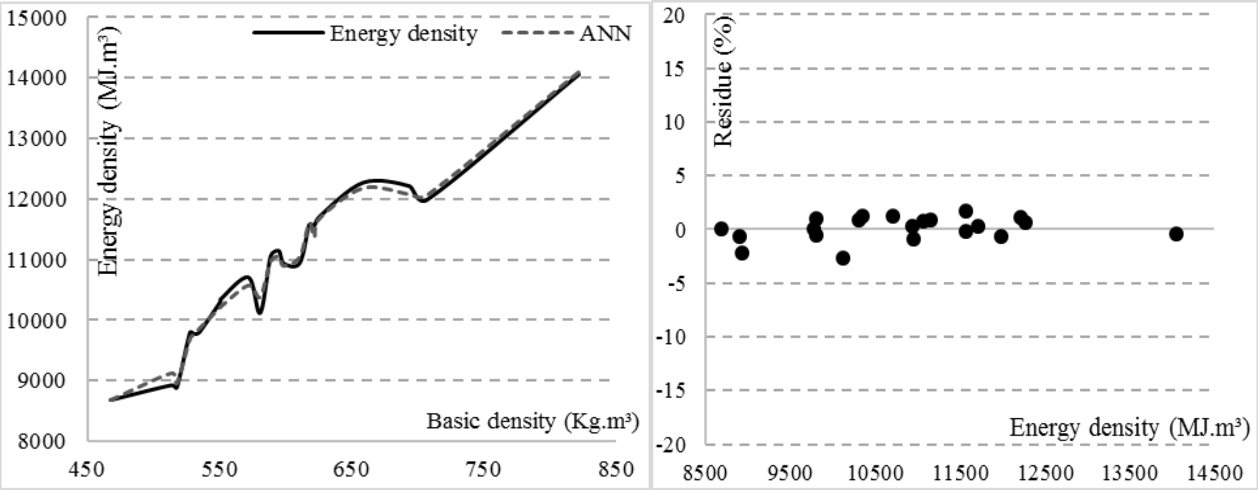

Figure 3. Validation of behavior between actual and estimated data, residual analysis of bamboo energy prediction by means of the neural network interface.

detailed graphical analysis of the residues was then used throughout the amplitude of the variable of interest for validation data, as shown in Figure 3. We could ascertain a satisfactory behavior of the ANN behavior since residue distribution was compact (± 5%) and homogeneous, without critical trend points. Therefore, this ANN can be considered as accurate and valid to estimate bamboo energy density using only basic density as a predictor variable. This fact had already been proven by the t-test.

Artificial intelligence has great potential for several applications, with emphasis on engineering and agriculture. However, for its most promising application, Thakare and Singhal (2009) asserted the need for direct relationships between input parameters and the target response, which is defined as the output variable. In these cases, ANNs are developed to achieve a performance typical of a biological system, based on connections of these elements, similar to biological neurons. Also, Egrioglu et al. (2014) mentioned that ANNs have advantages over the conventional techniques, such as generalization, parallelism and the chance of learning, as well as exemption of certain statistical assumptions like data normality or linearity.

Nevertheless, it is worth emphasizing that the results presented here only have validity for the studied species. This is due to variations of structures and physical/chemical compositions in each species. Therefore, further studies must be carried out testing different neural network settings to achieve a greater correlation between predictive data and responses. In this way, it will be possible to enhance accuracy in estimates of variables of interest. Inserting a "species" factor, as a categorical variable, into the input layer becomes an interesting alternative, which may result in a single ANN able of accurately predicting the energetic density of several species within the *Bambusa* genus.

Conclusions

In multilayer perception, artificial neural networks (MLPANNs) with sigmoidal function for layer activation, the training algorithm 'resilient propagation' associated with basic density, as predictor variable, was accurate and efficient in estimating energy density in stems of *B. vulgaris.* The results showed no statistical difference from energy density obtained in the laboratory. Therefore, its use is recommended in the prediction of this variable.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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