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Full Length Research Paper

Adaptability and stability parameters for potassium and calcium contents and grain yield in cowpea lines

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The aim of the present study is to estimate the adaptability and stability of K and Ca contents, and grain yield in cowpea lines for release as new cultivars. Forty-four inbred lines and cultivars were assessed in seven sites of the Brazilian semi-arid region. Significant statistical differences were observed in the treatment, environments and environment treatment interaction mean squares for all variables. The methods by Eberhart and Russell (1966), Lin and Binns (1988), and the additive main effects and multiplicative interaction (AMMI) showed similar results in the selection of superior materials. The C4I and C3O lines showed grain yield equal to or greater than the overall mean of 1050 kg ha^{-1} in the experiments, with mean of K and Ca higher than the values of the assessed cultivars, as well as wide stability and good predictability in the assessed environment series. The lines showed great potential to be released as new cultivars in the Brazilian semiarid region.

Key words: *Vigna unguiculata*, additive main effects and multiplicative interaction (AMMI), biofortification, genotype×environment interaction.

INTRODUCTION

In Brazil, cowpea cultivation has become a major social and economic alternative for rural populations in the North and Northeast regions, and its cultivation has expanded to other regions in the country (Oliveira et al., 2010). Besides that, the nutritional and functional benefits of cowpea have gained industrial importance for use as a potential ingredient for food formulations (Hamid et al., 2014). Currently, introduction of biofortified agricultural products containing high protein and mineral levels is considered an important component in breeding programs focused on eliminating human malnutrition (Santos and Boiteux, 2013).

The nutritional deficiency in food has affected many poor families, particularly in developing countries (Bouis and Welch, 2010). According to FAO (2014), it is estimated that approximately 805 million people were chronically undernourished and that they did not have access to daily protein and carbohydrate intake recommended by the World Health Organization (WHO). According to Nutti et al. (2009), biofortification is a strategy used in agriculture to improve the health of the poor populations and it is an additional tool to combat nutrient deficiency.

Cowpea presents great variability in the chemical composition of the grains and it enables the selection of

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genotypes with high nutritional contents. Singh (2007) evaluated fifty cowpea lines and noted that the potassium content ranged from 12.7 to 16.2 g kg^{-1} and calcium content from 0.54 to 1.33 g kg^{-1}. Santos and Boiteux (2013) studying eighty-seven cowpea lines found K content from 21 to 27 g kg^{-1} and Ca content from 0.41 to 6.26 g kg^{-1}. These minerals are of great importance for human health. Ca is essential for muscle contraction, nervous system function, blood vessel expansion and contraction, and secretion of hormones and enzymes (McDowell, 1992). Potassium is the third most abundant mineral in the human body and is essential to human life (COMA, 1991).

In the selection phase of cowpea lines, the same line may have different behavior according to the year and place of cultivation. According to Cruz et al. (2012), this difference is often influenced by various environmental conditions treated as genotype×environment interaction (G×E). An alternative to minimize the influence of this interaction is to evaluate genotypes in many environments and apply methods to classify and select them according to their adaptability and stability.

The methods of adaptability and stability analysis are very helpful to identify stable and predictably genotypes in the presence of G×E (Silva and Duarte, 2006). Several adaptability and stability methods used to estimate the contribution of each genotype to the interaction stand out in the literature. Methods based on linear regression (Eberhart and Russell, 1966), non-parametric analysis (Lin and Binns, 1988) and the multiplicative based on principal components of additive main effects and multiplicative interaction (AMMI) have been the most used in the selection of cowpea genotypes with high productivity (Barros et al., 2013; Mano, 2009; Nunes et al., 2014). Differently from studies on grain yield, adaptability and stability studies related to the mineral content in cowpea are still scarce in the literature.

The aim of the current study was to estimate the adaptability and stability parameters of grain yield and mineral production in cowpea seeds, in two experiments assessed in seven irrigated or rainfed environments, in order to enable the recommendation and registration of new cultivars for São Francisco Valley region.

MATERIALS AND METHODS

Plant material

Cowpea lines selected due to their high mineral content and grain yield were assessed. The lines resulted from the crossing between three introduced accessions of the International Institute for Tropical Agriculture (IITA) and three cultivars adapted to the Brazilian semiarid region, according to the procedures described by Santos and Boiteux (2013). The selected lines composed of two experiments, according to the plant size type: I) semi-climbing habit and indeterminate growth (SCH), with 23 treatments - 20 lines (C2R, C3S, C3M, C3Q, C3B, C6P, C1M, C3F, C3L, C2C, C1T, C3R, C4G, C6A, C2T, C3P, C6D, C1V, C4I and T16_2R) and three control cultivars (BRS Acauã, BRS Pujante and Canapu landrace), and II) upright cowpea plants with determinate growth (UDG), with 21 treatments - 18 lines (C1N, C1R, C3O, C2I, C1G, C1S, C2J, C1J, C1F, C2O, C2S, C2B, C2A, C2Q, C1O, C1I, C2M and Marrom) and three control cultivars (BRS Carijó, BRS Tapaihum and Canapu landrace).

The experiments were conducted in the Brazilian States of Bahia, Ceará, Pernambuco and Piauí. The study adopted a randomized block experimental design with three replications in three irrigated environments, in the second half of the year, and four rainfed environments, in the first half of the year. Each plot had 3.0×2.0 m dimension. The experimental plot of the SCH experiment was formed by two rows, with 1.0 m space between rows and 0.1 m between plants, and it resulted in the population density of 100,000 plants per hectare. On the other hand, the experimental plot of the UDG experiment was formed by four rows, with 0.5 m space between rows and 0.1 m between plants, and it led to the population density of 200,000 plants per hectare.

Mineral quantification

Approximately 10 g of seeds from 924 plants were ground in a MA 630/1 mill (Marconi, Brazil) in order to obtain fine flour from each sample. The samples were analyzed in duplicate, according to the standard procedures of the Association of Official Analytical Chemists (AOAC, 1995). Five milliliters of nitric acid and 1 ml perchloric acid were added to each 500 mg of cowpea sample for acid digestion, which was carried out in a block digester. One milliliter of extract was transferred to a 50 ml beaker, identified by the sample protocol number, and 49 ml lanthanum oxide was added. The quantification samples were subjected to reading in flame atomic absorption spectrophotometer (Varian). The results were expressed in g kg^{-1} for potassium and calcium of grain dry matter. All the analyses were carried out in the soil laboratory of Semi-Arid Embrapa.

Statistical analyses

The statistical analyses of the experimental designs were performed in the SAS software (SAS, 1989), according to the GLM procedure (SAS, 1989). The grain yield was corrected in the SAS (1989) software, through covariance method, using the average plant stand of the plots in each experiment, as it was described by Vencovsky and Barriga (1992). Scott and Knott's (1974) clustering was applied at 5% of significance. The adaptability and stability of genotypes were assessed through the methods developed by Eberhart and Russell (1966) and Lin and Binns (1988) in the Genes software (Cruz, 2006), as well as by the multiplicative method based on principal components (AMMI), using the SAS software (1989) as described by Duarte and Vencovsky (1999).

According to the method by Eberhart and Russell (1966), the regression coefficient is associated with the linear component, and it indicates genotype adaptability: genotypes with index $\beta i = 1$ has wide adaptability; deviations from the regression equal to zero ($\sigma^2_{di} = 0$) indicate good stability. According to the method by Lin and Binns (1988), the Pi parameter defines the genotype stability as the mean square of the distance between the mean of a genotype and the maximum mean response of all locations. Genotypes with lower Pi values correspond to those with better performance.

The AMMI methodology stands out because it best describes the G×E interaction through the disposal of additional noises found in traditional interaction estimates. It uses together the variance analysis of the main effects of genotypes and environments and the principal component analysis (PCA) of the interaction. It also identifies the most stable and adaptable genotypes and performs the agronomic zoning of the environments (Duarte and Vencovsky, 1999).

Table 1. Treatment mean squares (TMS), residual mean squares (RMS), means and coefficient of variation (CV) related to yield, and potassium and calcium contents in 20 lines and three control cultivars (SCH experiment – semi-climbing habit) and in 17 lines and four cowpea cultivars (UDG experiment – upright cowpea plants with determined growth) assessed in seven irrigated and rainfed environments.

Locality	Yield				Potassium				Calcium			
	TMS	RMS	Mean	CV	TMS	RMS	Mean	CV	TMS	RMS	Mean	CV
	SCH Experiment											
Acauã	87189**	42345	684	30.0	3.5**	1.4	15.1^b	7.8	0.2	0.11	1.3^a	25.9
Petrolina A	306194**	57712	1322	18.1	7.9**	3.1	14.8^b	11.9	0.0*	0.02	0.8^c	17.2
Petrolina B	90050**	32140	727	24.6	3.2	3.7	14.9^b	12.9	0.1	0.06	1.1^b	22.1
Dormentes	355248**	60272	689	35.6	19.6**	5.4	14.7^b	15.8	0.1**	0.04	0.9^c	21.3
Limoeiro	278796**	114883	2192	15.4	15.0**	3.1	14.9^b	11.8	0.4*	0.15	1.1^b	33.6
Juazeiro	202060*	97575	729	42.8	5.5*	2.7	14.9^b	11.0	0.7**	0.07	1.3^a	20.7
Petrolândia	259048**	81818	897	31.8	5.9**	1.5	15.7^a	7.9	0.1**	0.03	1.2^a	14.9
	UDG Experiment											
Acauã	86308	78306	1087	25.7	1.6*	0.7	14.5^b	6.0	0.03	0.02	0.9^b	18.8
Petrolina A	121491*	62900	1697	14.7	5.3*	2.3	16.2^a	9.4	0.04*	0.02	0.8^b	16.8
Petrolina B	52592*	28273	734	22.9	3.4	3.4	14.1^c	13.1	2.20*	0.01	0.8^b	16.1
Dormentes	653413**	75526	887	30.9	2.5	1.8	14.0^c	9.6	0.05	0.03	0.9^b	21.5
Limoeiro	398371**	102030	2057	15.5	11.4**	4.3	14.8^b	14.0	0.24	0.04	0.8^b	24.5
Juazeiro	116106	83516	806	35.8	3.7*	1.9	14.6^b	9.5	0.75**	0.08	1.1^b	26.3
Petrolândia	98114	71214	692	38.5	5.2	3.9	16.4^a	12.1	0.16**	0.05	1.2^a	19.2

Values followed by the same letter in the column belong to the same group, according to the Scott and Knott test (1974) at 5% probability; **, * Significant at 1 and 5%, respectively, according to the F test.

RESULTS AND DISCUSSION

Cowpea lines of semi-climbing habit (SCH)

Statistically significant differences were observed in the mean squares of the treatments, for the grain yield and the potassium and calcium contents in most environments, except for the potassium and calcium contents in the Bebedouro environment, and for calcium content in the Acauã environment. The experiments in Acauã, Dormentes, Limoeiro and Petrolândia were conducted on farming properties. Such fact did not compromise the assessments as the variation coefficients were below 43% (Table 1) and allowed making the assessments in environments that represent the cowpea cultivation.

The Limoeiro environment showed the highest mean grain yield (Table 1), indicating the yield potential of the assessed lines. As it was observed in Limoeiro, some of them may exceed 3,000 kg ha^{-1} grain yield under high technology conditions. As for the minerals, the Petrolândia environment showed the highest mean potassium and calcium content.

The relations between the largest and smallest mean squared residuals observed in experiment were below or close to seven for all variables, and it indicated homogeneity in the residual variances, which is a required condition for the joint analysis of experiment (Cruz and Regazzi, 1997). The grain yield means in the three irrigated environments was 84% higher than the means found in the four rainfed environments (Table 1). This result corroborated those reported by Santos et al. (2008). However, the means of the assessed minerals showed similar values, regardless of the adopted handling, whether with or without irrigation.

The BRS Acauã cultivar showed the highest grain yield (Table 2). This cultivar was previously assessed in the same locations the lines of the current research were done (except for Limoeiro) and was selected exclusively for grain yield and earliness (Santos et al., 2008). The C3R and C3B lines presented grain yield close to that of the BRS Acauã control cultivar, as well as wide adaptability and good stability parameters through both the Eberhart and Russell (1966) and the Lin and Binns (1988) methods (Table 2).

The C2C, C3P, C6D, C1V, C4I e T16_2R lines showed the highest mean K contents. The Eberhart and Russell (1966) method highlighted the C6D and C1V lines with wide adaptability and stability. The Lin and Binns (1988) method highlighted the C41, C6D and C1V lines with the lowest Pi values. C1T, C6A, C2T and C4I lines showed the highest mean Ca contents and all showed unpredictable stability and only C1T presented broad adaptability by the Eberhart and Russell (1966) method. The Lin and Binns (1988) method were very different from Eberhart and Russell (1966) results, highlighting C4I

Table 2. Yield, potassium and calcium stability and adaptability in 20 lines and three cowpea control cultivars -semi-climbing habit (SCH) - assessed in seven irrigated and rainfed environments using the methods by Eberhart and Russell (1966) and Lin and Binns (1988).

Genotype	Yield				Potassium				Calcium			
	E&R			L&B	E&R			L&B	E&R			L&B
	βo	βi	σdii	Pi	βo	βi	σdii	Pi	βo	βi	σdii	Pi
C2R	886	1.3*	37767*	344349 (23)	13.4^{c}	-2.1*	0.90	18.4 (23)	0.9^{c}	0.6	-0.01	0.7 (23)
C3S	904	1.0	16770	305069 (19)	13.9^{c}	-2.5**	5.35**	17.0 (22)	1.2^{b}	0.4	0.14**	0.5 (13)
C3M	1150	0.9	-10959	152055 (5)	14.7^{b}	0.0	0.32	12.1 (16)	1.0^{c}	0.9	0.01	0.5 (15)
C3Q	1021	1.2	40905*	219184 (8)	13.5^{c}	1.4	-0.07	16.0 (21)	1.2^{b}	0.5	-0.01	0.5 (12)
C3B	1214	0.9	21638	144688 (4)	15.2^{b}	3.8*	2.22**	13.4 (19)	1.1^{b}	0.8	-0.00	0.5 (14)
C6P	101 l	0.9	-2161	224767 (9)	14.6^{b}	2.6	2.90**	11.7(15)	1.1^{b}	0.4	-0.00	0.6 (20)
C1M	959	1.4**	58313**	301820 (18)	15.3^{b}	2.0	0.93	8.3 (6)	1.2^{b}	1.5	0.00	0.4 (4)
C3F	883	0.8	1281	315024 (21)	15.1^{b}	1.9	0.24	10.1 (10)	1.2^{b}	0.8	0.01	0.5 (8)
C3L	950	1.0	-22570	249086 (13)	15.0^{b}	2.4	-0.12	10.8 (12)	1.1^{b}	0.5	-0.01	0.5 (16)
C2C	968	1.3*	29413	287946 (16)	16.0^{a}	1.6	0.21	6.4 (3)	1.1^{b}	1.0	-0.01	0.5 (9)
C1T	901	1.1	50964*	331871 (22)	14.4^{b}	2.1	0.69	14.0 (20)	1.3^{a}	0.9	0.06**	0.4 (5)
C3R	1228	0.8	-6056	125105 (2)	14.8^{b}	2.9	1.31*	11.2 (13)	1.1^{b}	1.1	0.01	0.5 (11)
C4G	1023	0.7*	27058	251814 (14)	14.6^{b}	2.4	2.21**	12.6 (18)	1.0^{c}	0.8	0.01	0.7 (21)
C6A	883	0.8	30778*	310255 (13)	14.9^{b}	1.8	0.12	9.0 (9)	1.4^{a}	1.9**	0.09**	0.2 (3)
C2T	934	0.9	6603	293622 (17)	15.2^{b}	1.4	0.07	8.6 (7)	1.5^{a}	1.5	0.11**	0.2 (2)
C3P	1055	0.7*	27301	239393 (11)	16.0^{a}	-0.7	-0.75	6.7 (4)	1.1^{b}	1.3	0.02	0.5 (7)
C6D	990	0.9	43453*	256330 (15)	15.9^{a}	1.0	-0.51	6.0 (2)	1.2^{b}	1.0	0.04*	0.5 (17)
C1V	1019	1.2	64770**	243650 (12)	15.8^{a}	-0.3	-0.67	7.0 (5)	1.1^{b}	1.7*	0.01	0.4 (6)
C4I	1102	1.0	-4448	171894 (6)	17.1^{a}	-4.3**	11.77**	1.1 (1)	1.7^{a}	3.5**	0.20**	0.1 (1)
T16_2R	1171	1.0	69547**	131728 (3)	15.8^{a}	1.2	1.94*	10.2 (11)	1.0^{c}	-0.8**	0.06**	0.6 (20)
Acauã	1341	1.0	112508**	63731 (1)	15.5^{b}	1.7	1.24	11.4 (14)	1.3^{a}	0.6	0.03	0.5 (10)
Pujante	1050	0.8	185586**	226464 (11)	15.4^{b}	1.0	-0.81	8.8 (8)	1.1^{b}	0.6	-0.01	0.5 (18)
Canapu	1153	0.5**	175495**	184265 (7)	14.8^{b}	1.7	1.17	12.4 (17)	0.9^{c}	0.5	-0.00	0.7 (22)
Mean	1034				15.08				1.15			

Values followed by the same letter in the column belong to the same group, according to the Scott and Knott test (1974) at 5% probability; **, * significant at 1 and 5%, respectively, according to the F-test.

line with the lowest Pi values, with better performance for calcium content (Table 2).

The genotype×environment interaction was decomposed in six principal components of the interaction (PCI) using the multivariate AMMI method. However, only the first axis (PCI1) showed significant residuals in the F_r test (p<0.01). Thus, the graphic interpretation of adaptability and stability was performed through the PCI1 alone, via AMMI1 biplot. Similar results were found by Barros et al. (2013) who assessed cowpea yield.

The first principal component of the interaction explained 49.78, 36.12 and 45.50% of grain yield and of K and Ca contents respectively in the SCH experiment (Table 4). BRS Acauã was the most stable environment and Limoeiro was the most productive for grain, although with high instability. The C3M and C3R were the most stable genotypes for grain yield (Figure 1). Petrolândia showed the lowest mean K content and was the most stable environment. The C3B, C4I and C3R genotype showed high stability and mean K content higher than that of the assessed cultivars. The Acauã environment was the most favorable to Ca content and the C4I, C2T and C6A, which showed the highest means, were also the most stable genotypes (Figure 1).

Cowpea lines of upright with determined growth (UDG)

Statistical significant differences were observed in the mean squares of the treatments for the grain yield, and the potassium and calcium contents. Three environments for each variable showed no statistical differences in mean squares of the treatments (Table 1). The experiments in Acauã, Dormentes, Limoeiro and Petrolândia were conducted in farming properties. Such fact did not compromise the assessments as the variation coefficients were below 39% (Table 1), which allowed making the assessments in environments that represented the species cultivation. The Limoeiro environment showed the highest mean grain yield (Table1).

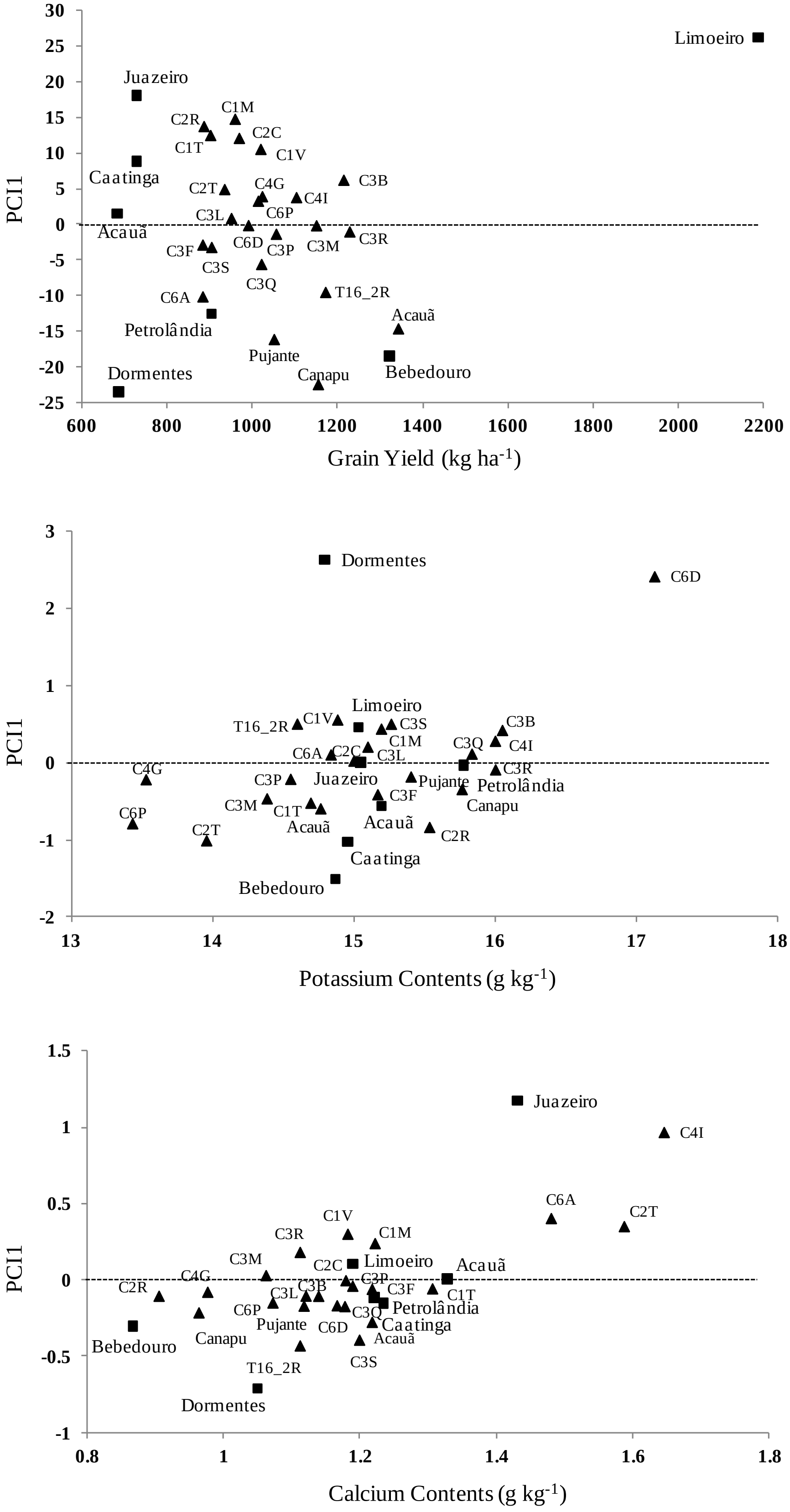


Figure 1. AMMI biplot for grain yield, potassium and calcium contents in 20 lines and three (▲) cowpea cultivars (*Vigna unguiculata*) with semi-climbing habit assessed in seven (■) irrigated and rainfed environments.

Table 3. Yield, potassium and calcium stability and adaptability in 17 lines and four cowpea cultivars – upright cowpea plants with determined growth (UDG) - assessed in seven irrigated and rainfed environments using the methods by Eberhart and Russell (1966) and Lin and Binns (1988).

Genotype	Yield				Potassium				Calcium			
	βo	E&R		L&B	βo	E&R		L&B	βo	E&R		L&B
		βi	σdii	Pi		βi	σdii	Pi		βi	σdii	Pi
C1N	1170	1.2	-55352	269488 $^{(9)}$	14.7^b	0.9	-0.55	4.7 $^{(11)}$	0.9^b	0.4	0.00	0.4 $^{(14)}$
C1R	1044	0.9	-3561	372225 $^{(18)}$	14.6^b	0.6	-0.08	5.4 $^{(17)}$	1.0^b	1.2	0.02*	0.2 $^{(4)}$
C3O	1203	0.4*	-5183	235209 $^{(7)}$	16.6^a	1.7	0.33	0.7 $^{(1)}$	1.1^a	2.4**	0.09**	0.1 $^{(2)}$
C2I	953	0.9	-53143	404583 $^{(19)}$	14.4^b	0.9	0.42	5.7 $^{(19)}$	1.3^a	2.7**	0.33**	0.1 $^{(1)}$
C1G	1129	1.0	-42325	304343 $^{(11)}$	14.8^b	1.1	1.54*	5.0 $^{(15)}$	0.9^b	0.8	-0.01	0.3 $^{(11)}$
C1S	1107	0.9	-28073	344578 $^{(14)}$	14.2^b	0.6	0.21	6.6 $^{(20)}$	0.8^c	0.7	-0.01	0.4 $^{(20)}$
C2J	1129	1.2	43212	202587 $^{(4)}$	14.3^b	0.7	-0.31	5.5 $^{(18)}$	0.9^b	0.9	-0.00	0.3 $^{(12)}$
C1J	1121	1.0	-38895	249457 $^{(8)}$	14.7^b	0.9	-0.27	4.7 $^{(12)}$	1.0^b	0.7	0.01	0.2 $^{(5)}$
C1F	1111	1.1	-45872	322260 $^{(12)}$	14.8^b	1.6	0.79	5.1 $^{(16)}$	0.8^c	0.4	0.01	0.4 $^{(19)}$
C2O	1243	1.1	-46357	232238 $^{(6)}$	14.5^b	1.2	-0.57	4.7 $^{(10)}$	1.1^a	1.2	0.01	0.2 $^{(3)}$
C2S	1196	0.9	-45261	276386 $^{(10)}$	15.4^a	1.1	2.48**	3.7 $^{(8)}$	1.0^b	1.5	0.00	0.3 $^{(7)}$
C2B	1009	0.6	71955	496665 $^{(21)}$	14.0^b	1.1	1.80*	8.1 $^{(21)}$	1.0^b	-0.4**	0.11**	0.3 $^{(8)}$
C2A	1111	1.2	-25378	329596 $^{(13)}$	15.4^a	1.4	0.03	2.7 $^{(4)}$	1.0^b	2.3**	0.09**	0.4 $^{(13)}$
C2Q	1032	1.0	-46745	364971 $^{(16)}$	15.6^a	1.5	0.42	2.4 $^{(2)}$	0.9^b	1.2	0.02*	0.4 $^{(15)}$
C1O	1022	0.8	-57381	367170 $^{(17)}$	15.2^a	0.4	0.04	3.8 $^{(9)}$	0.9^b	0.6	0.02*	0.4 $^{(18)}$
C1I	1078	0.8	-26876	353772 $^{(15)}$	15.1^a	1.1	1.32*	3.6 $^{(7)}$	0.8^c	1.0	0.02*	0.3 $^{(9)}$
C2M	893	0.9	-35771	479205 $^{(20)}$	15.4^a	1.2	-0.14	2.7 $^{(3)}$	1.0^b	-0.0**	0.09**	0.3 $^{(6)}$
Marrom	1307	1.4	6935	185480 $^{(3)}$	15.1^a	0.5	-0.27	3.6 $^{(6)}$	0.8^c	0.4	0.00	0.5 $^{(21)}$
Carijó	1344	0.9	-893	135731 $^{(2)}$	14.5^b	0.8	-0.18	4.9 $^{(14)}$	0.8^c	0.8	-0.01	0.4 $^{(16)}$
Tapaihum	1323	1.4	-15169	123155 $^{(1)}$	15.2^a	0.1*	3.17**	4.8 $^{(13)}$	0.9^b	0.7	0.00	0.4 $^{(17)}$
Canapu	1211	0.5*	493790	228627 $^{(5)}$	15.4^a	1.1	0.92**	3.3 $^{(5)}$	0.9^b	1.2	0.02*	0.3 $^{(10)}$
Mean	1130				14.96				0.95			

Values followed by the same letter in the column belong to the same group, according to the Scott and Knott test (1974) at 5% probability; **, * Significant at 1 and 5, respectively, according to the F-test.

As in the previous experiment, relations between larger and smaller squares of the residues observed were below or close to seven in all variables. The grain yield means in the three irrigated environments was 45% higher than the means found in the four rainfed environments (Table 1). This result corroborated those reported by Santos et al. (2008). However, the means of the assessed minerals showed similar values, regardless of the adopted handling, whether with or without irrigation.

The BRS Carijo and BRS Tapaihum cultivars showed the highest grain yields (Table 3). This cultivars were previously assessed in the same locations the lines of the current research were (except for Limoeiro) and were selected exclusively for grain yield and earliness (Santos et al., 2008). The C2O line presented grain yield close to that of the BRS Carijo e BRS Tapaihum control cultivar, as well as wide adaptability and good stability parameters, through both the Eberhart and Russell (1966) and the Lin and Binns (1988) methods (Table 3).

The C3O showed the highest K content, with wide adaptability by Eberhart and Russell method (1966). Lin and Binns (1988) highlighted the C3O line with the lowest Pi value for K (Table 3). For the Ca content, the C20 showed average greater than experiment mean and wide adaptability and good stability by Eberhart and Russell (1966). By the Lin and Binns (1988) method C3 and C2I presented the lowest Pi values for Ca content (Table 3).

The genotype×environment interaction was decomposed in six principal components of the interaction (PCI) using the multivariate AMMI method. However, only the first axis (PCI1) showed significant residuals in the F_r test (p <0.01). Thus, the graphic interpretation of adaptability and stability was performed through the PCI1 alone, via AMMI1 biplot.

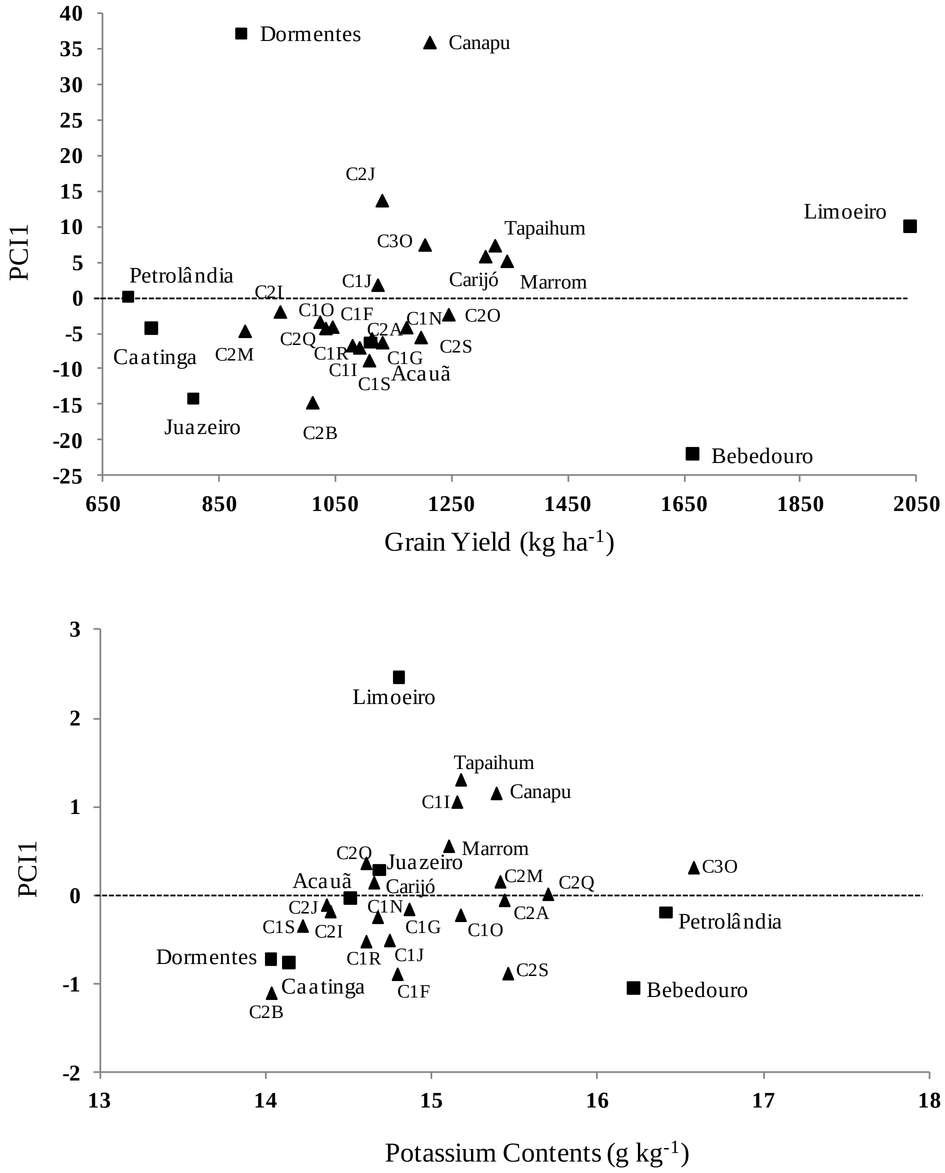
The first principal component of the interaction explained 54.46% grain yield, as well as 39.80% K and 46.96% Ca contents (Table 4). Petrolândia was the most stable environment and showed the lowest mean yield. The C2O stood out among the lines in the AMMI method due to high stability and mean yield close to that of the cultivars. The C3O line showed high K content stability. Bebedouro and Petrolândia were the most favorable environments. The C2I, C2A and C3O lines showed the highest mean Ca contents and good stability (Figure 2).

The methods by Eberhart and Russell (1966), Lin and

Table 4. Joint analysis of variance related to grain yield, and potassium and calcium levels in 20 lines and three cultivars (SCH Experiment –semi-climbing habit) and in 17 lines and four cowpea cultivars (UDG experiment – upright cowpea plants with determined growth) assessed in seven irrigated and rainfed environments.

Source of variation	Mean square							
	SCH Experiment				SCH Experiment			
	df	Yield	Potassium	Calcium	df	Yield	Potassium	Calcium
Genotype (G)	22	328825*	15.14**	0.64**	20	366806*	7.11**	0.29**
Environment (A)	6	20986713*	7.47*	2.07**	6	17240794*	58.08**	1.26**
G x A	132	209439**	7.54**	0.19**	120	200801**	4.38**	0.17**
PCI1	27	517149**	12.92*	0.45**	25	599283**	8.37*	0.61**
$\text{Residual}_{\text{AMMI1}}$	105	134136	5.87	0.14	95	131874	3.33	0.18
PCI1%		49.78	36.12	45.50		54.46	39.80	46.96
CV(%)		26.2	11.59	23.44		27.6	11.08	22.00

**,*, Significant at 1 and 5%, respectively, according to the F test.



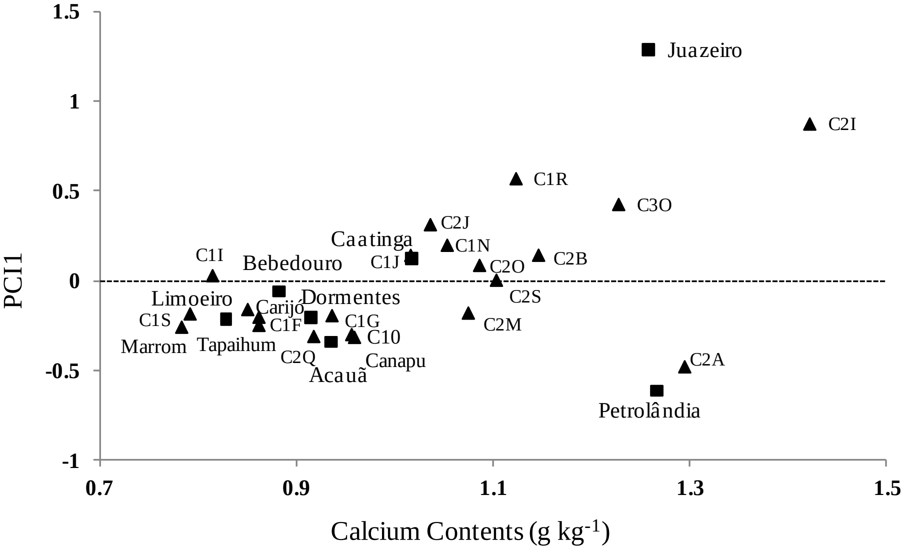


Figure 2. AMMI biplot for grain yield, potassium and calcium contents in 17 lines and four (▲) cowpea cultivars (*Vigna unguiculata*) of upright and determined growth assessed in seven (■) irrigated and rainfed environments.

Binns (1988), and the AMMI method showed similar results in the selection of superior materials, except for Ca content. Polizel et al. (2012) used seven methods to test 16 soybean genotypes in different environments. They found that the studied methods showed consistent and complementary results. Nunes et al. (2014), using parametric and non-parametric methods in 20 genotypes of cowpea found that some methods should not be used simultaneously, and those others should be complementary.

Cowpea is broadly grown in semi-arid regions due to its tolerance to water stress and substantial grain yield in comparison to other legumes such as common beans, lentils and chickpeas. Accordingly, the selection of superior cultivars through the combination of high yield and seed mineral content, and good adaptability and stability under different environmental conditions will have a huge positive impact on cowpea production-market chains, mainly in semi-arid regions.

Selection approaches have been being applied in many crop plants aiming to biofortify food crops with essential mineral elements most commonly lacking in human diets (White and Broadly, 2009). However, current efforts to select and release cowpea cultivars with high mineral content associated with good agronomic performance based on adaptability and stability parameters are still very restricted, even for important commodities, such as soybean. To our knowledge, the present study is the first one conducted to estimate adaptability and stability parameters for K and Ca contents in cowpea lines.

The C4I and C3O lines showed grain yields equal to or greater than the means of the experiments, high potassium and calcium means, wide stability and good predictability in the series of assessed environments, by the Eberhart and Russell (1966), Lin and Binns (1988) and the AMMI methods. The BRS Acauã, BRS Tapaihum and BRS Carijó, with the highest grain yield, should be used for crossing with C4I, C3O, C2I and C2T for selection of lines with higher grain yield, potassium and calcium contents, simultaneously.

Conclusion

The C4I lines cowpea, with semi-climbing habit, and C3O lines cowpea, with upright and determinate growth, identified in representative environments in the Brazilian semiarid region, both irrigated and rainfed conditions, have great potential to be recommended as new cultivars for the region, as grain yields were close to commercial cultivars, as well as potassium and calcium contents were greater than the average of the cowpea cultivar experiments.

Conflict of Interests

The authors have not declared any conflict of interests.

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Abbreviations

DSUG, Genotypes with determinate and semi upright growth; **ISCG,** genotypes with indeterminate and semi-climbing growth; **G×E,** genotype×environment interaction.

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Full Length Research Paper

Effect of temperature on the development and survival of immature stages of the peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae)

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The Peach fruit fly (PFF), *Bactrocera zonata* (Saunders) is known as a key pest of fruits in Egypt. The effect of temperature on the development and survival of the Peach fruit fly (PFF), *Bactrocera zonata* (Saunders) (Diptera: Tephritidae) from egg to adult was studied to understand the geographical pattern of occurrence of these fruit fly. Studding carried out in laboratory under four different constant temperatures: 15, 20, 25 and 30°C. Results showed that time required for development were decreased as the temperature increased from 15 to 30°C. Differences between the four tested temperatures in incubation periods were significant. Developmental time of the eggs significantly decreased over the range of 15 to 25°C but not between 25 and 30°C, Similarly, developmental time for the larva and pupa significantly decreased with increasing temperature from 15 to 30°C. The lower threshold of development (t_o) for the larval and pupae stages was 13 and 10.9°C respectively. The highest pupation rate of *B. zonata* was 87±.48 percentage at 25°C, which was considered the optimum and favorable temperature. The results will be good tool for predicting the fly's population dynamics, which would help develop the fly management strategies.

Key words: Bactrocera zonata, Egypt, fruit fly, immature stages, management strategies.

INTRODUCTION

The Peach fruit fly (PFF), *Bactrocera zonata* (Saunders) is known as a most serious pest of tropical and subtropical fruits, and considered as important fruit fly pest (Fletcher 1987). In 1924, *B. zonata* was first declared as present in Egypt based on detection in an imported consignment in Port Said, 1912 (Efflatoun, 1924). It originates in South and South-East Asia (Agarwal et al., 1999).

B. zonata is a highly polyphagous specie that attacks more than 50 host plants including guava, mango, peach, apricots, figs, date and citrus (White and Elson-Harris, 1992). Now, it is well established in most Egypt´s governorates even in the dry desert regions, Assiut (Darwish et al., 2012) and Sohag (Gaperallah et al.,

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2013). Temperature is considering the main environmental factor that affect the survival and developmental rate through each immature stage of life history, also, hence the rate of survival from egg to adult emergence in other fruit flies such as *Bactrocera tryoni* (Meats 1984). Studying this parameter is particularly important for *B. zonata* to obtain a useful forecasting and prediction of this insect population. Therefore, the aim of this study was focused on the following aspects:

1. Studying some biological aspects of PFF different immature stages under constant temperatures (15, 20, 25 and 30 ± 1°C) as an aim to limit its required heat units to develop.
2. Relationship between each constant temperature and rate of development, which give a quantitative expression for this relationship, using thermal accumulation.

MATERIALS AND METHODS

The experiments were conducted in incubators in the laboratory of zoology Department, Faculty of science, South Valley University, Egypt. Infested fallen fruits of guava used in this experiment were collected from the farm of the Faculty of Agriculture, South Valley University. These infested fruits where then transferred to laboratory and were kept under 25±1ºC. to get on a Full-grown larvae and pupae of *B. zonata* that needed in laboratory experiments. Pupae were collected daily from the sand and then transferred to Petri dishes until the emergence of adult flies. The Petri dishes were kept under average laboratory conditions 25±1º C, 50% RH. Adults of *B. zonata* were reared in a cage (60 x 40 x 40 cm) with wooden frames and covered from each side with metal screen (Figure 2). Flies in rearing cage fed on sugar and fortified protein hydrolysate at ratio of 3:1, respectively. In addition, water was supplied in a plastic bottle. A plastic ball that had many fine pores (as oviposition receptacles) (Figure 2) was placed inside the cage. These plastic balls filled with 3 cm of water to receive and prevent drying of the eggs. In addition, at the top of this plastic ball, small plastic vials containing cotton wicks saturated with guava juice was put to enhance egg laying within these false fruits. Larvae were reared on an artificial diet (Shehata et al., 2006) (Table 1).

Table 1. Artificial diet for *B. zonata* larvae rearing.

Parameter	Qty
Wheat bran	330 gm
Molasses or sugar	84.50 gm
Brewer’s yeast	84.50 gm
Sodium benzoate	3.00 gm
Citric acid	1 ml
Water	500 ml

These ingredients were carefully mixed in large plastic box. Then eggs were transferred and scattered on the surface of the diet, which placed in plastic trays of 25x15x10 cm that tightly covered with muslin clothes using rubber bands. After that, these trays placed in a cartoon cage with sand at the bottom to allow the jumping larvae to pupate (Figure 2). All pupae were separated by sieving from sand (Shehata et al., 2006). Mature larvae were removed from rearing cups and entered another plastic cups that contained a layer of 0.5 cm of sand on the bottom for pupation. B. zonata was reared for four successive generations before starting the experiments (Qureshi et al., 1974).

Effect of constant temperatures on the different stages of the Peach Fruit Fly

This study was carried out to evaluate the effect of different temperatures on the peach fruit fly development stages. The study was conducted with a laboratory culture reared on artificial diet. The time required for development for each stage was determined at the four following constant temperatures: 15, 20, 25, and 30°C (±1°C).

The incubation experiments were conducted in the laboratory of Zoology Department, Faculty of Science- South Valley University.

Eggs treatment

100 eggs for each temperature dirge were divided to 4 replicates (4treatment ×4 replicats×25units) every 25 eggs were placed in clean Petri dishes. Diet guava slides was used for natural conditions and put in Petri dishes .The surface of the diet guava slides was covered with a layer of toilet tissue paper. 25 eggs were counted under a binocular microscope. These were carefully transferred on the tissue paper. The Petri dishes were covered and placed in incubator) set to four constant temperatures (15, 20, 25, and 30°C [± 1°C])). After 24 h, each Petri dish examined for egg hatching by observing the eggs intervals under a stereo microscope. Incubation period, number of hatching eggs, unhatching eggs and developmental rate were recorded.

Larvae treatment

For each treatment 100 larvae were used, each treatment repeated four times every replicate content 25 larvae(4×4×25). Each 25 larvae were put in Petri dish, Petri dishes maintained at the different experimental temperatures (15°C, 20°C, 25°C and 30°C). When the larvae reached third instar, the Petri dishes were put inside a larger plastic container bottomed with a layer of sand for pupation, where larvae jumped (by curling into a 'U'-shape and then rapidly straightening) out of the diet from the Petri dishes onto sand for pupation. The plastic containers were checked daily from the fifth day for pupae; pupae were separated from the sawdust by sifting. The mortality, duration, and developmental rate were recorded.

Pupae treatment

100 pupae/temperature degree (4 T×4 R×25 Pupa), pupae kept in four cups provided with sand. 25 pupae /cup and cover with plastic net and maintained the same four constant temperatures until emergence. All developmental tests were replicated five times for each constant temperature. The mortality, emergency flies, duration, and developmental rate were recorded.

Data analysis

Data were analyzed by the analysis of variance (ANOVA) and Duncan's multiple range. Day-degrees "DD's" were calculated using linear regression method. Development rate (100/developmental time) was plotted against temperature. The lower development threshold to (the temperature at which the development rate is

Table 2. Incubation periods, hatching percentages, developmental rate and thermal units for *B.zonata* at different constant temperatures.

Temperature °C.	Incubation period				m.r.v (days)	m.c.v%	Hatchability	
	Duration (days)		Rate of development	Thermal Units (DD)				
	Range	Mean ± S.E.					Range	Mean ± S.E.
15	8-11	9.50±0.645	10.53	48.5	1.5	33.33	2-4	20.25±0.85
20	5-6	5.75±0.250	17.39	46	0.5	11.11	7-11	45.50±1.85
25	1-4	3.00±0.408	33.33	39	1	11.76	18-23	83.00±2.20
30	1-2	2.00±0.408	50.00	36	1	10.27	16-20	78.00±3.19
Average				37.375				
LSD o.o5		1.3887						

Thermal units (DD) for egg stage based on a developmental threshold (to) 12 °C Means within a column followed by the same letter are not significantly different at 5% probability.

zero) was then determined by the regression line back to the x-axis. The day-degrees required for development of each stage were calculated by Fletcher (1989) equation:

K = y(x-**t)**

Whereas:
1. K represents day-degrees
2. y represents stage duration (in days)
3. x represents temperature (°Q during development)
4. **t** represents the lower development threshold (°C).

RESULTS AND DISCUSSION

Hatchability and incubation period

As shown in Table 2, there are reverse relationship between the effect of temperature and incubation period, the embryonic development (incubation period) of B.zonata eggs significantly decreased over the range of 15 to 25°C but not between 25 and 30°C (F = 55.462, df = 3, 12, P < 0.05). However, the developmental times for egg stage varied from 1 to 11 days. Differences between the incubation periods at the three constant temperatures were highly significant. The shortest mean incubation period (2.00±.408Days) was recorded at 30°C whereas the longest one (9.50±.645days) took place at 15°C.

The mean hatching percentage of eggs varied from a minimum of 20.25±0.85 % (at 15°C) to a maximum of 83.00±2.20% (at 25°C). It is worth noticing that the percentages of hatching increased with the increase in the number of deposited eggs (Table 2). On the other hand, the lower threshold of egg development was 12°C as shown in Table 2, the thermal units required for the development of this stage were 28.5, 46, 39 and 36 day-degrees at 15, 20, 25 and 30 °C respectively. The fourth observed values of egg's rate of development at the constant temperature range (15-30 °C), gave a remarkable good fit to the calculated temperature-velocity line having the formula Y = 2.69x - 32.65 (Figure 1). A linear regression model established for Egg stage, a strong and positive relationship observed between temperature and development rate (R^2) = 0.9704. A lower developmental threshold for the egg was 12°C$^{.}$ For the hatchability, results showed that the highest percentage of hatchability (83.00±2.20%) was recorded at 25 °C. Statistically, significant differences-($R^2 = 0.9704$)were recorded at 15 °C and values of 20, 25and 30 °C, whereas there are no significant differences between the values at 25 and 30 °C.

Larval stages

The average larval durations of *B. zonata* varied from 27.25±.629 days at 15°C to 4.50±.289 days at 30°C (Table 3). Significant differences (F = 492, df = 3, 12, P < 0.05) were observed between the mean larval durations at the different constant Temperatures, it gradually decreased with the increase in the tested temperatures. The developmental rates of *B. zonata* larvae gradually increased with the increase in the tested temperatures, they were 3.67, 7.69, 12.50 and 22.22 at 15, 20, 25 and 30°C, respectively, and it increased with the increase in the tested temperatures. from The four observed values of larval developmental rate at the constant temperature range (15 to 30°C), gave a remarkable good fit to the calculated temperature-velocity line having the formula Y= 1.2093x - 15.688 (Figure 2). The calculated lower threshold of development (t_0) for the larval stage was 13°C as indicated in previous figure and the average of the thermal units required for the development of this stage was 79.5 DD's as determined by the thermal summation equation K= y (x-13). The highest pupation rate of *B. zonata* larvae was 87±.48percentage at 25° C, which was considered the optimum and favorable temperature. Although, mortalities of larvae decreased with the increase of temperature till 25°C then its increase followed

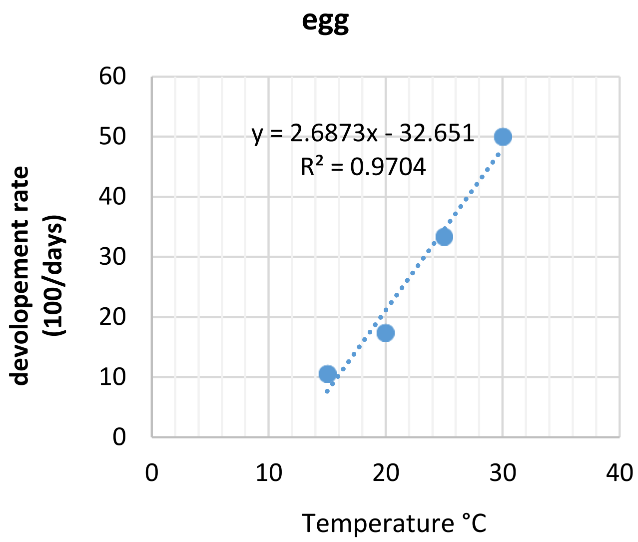

Figure 1. Linear regression of the relationship between the developmental rate of *B. zonata* eggs and different constant temperatures.

Table 3. Developmental time, survival percentages, developmental rate and thermal units for *B. zonata* larval stage at different constant temperatures.

Temperature °C	Larval stage					
	Duration (days)		Rate of development	Thermal Units (DD)	Pupation %	
	Range	Mean±S.E.			Range	Mean±S.E.
15	26-29	27.25±0.629	3.67	54.5	12-14	51±0.48
20	12-14	13.00±0.408	7.69	91	17-19	73±0.48
25	7-9	8.00±0.408	12.50	96	21-23	87±0.48
30	4-5	4.50±0.289	22.22	76.5	17-20	75±0.63
Average				79.5		
LSD o.o5		1.38				

Thermal units (DD) for larval stage based on a developmental threshold (to) 13 °C. Means within a column followed by the same letter are not significantly different at 5% probability.

by increasing temperatures (figure 2).

Pupal stages

As shown in Table 4, the developmental trend for pupa was similar to that which was observed in the egg and larvae stages. The developmental time for *B. zonata* pupa decreased from 36± 1.08d at 15°C to 8± .408d at 30°C. The developmental time decreased with increase in temperature. Developmental times measured at all other temperature tested were significant (Table 4). The developmental rates of *B. zonata* pupa gradually increased with an increase in the temperatures, it was 2.78, 6.25, 9.30 and 12.50 at 15, 20, 25 and 30°C, respectively. The lower threshold of development (t_o) for the pupal stage was 10, 9°C as shown in Figure 3, and the thermal units required for the development of pupa stage was 147.6, 145.6, 151.575 and 152.8 DD's at 15, 0, 25 and 30°C respectively, with an average of 149, 3938 DD's as estimated by the thermal summation equation K= y (x-10.9).

From the previous, the results showed that the time required for development was decreased as the temperature increased from 15 to 30°C. Differences between the four tested temperatures in incubation periods were significant. Individuals reared at 30°C completed their life cycles in significantly shorter period; 25°C was the most preferable temperature for the pest development. The threshold temperatures were 12°C for egg, 13°C for larvae, 10.9°C for pupae. The average thermal requirements needed for completing the development were 37.38, 79.5, 37.38, day-

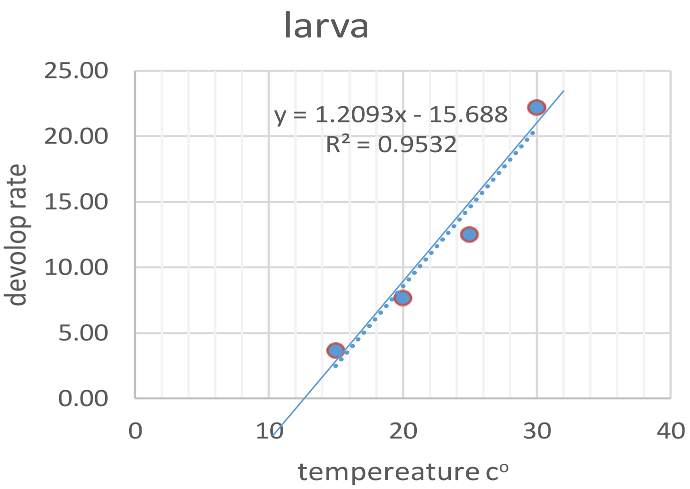

Figure 2. Linear regression of the relationship between the developmental rate of *B. zonata* larvae and different constant temperatures

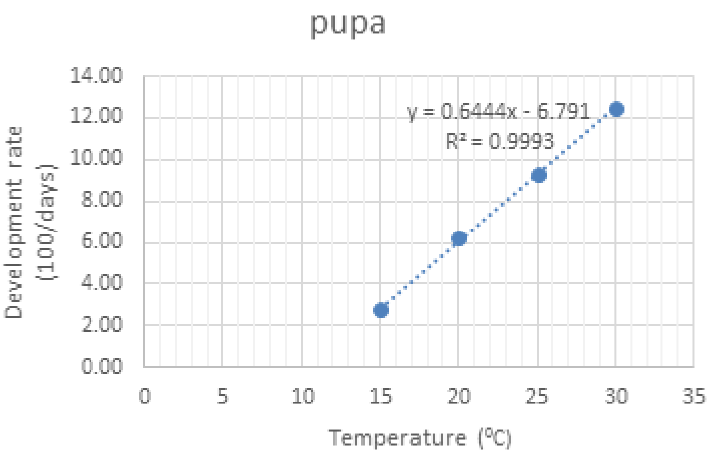

Figure 3. Linear regression of the relationship between the developmental rate of *B. zonata* pupa and different constant temperatures.

Table 4. Developmental time, survival percentages, developmental rate and thermal units for *B. zonata* pupal stage at different constant temperatures.

Temperature °C	Pupal stage					
	Duration (days)		Rate of development	Thermal Units (DD)	Emergence %	
	Range	Mean±S.E.			Range	Mean±S.E.
15	34-39	36±1.08012	2.78	147.6	8-13	42±1.19
20	15-17	16±0.40825	6.25	145.6	15-19	68±0.91
25	10-12	11±0.47871	9.30	151.575	19-22	83±1.03
30	7-9	8±0.40825	12.50	152.8	17-19	72±0.40
Average				149.3938		
LSD o.o5		2.026				

Thermal units (DD) for pupal stage based on a developmental threshold (to) 10.9 °C. Means within a column followed by the same letter are not significantly different at 5% probability.

degrees for egg, larvae, and pupae respectively.

DISCUSSION

Temperature is one of the most important factors affecting the developmental rate through the various life stages of fruit fly (Fletcher, 1987). Linear approximation is one of the commonly used models for describing the relationship between temperature and developmental rate of insects (Wagner et al., 1984).

Data obtained indicated that the immature stages of *B. zonata* developed successfully within a temperature range between 15 and 30°C. Where, temperature thresholds of eggs, larvae and pupae were 12, 13 and 10.9°C, respectively. Meanwhile, the thermal units for eggs, larvae and pupae ranged between 36 and 48.5, 54.5 and 76.5, and 147.6 and 152.8 degree days, respectively. These findings are in general agreement with those obtained by many authors such as Duyck et al (2004) and Afia (2007) who had reported nearly similar results for incubation period. On the other hand, Mohamed (2000) who recorded 3.0 to 4.66 days obtained different results, and Younes and Akel (2010) who recorded 2 to 4.5 days also agree with many authors, who showed that the hatching period decreased with increase in temperature from (15°C to 30°C) (Vargas et al., 1997; Brévault and Quilici 2000; Duyck and Quilici 2002; Rwomushana et al., 2008, Vayssières et al., 2008; Younes et al., 2010; Hosni et al., 2011; Danjuma et al., 2014; Gomina, 2014). These results are similar to the findings of Qureshi et al. (1993), Mohamed (2000) and Afia (2007) who reported that the larval stage lasted 5.8 to 12.2, 6.13 to 13.06 and 5.35 to 14.8 days, respectively but these result different with Vargas et al. (1996) found a lower temperature threshold of 5.2°C and a thermal constant of 139 DD for the larval stages of *C. capitata,* whereas the pupal stage elapsed 7.9-18, 7.44- 16.1 and 7.47-18.68 days, respectively. Also similar with Younes (2010), Solomon Danjuma (2014) they found similar result.

Conclusion

The Peach Fruit Fly (PDF) *B. zonata* (Saunders) (Diptera: Tephritidae) was reared on artificial diet to study the effect of three constant temperatures (20, 25, and 30°C) on certain biological aspects. The incubation period, larval duration and pupal duration were estimated. The time required for development was decreased as the temperature increased from 15 to 30°C. Differences between the 4 tested temperatures in incubation periods and adult longevity were significant. Low mortality of larvae and pupae occurred at 30°C. Larvae reared at 30°C pupated in significantly shorter time than those developed under other temperatures. Pupation periods differed significantly at all temperatures.

Individuals reared at 30°C completed their life cycles in significantly shorter period. 25°C was the most preferable temperature for the pest. The threshold temperatures were 12°C for egg, 13°C for larvae, 10.9°C for pupae. The average thermal requirements needed for completing the development were 37.38, 79.5, 149.39 and 232.37, 487.92 day-degrees for egg, larvae and pupae, respectively.

Conflict of Interests

The author has not declared any conflict of interests.

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Full Length Research Paper

Salinity in irrigation water with organic fertilizer application on growth of castor bean

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Plants grown under salt stress are adversely affected, however, it has been suggested the use of organic inputs in order to mitigate the deleterious effects of salinity. As a result, it aimed to evaluate the effect of different electrical conductivities of irrigation water due to the application of organic fertilizers in the cultivation of castor bean. The experiment was conducted in greenhouse located at State University of Paraiba, municipality of Catolé do Rocha-PB, Brazil. It adopted a completely randomized design (CRD), in a factorial scheme 5 x 3, with 8 repetitions. The first factor was the electrical conductivity of irrigation water (ECw) 0.5; 1.5; 2.5; 3.5 and 4.5 dS m^{-1} and the second factor refers to organic fertilizers: control treatment, biofertilizers beef and cow urine. There was interaction between the electrical conductivity x organic fertilizer factors. The unit increased from 0.5 dS m^{-1} of electrical conductivity of irrigation water reduced the growth, development and dry matter production of castor bean. The application of bovine growth provides greater biofertilizer castor. Furthermore, the organic raw material attenuates the effects of salt stress.

Key words: *Ricinus communis* L. salt stress, biofertilizer, cow urine.

INTRODUCTION

The castor bean (*Ricinus communis* L.) has great economic importance because of the diversity of products derived, like oil, used for the production of biodiesel, and the pie that can be applied as fertilizer and soil conditioner. Moreover, after getting the necessary benefits, castor bean pie can still be used as animal feed supplement (Mesquita et al., 2012).

The main castor bean crops are located in northeastern Brazil, especially in the semiarid region, however, in these areas there is a huge climate change and is characterized by high temperatures, low rainfall, uneven distribution of rainfall, as well as high rates of evapotranspiration, resulting in drought in most regions. Thus, irrigated farming is essential to meet the water needs of crops (Nobre et al., 2013), concurrently, irrigation water quality is a factor that directly influences

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the production and quality of crops.

Although castor is adaptable semi-arid conditions, it is important that the water supply is met so that the culture can develop properly; achieving satisfactory yields in the physical and economic point of view (Ribeiro et al., 2012). Thus, the research of monitoring the vegetative behavior, planting the beginning of flowering or fruiting, is an essential step for making decisions on how to manage irrigation and crop fertilization (Rios et al., 2011; Mesquita et al, 2012).

The irrigation management is one of the best agricultural strategies to ensure the quality of production, however, inadequately associated with high evapotranspiration combined with low rainfall has caused several problems, including salinization of soils, due to the accumulation of salts in the soil (Lima et al., 2014a).

As a strategy to mitigate the effects of salt stress have used organic inputs that demonstrate benefits (El-Dardiry, 2007, Miranda et al., 2011), mainly organic matter, promoting improvements in soil aeration, provides conditioning effect also improves soil permeability, enhancing water movement (El-Dardiry, 2007), moreover, release humic substances that act as mitigating the effects of salinity (Aydin et al., 2012).

The use of saline water in the cultivation of castor bean has been studied for several researchers (Santos et al., 2013; Lima et al, 2014a; Nobre et al., 2013; Lima et al., 2015), which generally observed that the culture is moderately sensitive to salts and irrigation water salinity provides negative effect on germination, growth and production of castor bean.

Despite these studies with the culture of castor bean, it is clear that more information is needed about the interaction of irrigation water salinity with the use of organic fertilizers in castor bean as a way to mitigate the negative effects of the use of saline water in the cultivation of this oleaginous. In this sense, the objective was to evaluate the effect of different electrical conductivity in the irrigation water associated with the application of organic fertilizers on growth and development of the castor bean crop.

MATERIALS AND METHODS

The experiment was conducted at the State University of Paraiba (UEPB), Catolé do Rocha, Paraíba, (6°20'38"S, 37°44'48"W) Brazil, from September 2014 to January 2015, in the greenhouse. The plants were grown in plastic pots filled substrate composed of soil classified as Fluvisol, sandy clay loam texture, with the following chemical and physical characteristics: pH (H_2O) = 5.02; P (Mehlich) = 0.70 mg dm^{-3}; K = 0.76 mg dm^{-3}; Ca^{+2} + Mg = 7.02 cmol$_c$dm^{-3}; H + exchangeable Al = 0.0 cmol$_c$dm^{-3} and organic matter = 8.05 kg dm^{-3}.

The experimental design was completely randomized, with a factorial scheme of 5 x 3, with 8 repetitions. The treatments consisted of irrigation water application in the electrical conductivities (ECw) 0.5; 1.5; 2.5; 3.5 and 4.5 dS m^{-1} combined with application of organic fertilizers (control treatment, biofertilizers beef and cow urine). The experimental units were composed of three plants, grown in plastic pots with 8 dm³ capacity.

Table 1. Chemical attributes of bovine biofertilizer and cow urine used in the experiment. Catolé do Rocha - PB, UEPB 2014.

Characteristics	Biofertilizer bovino	Cow urine
pH $CaCl_2$	4.68	4.50
CE (dS m^{-1})	4.70	0.40
Ca^{+2} (cmol$_c$ dm^{-3})	3.75	3.10^{-4} mg L^{-1}
Mg^{+2} (cmol$_c$ dm^{-3})	3.30	4.10^{-5} mg L^{-1}
Na^{+} (cmol$_c$ dm^{-3})	1.14	2.10^{-4} mg L^{-1}
K^{+} (cmol$_c$ dm^{-3})	0.71	1 mg L^{-1}
P (mg dm³)	14.45	4.8.10^{-4} mg L^{-1}
Al^{3+} (cmol$_c$ dm^{-3})	0.00	0.00 mg L^{-1}
H^{+} + Al^{3+} (cmol$_c$ dm^{-3})	1.00	-
SB	7.76	-
T	8.90	-
MO (g kg^{-1})	8.00	-

EC = Electric Conductivity extract 1: 2.5; SB = Ca^{+2} + Mg^{+2} + K^{+} + Na^{+} H^{+} + Al^{3+} CTC = SB + H^{+} + Al^{+3}; OM = organic matter.

The water used for irrigation was acquired from a local supply well located in UEPB and showed electrical conductivity of 0.5 dS m^{-1}. The plants were irrigated daily with each type of water, from the fifteenth day after sowing was carried out by manually irrigation sprinkler, providing a sufficient blade to raise the soil moisture level of field capacity.

The bovine biofertilizer was prepared according to the methodology of Silva et al. (2012) obtained by anaerobic fermentation in hermetically sealed container. For release of methane at one end of a thin hose upper base of each digester was coupled and the other end was immersed in a container of water. For the preparation of bio-fertilizer, we used 70 kg of manure from dairy cows and 120 liters of water.

Treatments with biofertilizer and cow urine were applied 15 days after sowing (DAS), at 8 days intervals, totaling 6 applications in the dosage of 10% of the substrate. Before application, bovine biofertilizer and cow urine were diluted in water (5%), bovine biofertilizer was subsequently subjected to the filtering process by the screen to reduce the risk of clogging of the sieve watering holes. The biofertilizer and cow urine was analyzed, and had the following chemical characteristics as shown in Table 1.

The different ECw levels were obtained by addition of sodium chloride (NaCl) water from the local supply system according to the study of Rhoades et al. (2000), and the quantity of salts (Q) was determined by the equation:

Q (mg / L$^{-1)}$) = ECw x 640. Wherein, ECw (0.5 dS m^{-1}) is the desired value of electric conductivity from water.

Sowing was carried out directly in the pots, placing five seeds of the castor bean cv. The growth of castor beans was evaluated at 30, 60, 90 and 120 days after sowing (DAS) by measuring height of the plant, number of leaves, stem diameter and leaf area. At the end of the experiment at 120 DAS, the dry matter of root, stem and shoot were also evaluated.

In plant height measurement, graduated tape measured in cm was used, measuring the distance between the neck and the apex of the plant (younger sheet insert fully formed). The number of leaves was obtained by counting. The stem diameter measurements were taken with a digital caliper to 2 cm above the plant lap. The leaf area was obtained according to the study of Severino et al. (2005). From the monthly average values of plant height, stem diameter and leaf area were calculated according to

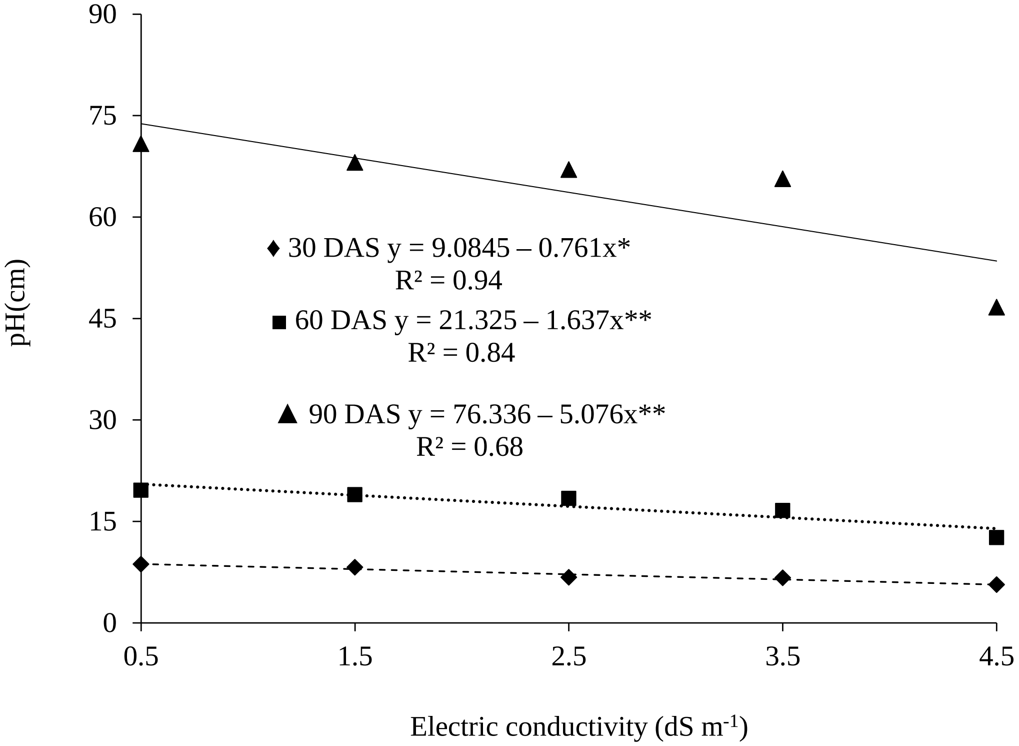

Figure 1. Castor bean plant height (PH) at 30, 60 and 90 DAS under different electrical conductivities of irrigation water ((♦) Control; (■) Biofertilizer; and (▲) Cow Urine).

their respective absolute growth rate (AGR) and relative growth rates (RGR) according to the study of Benincasa (2003).

Dry mass of root, stem and shoot determined after fresh weight remain approximately 48 h in air circulating oven forced into a 60°C until obtaining a constant weight were weighed in a balance 0.0001 g precision. The total dry matter production data were used to calculate the percentages partitioned between vegetative organs and the rate of salinity tolerance, comparing the data from saline treatments with the control (ECw = 0.5 dS m^{-1}) according to Aquino et al. (2007).

Data were evaluated by analysis of variance by F test at 0.05 and 0.01 probability, and in cases of significance, there was linear and quadratic polynomial regression analysis using the statistical software SISVAR 5.0 (Ferreira, 2011).

RESULTS AND DISCUSSION

There was interaction between the electrical conductivity of irrigation water (CIW) and organic fertilizers for the number of leaf growth variables (NL), stem diameter (SD) and leaf area (LA) in all growth stages evaluated, plant height was statistically influenced by the interaction only 120 days after sowing (DAS), with isolated effect of ECw in other periods.

Analyzing the growth variables, it is observed that the increase in ECw provided a reduction in the castor bean plant height in all evaluation periods, however, in the 90 DAS, the plants showed superiority compared to those at 30 and 60 DAS, even under heavy conditions salt (Figure 1). The increase of ECw caused a decrease in plant height at 30, 60 and 90 DAS 0.76; 1.63 and 5.07 cm per unit increased in ECw, being verified smaller plant height values for irrigated with water of 4.5 dS $m^{-1,}$ 5.65; 12.6 and 46.66 cm.

Nobre et al. (2013) also observed that ECw negatively influenced plant height of castor bean BRS Energy to 67 DAS, which found that there were decreases in the order of 6.22% (16.72 cm) in AP per unit increased in ECw. Sá et al. (2016) found a decrease of 3.73 cm in plant height per unit increased in ECw.

With regard to plant height at 120 DAS, there is interaction between CIW and organic fertilizers, which according to the regression equations (Figure 2), there was a decreasing linear response of plant height at increasing ECw occurring decreases in the order of 9.7; 4.12 and 9.8 cm per unit increased in ECw for plants treated without application of fertilizer, biofertilizer beef and cow urine, respectively. It is also observed that the highest values were obtained in salinity (0.5 dS m^{-1}) with a height of 77.75; 88 and 78 cm. The cow urine behaved similarly to the control, however, bovine biofertilizer promoted the highest values.

Lima et al. (2015) related that salinity levels interfered negatively on the castor bean height to 100 DAS when it was under salt stress and nitrogen fertilizer, verifying a

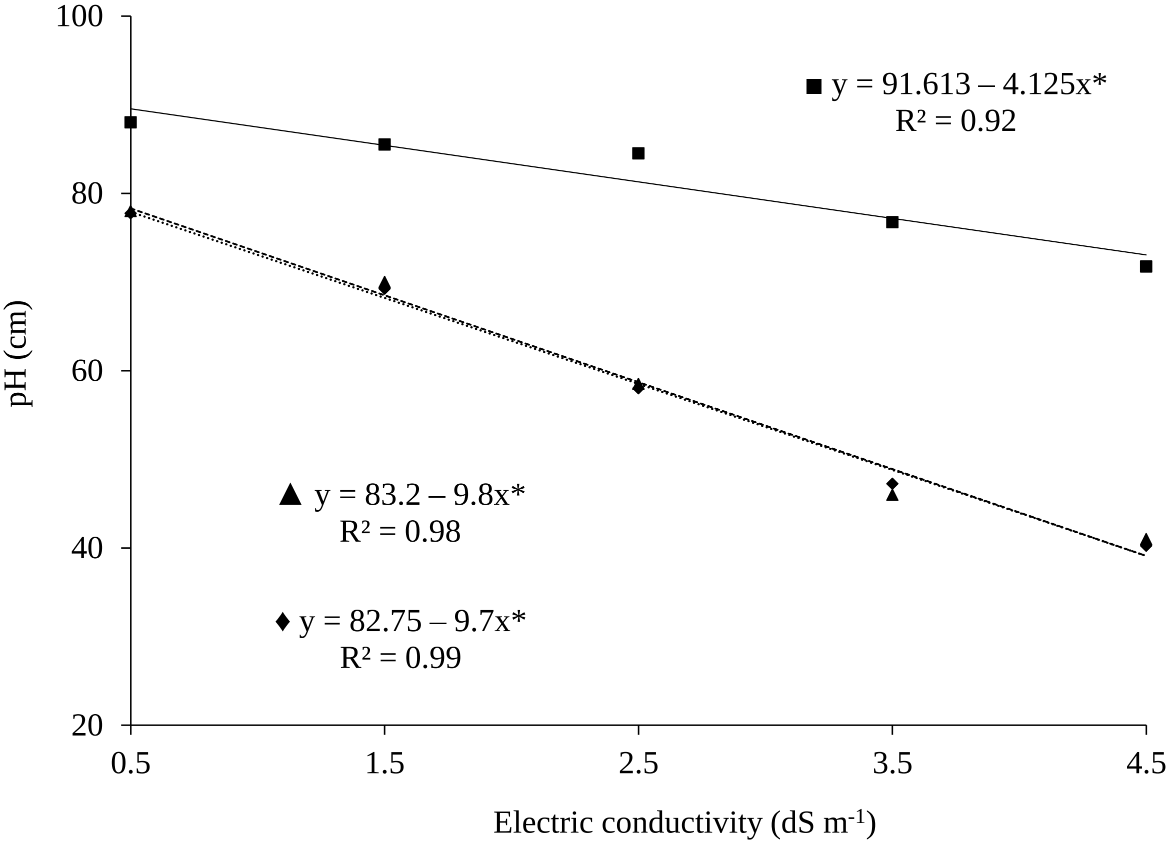

Figure 2. Castor bean plant height (PH) at 120 DAS under different electrical conductivities of irrigation water due to the application of organic fertilizers ((♦) Control; (■) Biofertilizer; and (▲) Cow Urine).

reduction of 9.64 cm for each unit increase in ECw. Nobre et al. (2013) also observed that ECw negatively influenced plant height of castor bean BRS Energy 'to 120 DAS, with decreases in the order of 17.86 cm AP per unit increased in ECw.

As for the height of the plant, the interaction between ECw x organic fertilizer factors had a significant effect on the number of sheets in the evaluated dates and, as shown in Figure 3, there was a linear reduction in plants with decreases of 2.3; 1.4 and 3.3 leaves at 30 DAS (Figure 3A) of 2.65; 2.5 and 3.0 leaves at 60 DAS (Figure 3B) per unit increase in CEA plants treated without the application of fertilizer, biofertilizer and beef cow urine, respectively.

Regarding the number of leaves at 90 and 120 DAS, it appears that as it increased ECw 0.5 to 4.5 dS m^{-1} it promoted a reduction in the number of leaves of castor bean, where the maximum values were obtained with the application of bovine biofertilizer, registering 28 sheets at 90 DAS (Figure 3C) and 41.5 leaves to 120 DAS (Figure 3D). In the same ECw obtained the lowest values of 10 sheets at 90 DAS and 24 sheets to 120 DAS in plants without organic fertilizer application.

Nobre et al. (2013) observed that the number of castor bean leaves suffered decreases to 67 DAS and 120 DAS, of 26.57 and 19.52 sheets per unit increase of ECw, when comparing the plants irrigated with water of 4.4 dS m^{-1} with 0.4 dS m^{-1}. Sá et al. (2016) evaluated castor bean cultivars under salinity in irrigation water found that BRS Gabriela and IAC 028 decreased linearly with increasing salinity level, with respective reductions of 0.44 and 0.55 leaves of the $plant^{-1}$. Lima et al. (2015) found that the salts in irrigation water interfered negatively on the number of castor bean leaves to 100 DAS, registering a decrease of 34.54% compared to plants receiving water of 0.3 dS m^{-1} when compared with those irrigated with water of 3.9 dS m^{-1}. Costa et al. (2013) found no significant effect of different treatments with saline water on the growth of castor bean cultivar BRS Energy 100 days after sowing. This reduction in the number of leaves may have occurred because of damage to the photosynthetic apparatus, thereby restricting the synthesis of carbohydrates (Silva et al., 2014).

It is observed in Figure 4 that increased ECw promoted reduction in stem diameter (SD) of castor 0.79; 0.53 and 1.37 mm at 30 DAS (Figure 4A), 1.14; 0.42 and 1.66 mm at 60 DAS (Figure 4B) 1.09; 0.52 and 1.76 mm at 90 DAS (Figure 4C) and 0.70; 0.53 and 1.61 mm to 120 DAS

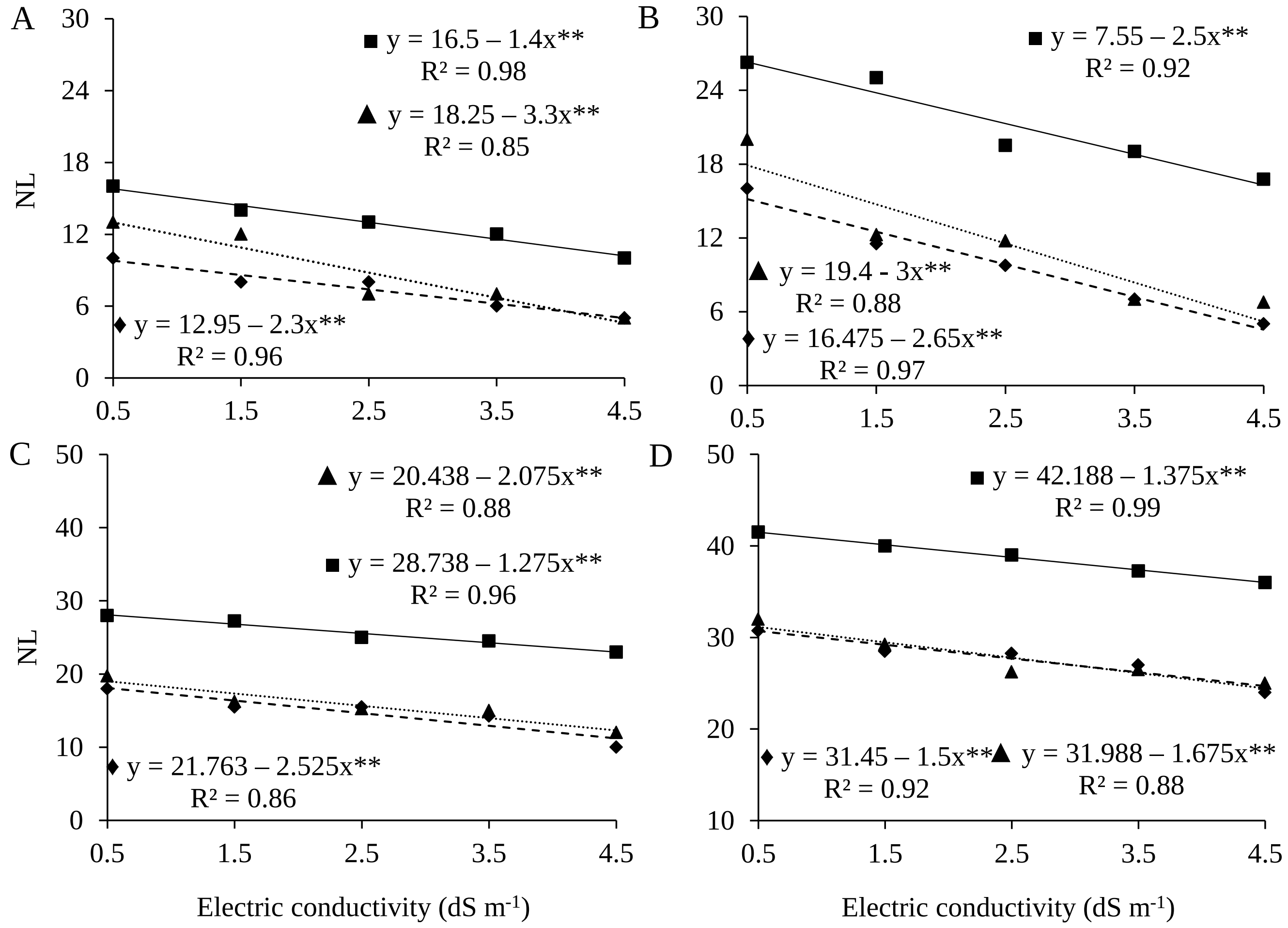

Figure 3. Number of leaves (NL) of castor bean at 30 (A), 60 (B), 90 (C) and 120 (d) to under the effect of different electrical conductivities of irrigation water according to the application of organic fertilizers ((♦) Control; (■) Biofertilizer and (▲) Cow Urine).

(Figure 4D) per unit increased in ECw for plants treated without application of fertilizer, biofertilizer beef and cow urine, respectively.

Sá et al. (2016) found that the diameter of the stem of the castor bean cultivars was reduced by 0.455 mm with the increase in water salinity, with a total reduction of 18.1% in plants grown from the highest (3.0 dS m^{-1}) and lower (0.6 dS m^{-1}). Nobre et al. (2013) also found in 67 DAS, there were declines of 4.68; 5.17; 8.53; 6.64; 8.89 mm in SD plants irrigated with ECw 4.4 dS m^{-1} in relation to those under 0.4 dS m^{-1}.

We observed that the increase in ECw also committed castor bean leaf area (Figure 5), being registered reductions of 51.95; 26.39 and 38.56 cm² at 30 DAS (Figure 5A) 20.35; 10.33 and 28.56 cm² at 60 DAS (Figure 5B), 35.91; 14.33 and 61.56 cm² at 90 DAS (Figure 5C) and 35.51; 32.33 and 71.56 cm² at 120 DAS (Figure 5D) per unit increased ECw for plants treated without application of fertilizer, biofertilizer beef and cow urine, respectively. Corroborating, Lima et al. (2014b) to establish that the ECw had a negative effect on leaf area of castor bean, occurring decreases at 30 and 60 DAS 0.176 and 0.504 m^2 in the AF of plants irrigated with water of 3.9 dS m^{-1} in relation to the submitted 0.3 dS m^{-1}, respectively. Santos et al. (2013) also observed that the leaf area of castor bean had 53 and 42% reductions at 35 and 65 DAE for each unit increase in ECw. According to Sá et al. (2016), sheet increasing occurs due to a tolerance mechanism, which attempts to increase leaf area and produce a greater number of photosynthetically active leaves, stimulating the growth of plants.

Lima et al. (2014a) evaluating the growth of the castor 80 DAS noted that CEA promoted decline 963.3 cm^2 leaf area for each unit increase of ECw corresponding to a reduction of 3467 cm^2 in plants that received water CEA 3, 9 dS m^{-1} compared to those irrigated with ECw 0.3 dS m^{-1}. Lima et al. (2015) and Lima et al. (2014b) found that leaf area of castor bean to 100 and 120 DAS was negatively affected, with 0,068 reductions; 0.079; 0.079 and 0.061 m^2 of plants under irrigation with ECw 3.9 dS m^{-1} compared to plants irrigated with water ECw 0.3 dS $m^{-1.}$

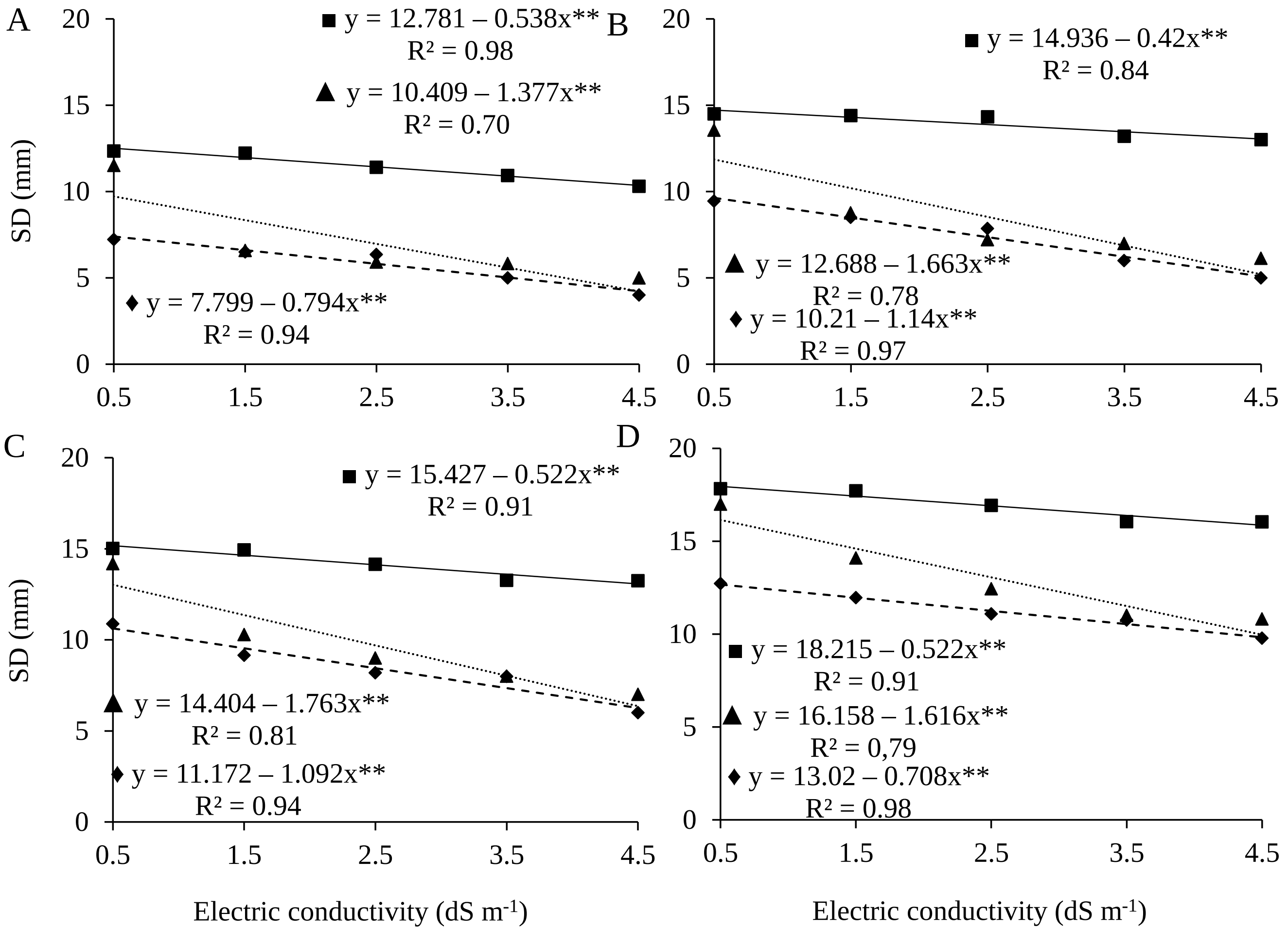

Figure 4. Stem diameter (SD) and 30 (A), 60 (B), 90 (C) and 120 (d) to different electrical conductivities in the irrigation water according to the application of organic fertilizers ((♦) Control; (■) Biofertilizer and (▲) Cow Urine).

There was a significant effect for the interaction between ECw x organic fertilizer to the dry mass of roots, stems, shoots and index of tolerance, and the factor ECw variables analyzed. There was a significant effect for the application of organic fertilizer to the dry mass of roots, stems, shoots and tolerance index. It is observed that the absolute growth rate in plant height (AGRph) had the lowest value, obtaining 0.3 cm day^{-1} to 90-120 DAS when the plants were irrigated with saline water of 4.5 dS m^{-1} while the highest rate of 2.26 cm^{-1} was observed at day 30-60 irrigated water with 0.5 dS m^{-1} (Figure 6A). The relative growth rate in height (RGRph) plants was reduced with increased ECw observing maximum values of 0.08 da^{-1} cm^{-1} cm in plants irrigated with water of 0.5 dS m^{-1} in period of 30 to 60 DAS and lower rate in plants irrigated with water of 4.5 dS m^{-1} cm^{-1} 0.01 cm^{-1} day (Figure 6B).

The ECw negatively influenced the absolute growth rate in stem diameter (AGRsd) (Figure 6C), indicating decreased AGRsd 50% per unit increase of ECw in the period of 30 to 60 DAS and 19.90% in the period of 90 to120 DAS. The highest absolute growth rate was achieved in plants irrigated with water of 0.5 dS m^{-1} to 0.92 mm^{-1} mm day^{-1} to 30 to 60 DAS and minor irrigation of 4.5 dS m^{-1} getting a rate of 0.1425 mm mm^{-1} day^{-1} to 90 to 120 DAS. It is observed in Figure 6D that the relative growth rate (RGRsd) was influenced by the levels of ECw RGRsd linear decrease of the order of25% per unit increase in the ECw level period and 30 to 60% at 90 to 120 of 30.

It can be seen in Figure 7B that the castor bean plants when subjected to ECw 4.5 dS m^{-1} showed relative growth rate in lower leaf area compared to plants irrigated with low salinity (0.5 dS m^{-1}) in the periods of 30 to 60 and 90 to 120 DAS, in the first study period (30-60 DAS) there is a decrease of 28.57% and in the second period (90-120 DAS) 16.66% when the plants were irrigated with low salinity (0.12 dS m^{-1}) than those irrigated with water of 4.5 dS m^{-1}.

Lima et al. (2014c) found the AGRph of castor bean in the range of 22 to 30 DAS, with increasing ECw, reaching a 2.47 cm day^{-1} in plants irrigated with water of 0.3 dS

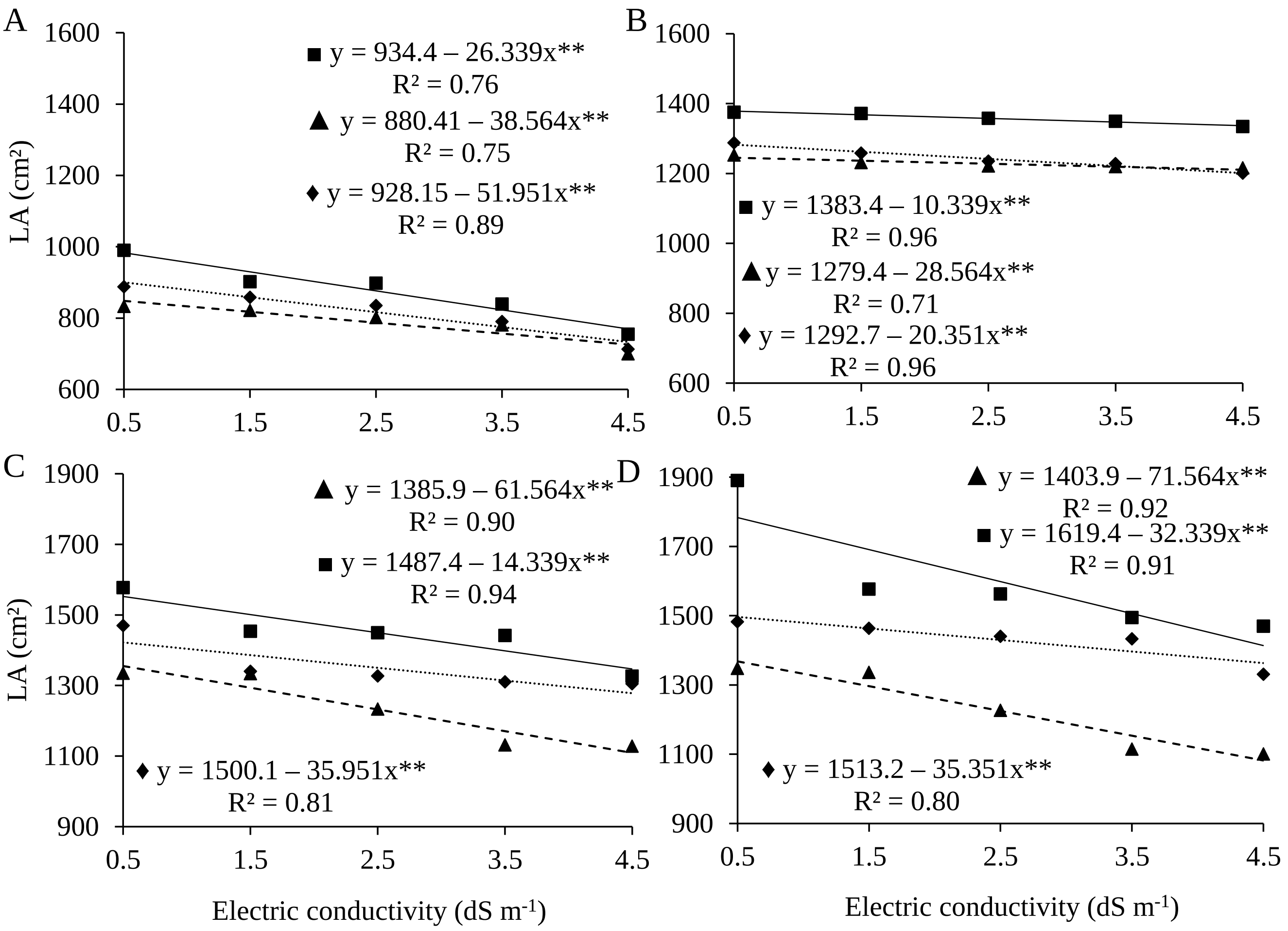

Figure 5. Leaf area (LA) of the castor 30 (A), 60 (B), 90 (C) and 120 (d) to different electrical conductivities in the irrigation water according to the application of organic fertilizers ((♦) Control; (■) Biofertilizer and (▲) Cow Urine).

m^{-1}, however, measured only 0.50 cm day^{-1} for plants under irrigation with ECw water of 3.9 dS m^{-1}. Nobre et al. (2014) observed that the salinity in irrigation water adversely affected the AGRph, down 0.14 cm day^{-1} in plants irrigated with ECw 4.4 dS m^{-1} in relation to the subject to 0.4 dS m^{-1}. The same authors found that the relative growth rate in plant height at 30-40 DAS period was lower in plants irrigated with low salindidade water (0.3 dS m^{-1}) afforded 0.024 cm cm^{-1} day^{-1}, and higher in plants irrigated with ECw water of 3.9 dS m^{-1} the maximum values in RGRpg of 0.0659 cm cm^{-1} day^{-1}.

Different results were obtained by Nobre et al. (2014) who observed that RGRph had a linear increase in the order of 1.63% per unit increase in the ECw, that is, increment of 6.52% on RGRph plants irrigated with water 4,4dS m^{-1} compared the control (0.4 dS m^{-1}). Santos et al. (2013) concluded that the AGRsd was reduced with increasing irrigation water salinity, which obtained the highest rate at 80 DAE with 4.8 dS m^{-1} getting 2.95 mm day^{-1} and 0.006 mm day^{-1} when the plants were irrigated with water of low salinity (0.12 dS m^{-1}). For RGRsd, the same authors observed a decrease during the evaluation period, regardless of the salt content of irrigation water, which obtained the highest relative growth rate in stem diameter of 0.03 mm mm^{-1} d^{-1} in irrigated plants with low salinity water (0.12 dS m^{-1}) and water of higher salinity, the growth rate of stem diameter was 0.02 mm mm^{-1} day^{-1} and the AGRlf of castor beans was reduced with the increase in ECw, where they obtained the highest AGRlf of 194 cm^{-1} to 2 days 35 and 20 DAE under irrigation with water of 0.12 dS m^{-1} and -51 4 cm^{-1} to 2 days 80 and 65 DAE under irrigation with high salinity (4.8 dS m^{-1}).

The dry mass of roots, stems, shoots and tolerance index were negatively affected by ECw, with decreases in root dry mass of 1.20; 0.72 and 1.37g (Figure 7A), the stem dry weight decrease of 2.51; 1.33 and 424 g (Figure 7B), shoots of 6.07; 8.38 and 10.54 g (Figure 7C) and the index of tolerance 14.22; 9.22 and 13.82% (Figure 7D) per unit increased ECw, plants were treated without application of organic fertilizer, biofertilizer beef and cow urine, respectively.

Corroborating, Lima et al. (2014b) observed that the

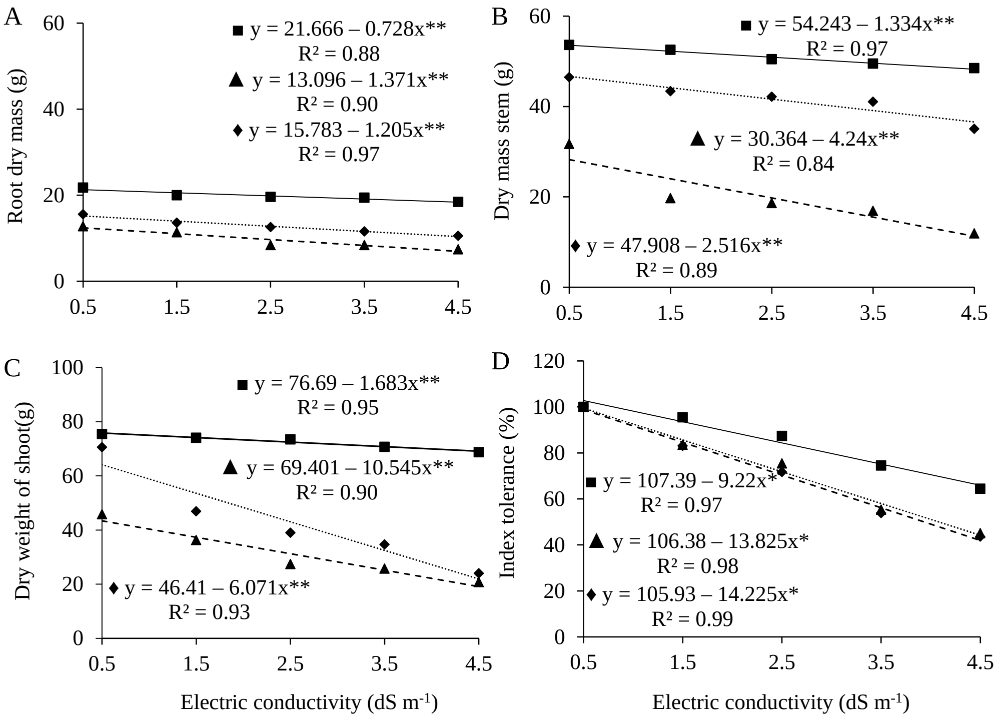

Figure 6. Absolute growth rate (AGR) and relative (RGR) of plant height (A and B), stem diameter (B and C) and leaf area (D and F) of castor bean under different electrical conductivities of water irrigation in the period from 30 to 60 and 90 to 120 days after sowing (DAS).

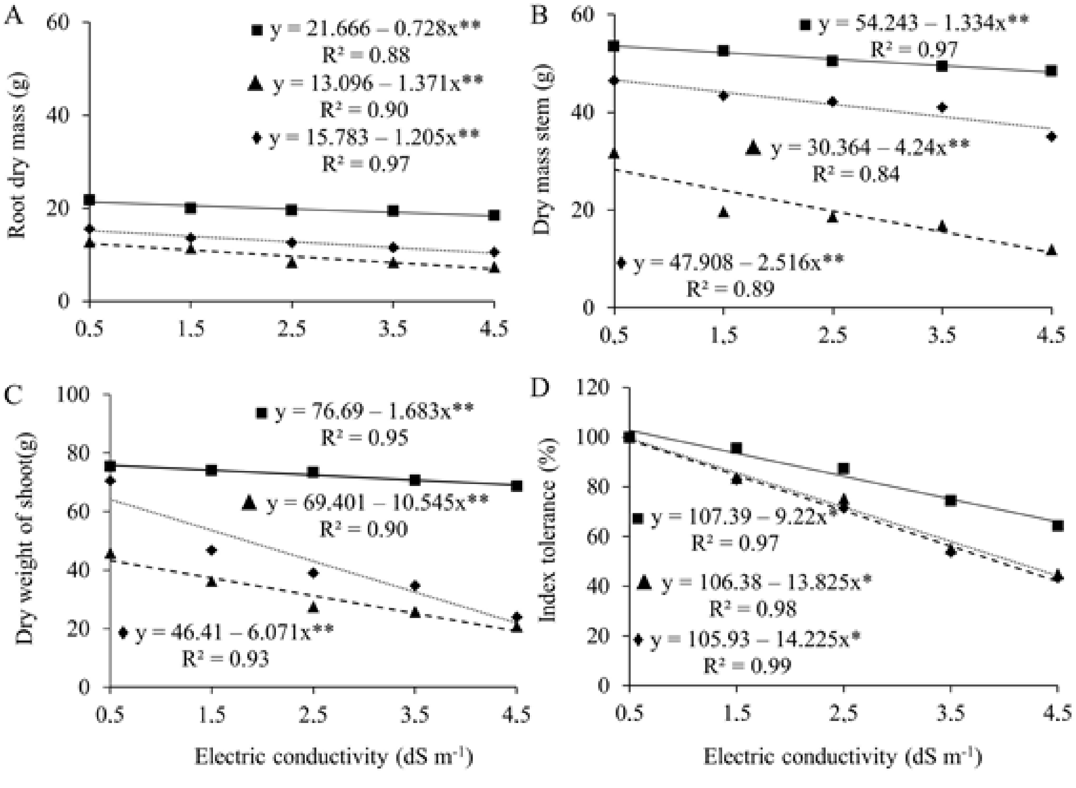

Figure 7. Dry root mass (A), dry matter of the stem (B), dry weight of shoot (C) and tolerance index (D) of castor bean under different electrical conductivities of irrigation water due to the application of fertilizers organic ((♦) Control; (■) Biofertilizer and (▲) Cow Urine).

dry mass of root and stem were affected by ECw, getting the maximum accumulation (48.25 g) of dry root mass in plants receiving water of 0.3 dS m^{-1} and the mass stem dried found that there was a decrease 13.33; 18.84; 16.36 and 13.36% per unit increase in ECw in plants irrigated with water of 3.9 dS m^{-1} compared to those that were irrigated with 0.3 dS m^{-1} water.

Nobre et al. (2013) also observed that ECw negative affect the root dry mass, with reductions of 8.32 g, 11.82 g, 16.45 g, 12.92 g and 25.86 g dry mass of root, and reductions of 45.44 g plant $^{-1}$ in the dry mass of shoots per unit increased ECw in plants irrigated with ECw 4.4 dS m $^{-1}$ relative under the ECw 0.4 dS m $^{-1}$. Sá et al. (2016) found that the increase in salinity levels caused linear reductions in salt tolerance index of all the varieties of castor bean, with 63.82% reductions to cultivate LA Guarani, 79.80, 75.51 and 77.91% for BRS Energy cultivars, BRS Gabriela and IAC 028, respectively.

Conclusions

The increase in electrical conductivity of irrigation water reduced the growth, development and dry matter production of castor bean. The application of bovine growth provides greater biofertilizer castor when under salt stress conditions. The cow urine does not attenuate the effects of salt stress on the culture of castor bean.

Conflict of Interests

The authors have not declared any conflict of interests.

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Analysis of levels and determinants of technical efficiency of wheat producing farmers in Ethiopia

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Wheat is one of the most important cereal crops in Ethiopia, ranking fourth in total cereals production (16%) next to maize, sorghum and teff. Despite its potential for wheat grain production, Ethiopia falls short of being self-sufficient in wheat, and is currently a net importer of wheat grain. This study examines levels of and determinants of technical efficiency of wheat producing farmers in Ethiopia. Data was collected from 2017 farm households from the four major wheat growing regions of Ethiopia where around 85% of the country wheat production comes from. Cobb-Douglas functional model were used to analyze level of technical efficiency whereas quantile regression (QR) technique were employed to analyze factors that affect technical efficiency. The study indicated the average efficiency level of wheat producing farmers is 0.66 implying the huge potential to increase wheat production given the existing technological level and without any additional investment in agricultural research. Several institutional, socioeconomic and biophysical and agro ecological factors affect technical efficiency in wheat production in Ethiopia.

Key words: Technical efficiency, wheat, Ethiopia.

INTRODUCTION

Agricultural research and development, in general, contributes to agricultural growth and total factor productivity by increasing crop and livestock yields through development of new technologies and increased technological diffusion and adoption (Nicostrato and Mark, 2015). Therefore, investment in agricultural research is one of the key priority area of governments in developing countries that aimed at improving production and productivity of agriculture which play crucial role in the development of the entire economy.

Transformation of the agriculture sector will be central in Ethiopia's drive to reach middle-income country status by 2025 (ATA, 2014). But the transformation process could be hampered by many challenges which includes limited farmers access to information on technologies, limited access to inputs and financial services, poor market access, among others. These bottle necks are identified as key impediments for improving productivity of major crops such as wheat, maize and tef that have strategic importance to transform the country's economy and

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contribute to the overall socioeconomic transformation of smallholder farmers in the country (ibid).

Wheat is one of the strategic crops that is given due emphasis both in the country's GTP-I and GTP-II as well as in the agricultural transformation agenda of the country. Increasing its production and productivity has been key strategic goal of research and extension institutions in the country. Despite several efforts that have been made to achieve self-sufficiency in wheat, the country is still importing large volume of wheat every year (FAO STAT, 2014).

In an effort to achieve higher growth, several yield enhancing technologies have been generated and disseminated to farm households, but production of wheat continued to face inefficiencies which posed serious challenge to improve the country's ability to fulfill the ever growing demand for wheat. This calls for the need for investigating factors that are the very causes of inefficiencies in wheat production system so that appropriate policy measures that address the causes could be designed and implemented. For making sound and appropriate policy measures information that represent the entire wheat growing areas of the country should be made available. Previous studies conducted by Shumet, (2012), Solomon (2014), Mesay et al. (2013) and Kaleab (2011) conducted to analyze technical efficiency lack country-wide representativeness as they were based on data collected only from very few woredas1. This study, however, have used data collected from seven major agro-ecological areas of the four biggest regional states in Ethiopia (Oromia, Amhara, Tigray and SNNP) which are known for their high wheat production potential where more than 85% of the country wheat production is obtained from. Therefore, nationally representative information on technical efficiency of wheat production is produced which provide reliable information for national level program design and policy response for the entire wheat production system in Ethiopia.

This study, therefore, analyzes technical efficiency of wheat production in major wheat growing areas of Oromia, Amhara, Tigray and SNNP. The study employed a stochastic production frontier technique for investigating technical efficiency of smallholder farmers that are using improved technologies. This study has also investigated household, social, economic and institutional factors that affected technical efficiency of wheat producing farmers in the major wheat growing areas of the country.

CONCEPTUAL AND ANALYTICAL FRAMEWORK

Kopmans (1951) and Shephard (1953) were regarded as pioneers in developing theoretical literature on production efficiency, in the early 1950s. Koopmans (1951) provided a definition of technical efficiency as a producer is technically efficient if it is n longer possible to produce any further output without producing less of some other output or using more of some input. Ferguson (1996) defined production function as a function that relates maximum possible output using a given amount of combination of inputs.

Measuring efficiency empirically was started by Farrell (1957) which later inspired Koopmans et al. (1951) to develop and define ways of measuring cost efficiency, followed by the development of techniques of decomposing cost efficiency into technical and allocative efficiencies. The production technology of a farm is represented by a stochastic production function specified as:

$$Y_i = f(X_i;\beta)\exp(v_i - u_i) \qquad (1)$$

Y_i denotes output for firm, i, X is the vector of inputs used in the production process, by i^{th} firm, β is a vector of parameters to be estimated, $f(X_i;\beta)$ is a true representation of a farm production function, u_i is non-negative random variable associated with technical inefficiency, assumed to be independently and identically distributed, $N(0,\sigma_u^2)$ and truncated at Zero, of the normal distribution with mean μ and variance $\sigma_u^2(|N(0,\sigma_u^2)|)$. v_i represent the stochastic error term. The maximum likelihood estimates yield β, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma^2$. Following Jondrow et al. (1982), the technical efficiency estimation is given by the mean of the conditional distribution of inefficiency term μi given ε; and thus defined by:

$$E\left(\frac{u_i}{\varepsilon_i}\right) = \sigma^2\left[\frac{f(\frac{\varepsilon_i\lambda}{\sigma})}{1-F(\frac{\varepsilon_j\lambda}{\sigma})} - \frac{\varepsilon_i\lambda}{\sigma}\right] \qquad (2)$$

Where f and F represent the standard normal density and cumulative distribution functions, respectively, and:

$$\lambda = \frac{\sigma_u}{\sigma_v} \qquad (3)$$

where ${\sigma_v}^2$ and ${\sigma_u}^2$ are variance of the stochastic model and the inefficiency model, respectively. Equations 1 and 2 provides estimate of u and v after replacing ε, σ and λ by their estimate.

Quantile regression for analyzing determinants of technical efficiency

Standard linear regression techniques summarize the average relationship between a set of regressors and the outcome variable based on the conditional mean function

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[1] Woreda is the lower administrative unit which is equivalent to district. A woreda consists of several kebeles which are the lowest administrative units in the government structure of Ethiopia.

$\mathrm{E(y|x)}$. As a result, it fails to provide a more comprehensive picture of the effect of the predictors on the response variable.

For a distribution function $F_Y(y)$ one can determine for a given value of y the probability τ of occurrence. Now quantiles do exactly the opposite. That is, one wants to determine for a given probability τ of the sample data set the corresponding value y. In ordinary least square (OLS), one has the primary goal of determining the conditional mean of random variable Y, given some explanatory variable x_i, $\mathrm{E}[Y|x_i]$. Quantile regression (QR) goes beyond this and enables us to pose such a question at any quantile of the conditional distribution function. It focuses on the interrelationship between a dependent variable and its explanatory variables for a given quantile. Quantile regression overcomes thereby various problems that OLS is confronted with. Frequently, error terms are not constant across a distribution, thereby violating the axiom of homoscedasticity. Also, by focusing on the mean as a measure of location, information about the tails of a distribution are lost. And last but not least, OLS is sensitive to extreme outliers, which can distort the results significantly.

In this study, in analyzing determinants of technical efficiency, we will use quantile regression technique in order to reveal the overall picture of the relationship between the dependent variable an socioeconomic and institutional variables that affect efficiency. Quantile regression essentially transforms a conditional distribution function into a conditional quantile function by slicing it into segments. These segments describe the cumulative distribution of a conditional dependent variable Y given the explanatory variable x_i with the use of quantiles. For a dependent variable Y given the explanatory variable $X = x$ and fixed, $0 < \tau < 1$, the conditional quantile function is defined as the $\tau - th\ quantile$ $Q_{Y|X}(\tau|x)$ of the conditional distribution function $F_{Y|X}(y|x)$. In quantile regression, as opposed to OLS, the minimization is done for each subsection where the estimate of the quantile function is achieved with the parametric function. Consider the standard linear model in a population, with intercept α and $K\ x\ 1$ slopes β:

$$Y = \alpha + X\beta + u$$

Assume $E(u^2) < \infty$, so that the distribution of u is not too spread out. Given a large random sample, when should we expect ordinary least square, which involves:

$$\min_{a,b} \sum_{i=1}^{N} (y_i - a - X_i b)^2$$

and least absolute deviations which solves:

$$\min_{a,b} \sum_{i=1}^{N} |y_i - a - X_i b|$$

If $\mathrm{D(u|X)}$ is symmetric about zero then OLS and LAD both consistently estimate α and β if u is independent of X with E(u)=0, where E(u)=0 is the normalization that identifies α, then OLS and LAD both consistently estimate the slopes, β. If u has an asymmetric distribution, then med(u)≡ $\eta \neq 0$, and $\hat{\alpha}_{\mathrm{LAD}}$ converges to $\alpha + \eta$ because Med(y|X)= $\alpha + \mathrm{X}\beta + \mathrm{Med(u|X)} = \alpha + \mathrm{X}\beta + \eta$.

But in many application neither of the earlier described approaches is likely to be true mainly because the distribution of y, variance (u/X) is not constant. Therefore, quantile regression is an appropriate techniques because it is much less sensitive than the mean to changes in extreme values. We are interested in how covariates affect quantiles (of which the median is the special case with $\tau = 1/2$), under linearities:

$$Quant_\tau(Y_i|X_i) = \alpha(\tau) + X_i\beta(\tau)$$

Therefore, consistent estimators of $\alpha(\tau)$ and $\beta(\tau)$ are obtained by minimizing the "check" function:

$$\min_{\alpha\epsilon\mathbb{R},\beta\epsilon\mathbb{R}^K} \sum_{i=1}^{N} C_\tau(Y_i - \alpha - X_i\beta)$$

DATA

The data used for this study is obtained from the farm-household survey conducted during 2014/15 by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT). The data was collected with a purpose of wheat technology adoption analysis and its impacts on smallholder producers. Survey questionnaire was designed and was tested. After pre-testing, the questionnaire was revised. The questionnaire was carefully designed to capture all the most important issues such as household and farm characteristics, agroecological, input use, market, asset ownership, production constraints, access to information and other relevant variables.

The sampling frame covered seven major wheat-growing agro-ecological zones that account for over 85% of the national wheat area and production distributed in four major administrative regions (Oromia, Amhara, SNNP and Tigray) of Ethiopia. A total of 2017 farm households in seven agro-ecological zones, in 26 zones (provinces), 61 woredas (districts) and 122 kebeles/villages were interviewed.

A multi-stage stratified sampling procedure was employed to select villages from each agro-ecology, and households from each kebele/village. First, agro-ecological zones that account for at least 3% of the national wheat area each were selected from all the four major wheat growing. In the second stage of sampling procedure, up to 21 villages in each agro-ecology, and 15 to 18 farm households in each village were randomly selected with proportionate random sampling. Detailed and structured questionnaire were used to collect the data, and trained enumerators were used to ensure collection of quality data (Table 1).

Table 1. Summary of descriptive statistics of major variables used in the econometric models.

Variable	Description of variable	Aggregate mean (SD)
Output and inputs		
Output (wheat yield)	Natural logarithm of wheat output (kg/ha)	1248 (2112)
Land (wheat plot size)	Natural logarithm of cultivated wheat farm (ha)	0.70 (0.72)
Labor	Natural logarithm of man-days per hectare[2]	0.29 (37.5)
Seed	Natural logarithm of quantity of seed used (Kg)	120.4 (164.7)
Fert	Natural logarithm of fertilizer (Dap) used (kg/ha)	57.66 (70.5)
	Natural logarithm of fertilizer (Urea) used (kg/ha)	24.77 (36.4)
Oxen	Natural logarithm of oxen-days used	16.46 (16.5)
Household characteristics		
Wheat EXP	Age of household head in years	17.81 (11.1)
Model farmer (model=1)	Educational level of household head in number of years in schooling	0.42 (0.49)
HHAGE	# of members of the household	45.93 (12.6)
HHSEX (Male=1)	Dummy if training received in wheat production=1	0.919 (0.28)
HHEDU (Read&write=1)	Dummy: If household head is model farmer=1	0.62 (0.48)
FAMILYSIZE	# years of wheat growing experience of household head	6.57 (2.21)
Resources, constraints and market access		
MKTDSTNCE	Walking distance to village markets (min)	9.05 (5.88)
Input mkt	Walking distance to input markets (min)	4.26 (3.84)
TLU	Livestock holding size in Tropical Livestock Unit (TLU)	5.43 (4.40)
Plots	# of wheat plots owned	1.80 (1.06)
Agricultural support services		
Credit	Dummy for participation in credit program (1=credit received)	-
Mobile telephone	Mobile telephone ownership status (1=owned)	-
Ext contact	# of contact with extension worker in a year (2014)	0.96 (0.37)
Training	# of trainings received 2014/15	0.86 (0.34)
Agro-ecologies (reference=Cool humid mid highlands)		
Tepid semi-arid mid highlands	Dummy: Farmer is in Tepid semi-arid mid highlands=1	-
Tepid humid and sub-humid mid highland	Dummy: Farmer is in Tepid humid and sub-humid mid highland=1	-
Tepid moist & sub-moist mid-highland	Dummy: Farmer is in Warm moist and sub-moist lowlands=1	-
Cool moist and sub-moist mid highlands	Dummy: Farmer is in Tepid moist and sub-moist mid-highland=1	-
Warm sub humid lowland	Dummy: Farmer is in Cool moist and sub-moist mid highlands=1	-
Regions (reference=Amhara region)		
Tigray	Dummy: Farmer in Tigray region=1	-
SNNP	Dummy: Farmer in SNNP region=1	-
Oromia	Dummy: Farmer in Oromia region=1	-
Social capital		
Coop member (1=if member to coop)	Dummy: If member farmer is member of input/seed/marketing cooperatives=1	0.98 (0.10)
Trust rader	# of traders that farmers know and trust	3.60 (4.7)
Relatives	# of relatives living inside and outside the village	11.1 (24.8)
Soil fertility status (reference=poor)		

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[2] Man-day is calculated based on regular and common working hours in the study areas which is equivalent to 8 h.

Table 1. Contd.

Good	Dummy: Soil fertility if the soil fertility is good in status=1	0.42 (0.1)
Medium	Dummy: Soil fertility- if the soil fertility is medium in status=1	0.46 (0.01)
N	No of observations	1611

*, ** and *** denote significance level at 10%, 5% and 1%, respectively;. SD is standard deviation. Source: Own Survey, 2014/2015.

Table 2. Hypothesis tests (Aggregate model).

Null hypothesis	χ^2 statistics	p value	Decision
Testing there is no technical inefficiency in the model			
$H_o: \gamma = 0$	11.19	0.000	Reject H_o
Testing the null hypothesis that the translog SFPF can be reduced to a Cobb-Douglas SFPF			
$H_o: \beta_{ij} = 0$	0.42	0.21	Not Reject H_o
Test for variables included in the inefficiency model have no effect on technical inefficiency			
$H_o: \delta_1 + \delta_2 + .. \delta_8 = 0$	20.31	0.001	Reject H_o

Source: Own computation.

EMPIRICAL ANALYSIS

Importance of wheat in Ethiopia

Wheat is one of the most important cereal crops consumed in different forms in Ethiopia and the rest of the world. Ethiopia is the second largest wheat producer in sub-Saharan Africa (SSA) next to South Africa (Demeke and Marcantonio, 2013) and it ranked 4th after teff, maize and sorghum in terms of area coverage with 1,605,653.9 hectares and 3rd in terms of quantity production with 3,925,174.135 tons in 2013/14 cropping season in Ethiopia (CSA,2014).

Wheat in Ethiopia is grown as a staple food in the highlands at altitude ranging from 1500 to 3000 masl. The largest volume of the main season production of wheat originates from Oromia which constitute around 55% of the country's total wheat production followed by Amhara and SNNP with 29 and 9% respectively. Despite its potential for wheat grain production, Ethiopia falls short of being self-sufficient in wheat production, and is currently a net importer of wheat grain in which much of the domestic wheat demand of flour mill factories is met through imports (FAO STAT, 2014).

The Ethiopian agricultural research system has generated productivity enhancing improved wheat technologies which the national extension system has disseminated during the last couples of decades. Significant number of farmers has accessed these technologies but the national productivity level is still quite low which could be attributed mainly to inefficiencies under the modern technology use. Therefore, understanding the technical efficiency level of farmers in wheat production needs to be analyzed, and factors that cause inefficiencies in wheat production need to be well understood. In addition, information generated in this study will contribute for the existing stalk of knowledge on technical efficiency and factors that affect technical efficiency.

Description of variables

The production technology of sample farmers is represented by Cobb Douglas production function. The Cobb Douglas production function provides adequate representation of the production technology under the study as long as the interest is on measurement of efficiency not on the analysis of the general structure of the production technology (Taylor et al., 1986). Despite this, the generalized likelihood ratio test[3] were used to test Cobb-Douglas functional form is the right functional form than the translog. Likelihood ratio test have confirmed that the Cobb Douglas functional form is true representation of the data collected from the study areas (Table 2).

As both Cobb Douglas and Translog functional forms do not to satisfy linearity in parameters, taking logarithms of both sides of the equation is a common practice to make them amenable to estimation using linear regression as a result observation that have zero value for any of the variables included in the model are dropped due to the fact that it is impossible to construct logarithm using variable that contain zero (Coelli et al., 1998). Therefore, the Cobb-Douglas functional form used is specified as follows:

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[3] Likelihood Ratio (LR) statistics are only asymptotically justified, hence they can only be relied when the sample size is big.

$$lnY_i = \beta_0 + \beta_1 \ln land + \beta_2 \ln labor + \beta_3 \ln fertil\,izer + \beta_4 \ln seed + \beta_5 \ln Oxenday + (v_i - u_i) \quad (4)$$

where ln denote the natural logarithm; Y_i denote the total quantity of wheat output produced by household i in kilogram; $land$ denote the total land planted with wheat in $hectares$; $labor$ denote the amount of family labor in mandays; and was calculated as indicated onn Annex 4 using a conversion factor suggested by Storck et al. (1991); $fertilizer$ denotes the amount of both Dap and Urea added together in kilogram; $seed$ denote the quantity of seed utilized in kilogram; $oxendays$ represent the number of days oxen are used in producing the wheat measured in oxendays. However, as the number of farmers that use pesticide and herbicide in the 2014, production season was very small and the chemical is excluded from the model specified earlier, and this can be considered as the limitation of the study (Table 1).

Empirical results

The study hypotheses were stated in null terms. The first null hypothesis that describes inexistence of technical inefficiency among wheat producers is rejected. As pointed out by Coelli and Battese (1995), if a null hypothesis includes $\gamma = 0$ then the statistic has asymptotically a mixed Chi-squared distribution, since by its definition γ has to be non-negative.

In the third null hypothesis, we stated that the variables included in the inefficiency effect model have no effect on the level of technical inefficiency. This null hypothesis is also rejected for wheat producers, showing that the joint effect of these variables on technical inefficiency is statistically significant. Estimates of the model parameters were computed using the frontier model with a Cobb-Douglas functional form. The real investigations for the occurrence of inefficiency were calculated by estimating the stochastic frontier production function and conducting a likelihood-ratio test assuming the null hypothesis of no technical inefficiency. This test statistic is computed using *STATA software version 13*.

The technical efficiency and the factors influencing technical efficiency were examined by fitting a frontier production function model including the explanatory factors of technical efficiency Table 3 shows the presentation of the parameters estimate and related statistical test obtained from the stochastic frontier production function analysis for wheat producers. The likelihood ratio test for the null hypothesis $H_o: \gamma = 0$ is rejected indicating the presence of statistically significant variation among wheat producers that can be attributed to inefficiency. The lamda (λ) value is also greater than one which confirms the presence of inefficiency.

Wheat production of sample famers was represented by a Cobb-Douglas Stochastic Frontier Model, and half normal distribution of inefficiency. Because, a series of preliminary likelihood ratio tests revealed that Cobb Douglas stochastic frontier model best fit the data given the more flexible translog frontier model, and the distribution of inefficiency best represented by the half-normal distribution. The natural logarithms of the data on the input and output variables were taken for efficiency analysis. Table 4 shows estimated coefficients of land, labor, seed fertilizer and oxen for stochastic frontier model of Cobb-Douglas production function. The coefficients associated with the inputs measure the elasticity of output with respect to inputs. Positive and significant values indicate that there is a potential for increasing production or output of wheat by increasing the level of inputs used in the production process.

Estimates of production frontier for wheat producing farmers are presented in Table 4. In aggregate, all inputs except labor is found to be significantly and positively affecting wheat output indicating that there exists still potential for increasing level of output by increasing usage of these inputs.

Technical efficiency levels

Three dummy variables for regions were included in the inefficiency model representing Tigray, Oromia and SNNP region compared with Amhara region. The negative and significant value of coefficients for Tigray and Oromia regions at 1 and 5% level, respectively indicates lower inefficiency (higher mean efficiency) compared to Amhara region. Aggregate of all regions, the greatest proportion of wheat producing farm households fall in the range of 60 to 80% technical efficiency level

Determinants of technical efficiency: Quantile regression and maximum likelihoods (ML) estimates compared

Maximum likelihoods (ML) summarize the average relationship between a set of regressors and the outcome variable based on the conditional mean function E(y|x). This provides only a partial view of the relationship. But a more comprehensive picture of the effect of the predictors on the response variable can be obtained by using Quantile regression.

Quantile regression models show the relation between a set of predictor variables and specific percentiles (or quantiles) of the response variable. It specifies changes in the quantiles of the response. QR is more robust to non-normal errors and outliers and hence appropriate for response variable (technical efficiency) used in this study as it has outlier values both in agreegate and for each regions (Annex 1 and 2). Standard errors and confidence

Table 3. Maximum likelihoods estimate for wheat production frontier function and inefficiency model.

Variable	Coefficient	t-value
$Constant$	4.92	(27.76)***
$lnLAND$	0.43	(10.69)***
$lnLABOR$	-0.03	(-1.70)
$lnOXENDAYS$	0.069	(2.29)*
$lnSEED$	0.361	(12.41)***
$lnFERTILIZER$	0.188	(8.20)***
σ_v^2	-1.813	-19.78***
Function coefficient	1.01	-
λ	1.73	-
Constant	-0.120(-0.28)	-
Log likelihood	-1165.1	-
N	1465	-

***, **, * indicate significance at 1, 5 and 10% levels, respectively.

Table 4. Efficiency estimate by regions.

Efficiency estimate	Proportion of sample HHs disaggregated by regions (%)				
	Tigray	SNNP	Amhara	Oromia	Aggregate
≤ 0.1	-	0.62	0.43	-	0.20
> 0.1 and ≤ 0.2	1.25	0.62	1.08	0.39	0.68
> 0.2 and ≤ 0.3	2.5	2.48	3.23	1.45	2.18
> 0.3 and ≤ 0.4	-	7.45	3.66	3.68	3.89
> 0.4 and ≤ 0.5	2.5	6.21	9.48	5.39	6.62
> 0.5 and ≤ 0.6	10	17.39	16.81	9.21	12.56
> 0.6 and ≤ 0.7	18.75	31.06	27.16	21.97	24.44
> 0.7 and ≤ 0.8	38.75	21.12	29.74	35.13	32.08
> 0.8 and ≤ 0.9	21.25	13.04	8.41	22.63	17.00
> 0.9 and ≤ 0.99	5	-		0.13	0.34
Mean efficiency	**0.71**	**0.62**	**0.62**	**0.72**	**0.66**
Maximum	0.92	0.88	0.15	0 .94	0.92
Minimum	0.19	0.07	0.094	0.12	0.05
St.dev	0.13	0.15	0.17	0.13	0.14

limits for the quantile regression coefficient estimates can be obtained with asymptotic and bootstrapping methods. Both methods provide robust results (Koenecker and Hallock, 2000), with the bootstrap method preferred as more practical.

Quantile regression allows comparing how some percentiles of the technical efficiency may be more affected by certain socioeconomic characteristics than other percentiles. Coefficient estimates for the 25, 50, 75 and 95th quantile regression, and the ML estimates for technical efficiency are presented in Table 5. The ML and quantile regression estimates of the factors affecting technical efficiency are provided in Table 5. Variations in technical efficiency among wheat producer farmers are hypothesize to be due to farm and farmers attributes which reflect managerial ability of farmers and their access to information. The ML estimated coefficients[4] for age is positive and significant implying that efficiency decrease with increase in age. Technical efficiency was significantly but negatively affected by age at 25th and 50th quantile while have no effect at higher quantile level (75th and 95th). The main reason might be that while

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[4] In the inefficiency model specification, it is well understood that a negative sign on a parameter explaining inefficiencies means that the variable is improving technical efficiency, while for a positive sign, the reverse is true.

farmers are getting older they tend to less likely shift from their long adapted practices to new practices, hence declining technical efficiency. This finding is in conformity with findings of Tolesa et al. (2014), Arega (2003) and Ajibefun (2002). Contrary to this finding, Coelli and Battese (1995) reported farmers with older age were technically more efficient. Llewelyn and Williams (1996) observed that technical efficiency increases up to a certain age level and then eventually declines. This indicates that age has mixed impact on efficiency and may be depending on crop and study area.

The ML estimate for the effect of being a model farmer on technical efficiency was insignificant, while the quantile regression estimate revealed being a model farmer have significant impact at 10% level on technical efficiency at 25, 50 and 95th quantiles and at 1% significance level at 75th quantile. This indicates deficiency of ML estimation techniques which masked the real effect of the dummy variable *model farmer* in improving technical efficiency.

Mobile ownership has exhibited highly significant influence, at 1% level, on technical efficiency. Farmers that have mobile telephone were found to be more technically efficient *vis-a-vis* farmers who don't have mobile and the main reason might be due to the very instrumental role mobile is playing in improving farmers access for such information as new agricultural practices, market information, input sources and application methods from various sources mainly from development agents, other farmers, traders, and knowledge sources such as agricultural researchers and experts.

Similar results were reported by Falola and Matthew (2013) which indicated positive and significant impact of mobile telephone on technical efficiency of farmers in Nigeria; and other similar studies such as Aker (2008) study on the impact of introduction of cell phones on grain trade throughout Niger and Getaw, and Godfrey (2015) study on the impact of mobile phones on farmers' marketing decisions and prices they receive have reported positive and significant impact of mobile telephone.

Total Livestock Unit (TLU) as calculated by a conversion factor suggested by employing Storck et al. (1991) as indicated on Annex 3 is significant factor in improving technical efficiency. This is because livestock have direct implication on technical efficiency as it is major source of draft power during plowing and weeding, and means of transporting inputs from market to the farm, as a result households could carry out farm operation at the right time and right frequency (such as plowing and weeding). Apart from these, the higher number of total TLU owned implies the household capacity to procure inputs (seed, fertilizer and all other inputs) at the right time so that it could be made available in time which contributed in increased output. This is also consistent with findings of various studies such as Beyan (2014), Tolesa et al. (2014) and Temesgen and Ayalneh (2005). Livestock ownership measured in TLU is underestimated in ML estimate compared to the quantile regression which turned estimates at all quartiles when it becomes highly significant at 1% level.

The insignificant level of influence of credit on technical efficiency as estimated by ML technique was turned out to be significant at 25 and 50th level when employing quantile regression technique. This indicate that credit have significant influence on technical efficiency of farmers at lower level of technical efficiency than those at higher level. Financially, constrained farmers who lack also access to credit will have problem of undertaking farm operations timely and also may fail to optimize input use thereby affecting their level of technical efficiency. This is inconformity with the findings of Arega (2003), Tolesa et al. (2014) and Njeru (2010).

Significant variations in technical efficiency level were observed among the different regions, Tigray and Oromia region being the most efficient compared to Amhara and SNNP which could be attributed to the effectiveness of extension service in Tigray and Oromia which enabled farmers apply recommended practices properly. The remaining variables model farmer, training and education were insignificant.

Cooperative membership has significant influence on technical efficiency especially among those farmers at 95th quantile level. Cooperatives are key economic organizations that provide input and output market access which in turn improve farmers access to various agricultural information necessary for proper application of technologies.

Agro ecological differences are important factors that affect efficiency and there exists significant differences in technical efficiency among wheat producing farmers at all quantile levels. This is because wheat is affected by agro ecological variations which have an implication for identifying niches that is highly suitable for wheat production. Cool humid mid highlands and Cool moist and sub-moist mid highlands are the most suitable niches for wheat production.

CONCLUSION AND RECOMMENDATIONS

The objective of this study was to measure the level of technical efficiency of wheat producing farmers in the four major regional states, and identify the sources of technical inefficiencies. A Cobb-Douglas model was used to determine levels of technical efficiency and the analysis of its determinants were done using both ML and quantile regression techniques.

Wheat producing farmers in Tigray, SNNP, Amhar and Tigray regional states have experienced significantly high level of technical inefficiencies which indicated the existence of enormous potential for increasing productivity using the current level of technology. By strengthening the extension service delivery, government can achieve higher wheat yield through improving

Table 5. Quartile regression and ML estimates compared.

Variable	ML Estimates[5]		Quantile regression estimates[6]							
			(25th)		(50th)		(75th)		(95th)	
	coefficient	t-value	Coefficient	t-value	Coefficient	t-value	coefficient	t-value	coefficient	t-value
Household characteristics										
Wheat EXP	0.0177*	(2.49)	-0.0116	(-1.29)	-0.478	(-0.89)	-0.364	(-0.99)	-0.0645	(-1.23)
Model farmer	-0.180	(-1.32)	0.0257*	(2.02)	0.0228*	(2.38)	0.0201***	(4.44)	0.0164*	(2.56)
HHAGE	0.0116*	(1.77)	-0.00269***	(-3.65)	-0.00153***	(-3.53)	-0.000255	(-0.65)	-0.000374	(-0.74)
HHSEX	-0.015	(-0.07)	0.0171	(0.89)	0.00335	(0.32)	0.0115	(1.18)	-0.00203	(-0.19)
HHEDU	0.155	(1.05)	-0.0149	(-0.97)	-0.00994	(-1.33)	0.00691	(0.97)	0.0134	(1.11)
Family size	0.019	(0.68)	-0.896	(-0.07)	0.385	(0.28)	0.0196	(0.15)	0.00123	(0.87)
Resources, constraints and market access										
MKTDSTNCE	-0.0940	(-0.84)	-0.0751	(-0.60)	-0.0646	(-1.30)	-0.00339	(-0.74)	-0.309	(-0.67)
INPUTMKT	0.0327*	(1.90)	-0.0457**	(-2.59)	-0.0118	(-1.41)	-0.00123	(-1.63)	-0.545	(0.72)
TLU	-0.0471*	(-2.22)	0.00920***	(9.79)	0.00658***	(5.74)	0.00413***	(5.18)	0.00389***	(4.29)
Plots	-0.281**	(-3.02)	0.0295***	(7.28)	0.0206***	(7.04)	0.0104***	(3.37)	0.00877**	(2.98)
Agricultural support services										
Credit	-0.282	(-1.03)	0.0395*	(2.28)	0.0210*	(1.98)	0.00862	(1.06)	0.00668	(0.76)
Mobile telephone	-0.493***	(-3.34)	0.0936***	(7.00)	0.0750***	(10.60)	0.0677***	(8.64)	0.0368***	(4.78)
EXT contact	0.01	(0.76)	0.0205	(1.39)	0.499	(0.59)	0.115	(0.7)	0.00201	(0.12)
Training	-0.0825	(-0.43)	0.0197	(0.94)	0.00520	(0.44)	0.0159	(1.19)	0.00595	(0.49)
Social capital										
Coop member	-0.0349	(-0.02)	0.0161	(0.11)	0.0118	(0.94)	0.0123	(0.51)	-0.0447***	(-4.79)
Trust rader	-0.0229	(-0.59)	0.000705	(0.19)	-0.000782	(-1.38)	-0.00124	(-0.74)	0.296	(1.75)
Relatives	-0.907	(-1.54)	-0.909	(-0.83)	-.106639	(0.027)	0.902	(1.15)	-0.0544	(-0.76)
Soil fertility status										
Soilfert_medium	-0.417*	(-2.51)	0.0721***	(4.52)	0.0496***	(5.35)	0.0738***	(8.09)	0.0229*	(2.38)
Soilfert_good	-0.803***	(-4.48)	0.133***	(8.23)	0.0925***	(9.75)	0.0423***	(4.81)	0.0138	(1.44)
Agro ecologies (Cool humid mid highlands=0)										
Tepid semi-arid mid highlands	-2.227*	(-2.21)	-0.195***	(-4.59)	-0.155***	(-6.85)	-0.124***	(-6.43)	-0.0674**	(-3.06)
Tepid humid and sub-humid mid highland	2.284*	(2.50)	-0.154***	(-3.36)	-0.131***	(-5.38)	-0.110***	(-5.14)	-0.0663**	(-2.78)
Tepid moist and sub-moist mid-highland	2.067*	(2.38)	-0.227***	(-5.43)	-0.170***	(-7.65)	-0.123***	(-6.44)	-0.0584**	(-2.73)

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[5] Negative sign of the coefficient indicate the variable have positive effect on technical efficiency and vice versa.

[6] Negative sign of the coefficient indicate the variable have negative effect on technical efficiency and vice versa.

Table 5. Contd.

Cool moist and sub-moist mid highlands	1.621	(1.93)	-0.861	(-0.19)	-0.0122	(-0.50)	-0.698	(-0.33)	0.0140	(0.62)
Warm sub humid lowland	2.313*	(2.45)	-0.262***	(-4.82)	-0.254***	(-8.69)	-0.183***	(-6.94)	-0.158***	(-6.98)
Regions										
Tigray	1.015***	(3.90)	0.104**	(3.06)	0.117***	(7.65)	0.0872***	(6.70)	0.0708***	(6.02)
Oromia	0.520***	(3.79)	0.0768***	(4.65)	0.0476***	(6.11)	0.0508***	(6.84)	0.0260***	(3.35)
SNNP	0.0576	(0.26)	-0.0112	(-0.50)	-0.00390	(-0.31)	0.0123	(1.09)	0.00780	(0.69)
_cons	-	-	0.660***	(23.15)	0.721***	(41.93)	0.734***	(43.97)	0.847***	(32.9)
N	1444	-	1444	-	1444	-	1444	-	1444	-

production practices, and then reducing the burden on the meager foreign currency the government is spending to import wheat from abroad. ML estimation techniques either overestimate or underestimate real effect of the different socioeconomic variables on technical efficiency, especially when the dependent variable (technical efficiency) has skewed distribution. For instance, ML technique underestimated a variable 'model farmer' as having insignificant effect on technical efficiency while the quantile regression estimate revealed significant effect of the variable on technical efficiency. Similarly, credit participation influence was underestimated by ML techniques but the quantile regression have revealed that credit participation in fact have positive and significant influence on technical efficiency. Therefore, a more comprehensive picture of the effect of the various socioeconomic variables on technical efficiency variable can be obtained by using Quantile regression, than ML estimation technique.

Using quantile regression credit participation, number of wheat plots owned, number of livestock owned and mobile ownership have positive and significant impact on technical efficiency while age has significant but negative influence on technical efficiency, while wheat growing experience, training and education level have no significant influence on technical efficiency.

Conflict of Interests

The authors have not declared any conflict of interests.

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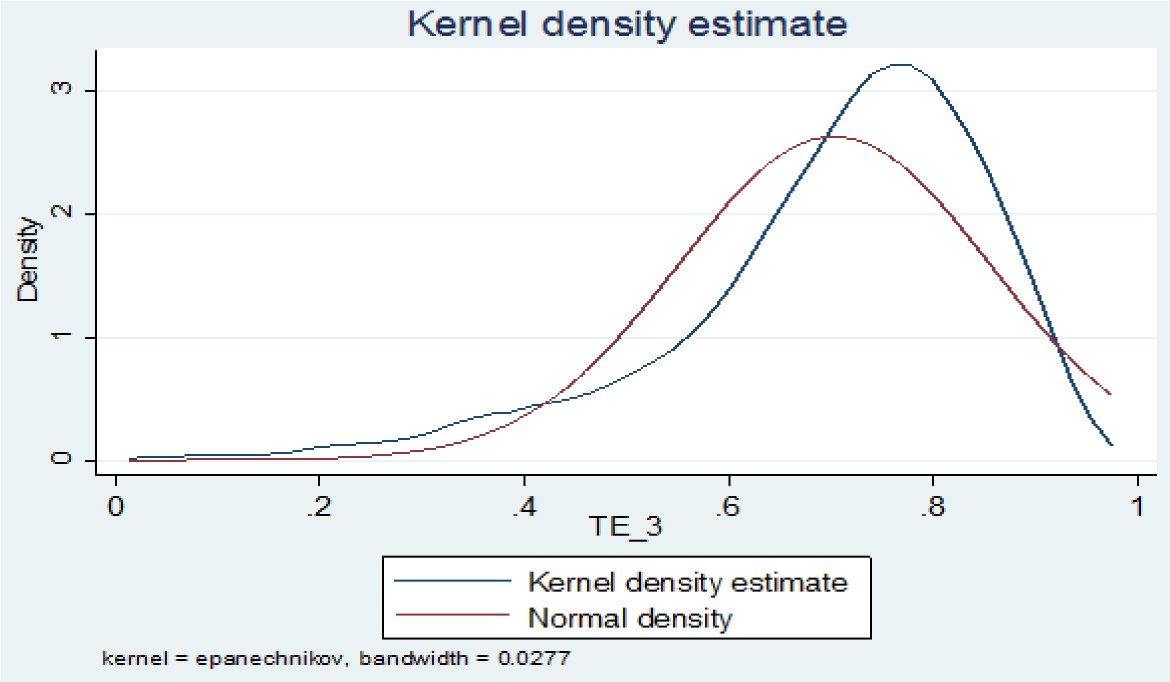
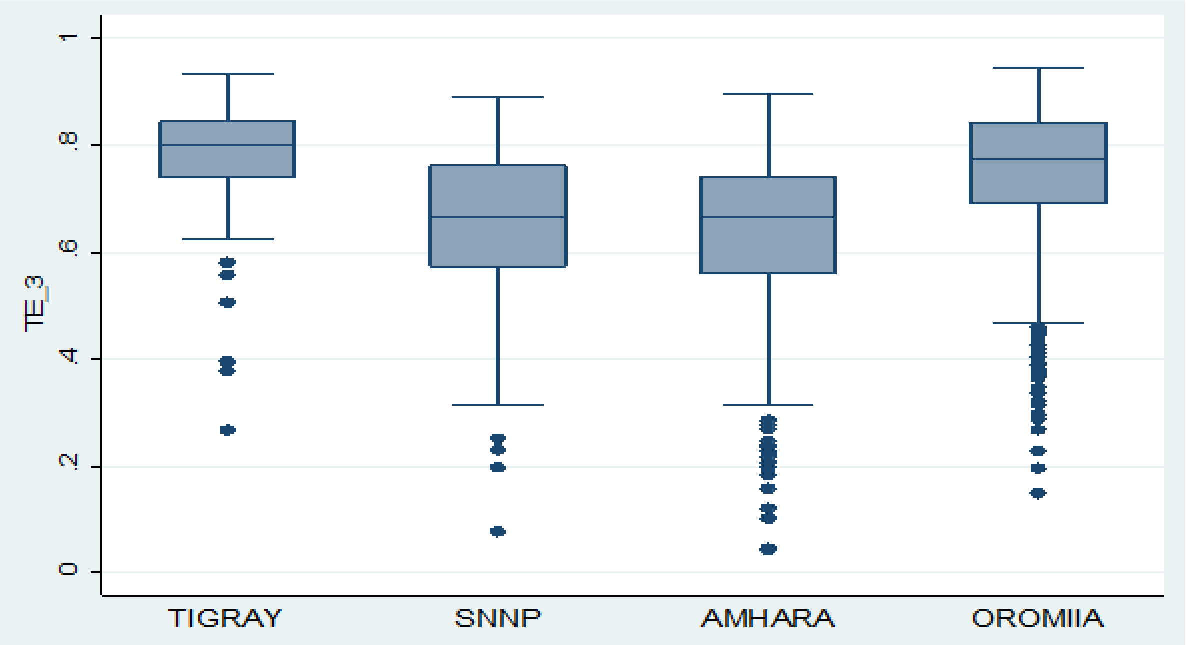
ANNEX



Annex 1. Kernel density distribution of technical efficiency (aggregate of all regions).



Annex 2. Distribution of technical efficiency by regions.

Annex 3. Conversion factor for total livestock unit.

Livestock type	Conversion factor(TLU)	Livestock type	Conversion factor(TLU)
Calf	0.25	Donkey(young)	0.35
Wearned calf	0.75	Camel	1.25
Cows and oxen	1.00	Sheep and Goat(Adult)	0.13
Horse	1.10	Sheep and goat(Young)	0.06
Donkey(Adult)	0.7	Chicken	0.013

Source: Storck et al. (1991).

Annex 4. Conversion factor for man-equivalent.

Age groups (Years)	Male	Female
<10	0	0
10-13	0.2	0.2
14-16	0.5	0.4
17-50	1.0	0.8
>50	0.7	0.5

Source: Storck et al. (1991).

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Soil fauna dynamics affected by decomposition of different legume combinations in alley cropping systems in São Luís, Maranhão, Brazil

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The objective of this study was to evaluate the temporal composition of epigeous fauna during decomposition of different legume combinations in alley cropping systems. Two legume species with high quality waste *Leucaena leucocephala* (*Leucaena*) and *Cajanus cajan* (Pigeon pea), and two species of low quality waste *Clitoria fairchildiana* (Sombrero) and *Acacia mangium* (*Acacia*), were combined forming six treatments: Sombrero + Pigeon pea (S + PP); *Leucaena* + Pigeon pea (L + PP); *Acacia* + *Leucaena* (A + L); Sombrero + *Leucaena* (S + L); *Acacia* + Pigeon pea (A + PP) and control (without legumes). We used the litter bag method to evaluate waste quality. Each bag was filled with 20 g of leaves of the two combined legumes and distributed in the treatments and were withdrawn on the day of pruning and at 3, 6, 10, 15, 30, 60 and 90 days after legume pruning. Two pitfall traps were used to capture epiedaphic fauna in each treatment. Eight evaluations were done based on the date of legume pruning. The initial amount of N was higher in the L + PP treatment (29.31 gKg^{-1}), which showed the highest decomposition constant, providing the fastest release of N in the soil; and presenting the lowest C/N ratio. The highest polyphenol content was found in A + L (4.84%). The soil fauna under different vegetation covers was composed mainly of Aranae, Coleoptera, Diptera, Formicidae, Coleoptera larvae, mites and Collembola; the latter two being the more abundant in all samples. The soil fauna group richness varied during the time of decomposition; the greatest diversity was recorded at 60 days after the legume pruning due to group homogeneity.

Key words: Arthropods, mites, springtails, soil ecology, decomposition.

INTRODUCTION

Alley cropping consists of a production system using dense lines of arboreal or shrubby green manures with high regrowth capacity, and crops of agronomic interest planted between the legume rows; this system is advantageous for increasing biomass production, soil covering and improving erosion control. Moreover, it

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improves soil physical, chemical and biological properties (Vasconcelos et al., 2012). Soil is the richest habitat of the terrestrial ecosystem and its fauna plays an essential role in its functioning and balance as well as in the maintenance of the food chain and energy flow in the organic waste decomposition dynamics (Morselli, 2007; Nunes et al., 2009). As a result of this connection with the processes occurring in the soil and its enormous sensitivity to changes in the environment, soil fauna composition reproduces the ecosystem functioning pattern (Vasconcelos et al., 2012).

Soil fauna abundance, diversity, and interference are indicators of soil quality (Cunha Neto et al., 2012), and significantly improve the soil physical and chemical properties in areas subjected to recovery processes (Morselli, 2007). Thus, well managed degraded areas increase the soil fauna population density, benefiting the establishment of soils suitable for agriculture (Nunes et al., 2009).

In addition, legumes act directly on the soil fauna population, promoting nutrient cycling, extraction and mobilization into the deeper soil and subsoil layers, higher Cation exchange capacity (CEC) values, higher organic matter content, increase in microbial biomass carbon, increase in microbial coefficient, reduction of soil density and increase in macroporosity and total porosity (Silva et al., 2013). These effects are related to organic waste maintenance on the soil (Cunha Neto et al., 2012).

Therefore, due to importance of alley cropping for the humid tropics, this study aimed to evaluate the soil fauna composition under different vegetation covers in the State of Maranhão, Northeastern Brazil.

MATERIALS AND METHODS

Study area

The study was conducted in São Luís, Maranhão State, Northeastern Brazil (2º30′S and 44º18′W). The soil of the study area is classified as Ultisol Yellow Dystrophic Hapludalf (Embrapa, 2013).

Experimental design

The alley cropping trial was established in 2002 in a randomised complete block design, with six treatments consisting of planting four legume species used for mulching in different combinations, and replicated four times. Two legumes of high- quality waste, *Leucaena leucocephala* (Leucaena) and *Cajanus cajan* (Pigeon pea) and two of low quality, *Clitoria fairchildiana* (Sombrero) and *Acacia mangium* (Acacia) were used. Plants were sown in double rows in such a way that each plot received two types of residue resulting from the combination of two legume species. Thus, treatments were: Sombrero + Pigeon pea (S + PP); *Leucaena* + Pigeon pea (L + PP); *Acacia* + *Leucaena* (A + L); Sombrero + *Leucaena* (S + L); *Acacia* + Pigeon pea (A + PP) and control (without legume species). The crops were sown in single rows, 0.5 m between plants and 4 m between rows, in 21 × 4 m plots.

Cassava (*Manihot esculenta*) was planted in 2006 between the legume rows at 12 × 4 m, representing 20 plants per plot. Fertilisers were used at the rate of 80 kg ha^{-1} of P_2O_5, 40 kg ha^{-1} of K_2O and 3 kg ha^{-1} of Zn. In January, 2008, the legume plants were pruned at 50 cm height and the pruning parts were weighed and spread uniformly on the soil surface of each treatment plot.

Residue evaluation

Litter bags of 35 × 35 cm with 2-mm openings were used to evaluate residue quality. Each bag received 20 g of mixed leaves of the two legume species and was placed in contact with the soil in the respective treatments (except control). Bags were removed from the plots in the day of pruning, and at 3, 6, 10, 15, 30, 60 and 90 days after legume plant pruning. The resulting material was carefully cleaned and oven dried at 60°C until a constant weight was obtained, and then weighed, grounded, and subjected to chemical analysis.

Nitrogen content was analysed according to the methodology proposed by Tedesco (1982), in which samples go through sulfuric digestion and N content is evaluated by vapor drag followed by titration. Organic carbon was evaluated using the method proposed by Sparks et al. (1996), which submits samples to potassium dichromate and sulfuric acid, followed by titration. Total polyphenols were extracted using the Folin-Denis method, which consists of total extraction of polyphenolic compounds, including condensed and hydrolysable, with a 50% methanol solution (Anderson and Ingram, 1993).

Fauna evaluation

Epiedaphic samplings were made two days before pruning (dbp) and at 3, 6, 10, 15, 30, 60 and 90 days after pruning (dap). Two traps were placed 1 m apart at the center of each plot, buried in the soil and filled with 200 ml of water with 2 drops of detergent. To prevent rainwater from directly entering, the trap opening was protected by a plastic dish suspended approximately 5 cm from soil level by wooden stakes. Traps remained 48 h in the field. Collected materials were washed and the organisms were placed in 70% alcohol and identified in great taxonomic groups using entomological keys.

Statistical analysis

Decomposed dry matter in function of time was computed by the difference between initial mass weight at the end of each sampling, and the percent of the remaining computed dry matter. The decomposition constant K was computed according to Olson (1963) with the exponential model of the dry matter in bags in time zero (t = 0): $X_0 . e^{-kt}$, where Xt = weight of the dry matter remaining after t days, X_0 = dry matter placed in bags at time zero (t = 0), after calculation of the mass remaining throughout the period.

Analysis of variance was carried out to evaluate the difference between decomposition constant for each combination of legume species using the Tukey test at 5% probability for mean comparisons. Soil fauna diversity was calculated using the Shannon - Wiener Diversity Index and the equitability. Orders of insects relative frequencies was obtained and those with values lower than 1% were grouped as “others.” The taxonomic groups were submitted to multivariate method and cluster analysis, to describe similarity among treatments.

RESULTS AND DISCUSSION

The initial amount of N was higher in the treatment L +

PP (29.31 g Kg^{-1}) followed by A + L (26.07 g Kg^{-1}), S + PP (25.63 g Kg^{-1}), A + PP (25.38 g Kg^{-1}) and S + L (23.42g Kg^{-1}). The highest polyphenol content was found in A + L (4.84 %), followed by L + PP and S + L (3.92 and 4.01%, respectively) and the lowest rates were in S + PP and A + PP (both with 3.35%). The C/N ratio was lower for L + PP (16 g Kg^{-1}) followed by A + L (17 g Kg^{-1}), S + L (18 g Kg^{-1}) A + PP (19 g Kg^{-1}) and S + PP (19 g Kg^{-1}) (Table 1).

The *Leucaena* and *Gliricidia* species have a robust capacity for regrowth; they can produce large amounts of high-quality biomass with high N and low lignin and polyphenol contents, thus contributing to higher production (Mafongoya et al., 1997). The C/N ratio reflects the speed by which the material decomposition can be processed. The residues with C/N ratios less than 25 (legumes) decompose faster; high contents results in lower C/N (Ferraz Júnior, 2004).

It was observed that in all evaluations, the treatments with the highest number of individuals were with *Acacia* or Sombrero (2 dbp and 3, 15, 30, 60 and 90 dap). These treatments also had the highest residue additions and the highest C/N relationship and the amount of polyphenols. The soil fauna variation behavior between treatments characterizes the influence of waste with different chemical compositions, because the residues with a higher C/N relationship rate are less vulnerable to the effect of decomposition agents, accelerating the loss (Resende et al., 2013). The social insects, saprophytes and herbivores, are among the few organisms able to feed on residues of low-quality material, indicating that the litter quality determines the ability of saprophagous organisms to release nutrients, influencing the faunal community size (Santos et al., 2008; Resende et al., 2013).

Regarding the constant decomposition of legume combinations, the treatment L + PP had the highest value, but it was not statistically different from S + PP, which, in turn, did not differ from the other treatments. It was expected that the treatment L + PP would be different from the treatments A + L, S + L and A + PP due to their smaller C/N relationship (Figure 1). The decomposition rates in this study were lower than the k values (1.24 and 1.80) to litter found for *Acacia mangium* by Castellanos-Barliza and León (2011). The modified microhabitat increases growth and development of the soil fauna. Furthermore, it facilitates litter decomposition, nutrient release and promotes biotic interactions (Wang et al., 2010).

A total of 78,210 individuals, distributed in 31 groups were found throughout the study period. The highest number of individuals (5,938 individuals/trap) was observed 2 dbp in the treatment A + L, where they were most abundant (Figure 2).

Before legume pruning, many weeds and remaining pruning material from previous years, such as branches, and trunks, were observed, particularly in the treatments with *Acacia* and Sombrero, and senescent leaves resulting from legume regrowth. The spontaneous plants present relevant ecological functions for the agroecosystems. According to Altieri et al. (2003) they are important, especially for biological control by providing an environment serving as support for pest natural enemies such as predators and parasitoids of many crops of economic importance, providing pollen, nectar, shelter and a microclimate favourable to their optimal development conditions.

At 3 dap, the number of arthropods decreased dramatically (1,611 individuals/ trap), with treatment A + L showing higher abundance. This marked decrease in the number of organisms may have occurred because the vegetation cover may have increased the foraging area of arthropods in each treatment, favouring the dispersion of soil fauna and decreasing their probability of falling into the traps. Santos et al. (2008) observed significant differences in an arthropod population with the use of cover crops compared to fallow. Thus, it is possible that the cover crops used to protect the soil significantly affected the soil fauna community.

At 15, 30 and 60 dap, it was observed that the abundance of arthropods declined sharply, with 2,288, 1,198 and 825 individuals/trap, respectively, but at 90 dap, the amount of organisms increased, on average, to 1,419 individuals/trap, highlighting the treatment A + PP as the most abundant (Figure 2); in this period, it was observed that the plant material was already at an advanced decomposition stage. The final decomposition stage was characterized by gradual decomposition of the most resistant compounds, which is carried out by actinomycetes and fungi activity; thus, there may be an increase in the amount of bacteria and fungi (microorganism decomposers) to decompose the material (Eisenhauer et al., 2010), and these bodies can lead to an increase in the micro herbivorous arthropod abundance and/or species richness and consequently, their predators (such as Collembola and some mites) that were the most abundant groups, causing the so-called bottom-up control (Kaspari, 2004).

The Collembola and mites were more abundant in most collections in all treatments. Except, in the treatments L + PP (23.5±4.3) and the control (25.3±8.9) at 60 dap, Formicidae presented the highest average (Table 2). Collembola and Acari play an important role in the soil, because they are predators of some soil organisms, especially the microbiota, besides assisting in the soil organic matter decomposition and regulating microorganism populations, particularly the fungi (Baretta et al., 2008). Feeding specificity, weatherproof resistance levels, reproductive biology and dispersal capacity are considered possible reasons of higher occurrence of such bodies in certain areas. Some studies show that these two groups are present at various levels of organic matter decomposition (Hoffmann et al., 2009; Monroy et al., 2011).

Table 1. Chemical composition and dry matter resulting from the legume combinations in the alley cropping system.

Treatments	C/N*	C (g kg^{-1})	N (g kg^{-1})	Polyphenol (%)	Dry matter (Mg/ha)**
Sombrero + Pigeon pea	19	497.55	25.63	3.35	4.92
Leucaena + Pigeon pea	16	485.26	29.31	3.92	0.78
Acacia + *Leucaena*	17	440.22	26.07	4.84	6.42
Sombreiro + *Leucaena*	18	415.65	23.42	4.01	5.71
Acacia + Pigeon pea	19	472.98	25.38	3.35	5.64

*Carbon/Nitrogen ratio; **Megagram/ha.

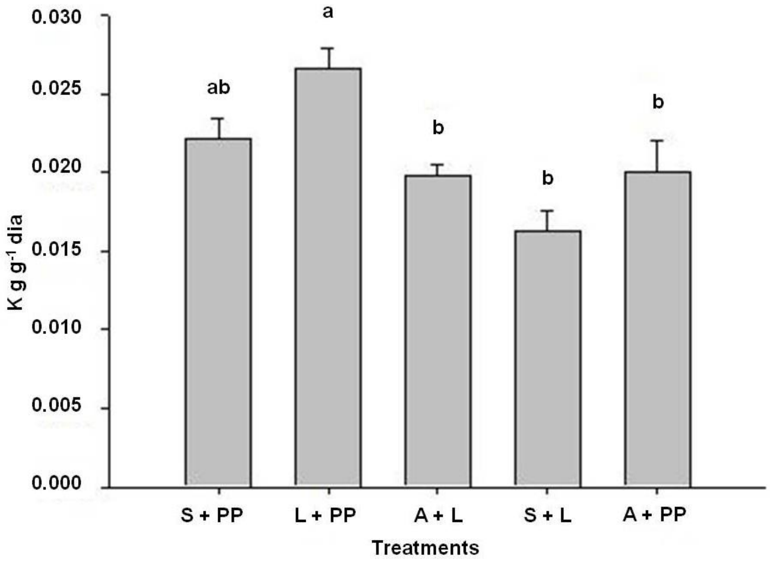

Figure 1. Decomposition constant (K) of legume combinations in the alley cropping systems. *Treatments with the same letter in columns are not statistically different by Tukey test at 5%. Error bars show the standard deviation.

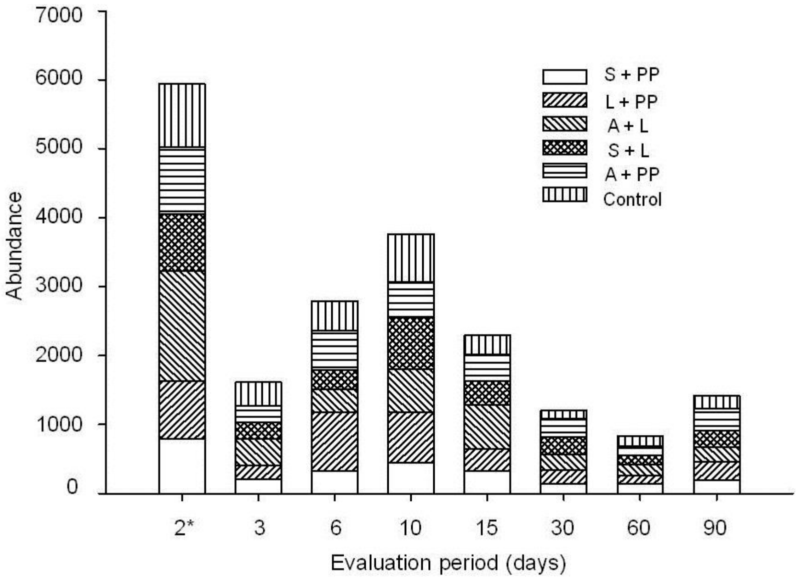

Figure 2. Number of arthropods collected in legume combinations in the alley cropping system. *Two days before legume pruning.

Table 2. Composition (%) of edaphic arthropod community in legume combinations in the alley cropping system.

Groups	Days after pruning						
	2*	**3**	**6**	**10**	**15**	**30**	**60**	**90**
Sombrero + Pigeon pea								
Acari	31.54	30.31	14.76	11.36	18.26	39.10	24.53	6.83
Aranae	0.51	5.19	1.81	1.83	3.62	2.42	8.87	2.40
Collembola	58.91	27.48	67.43	68.18	53.89	25.61	16.60	69.15
Coleoptera	1.24	3.54	4.79	4.49	3.70	6.40	20.19	4.93
Diptera	0.63	2.36	2.12	1.77	5.28	1.73	2.64	2.15
Formicidae	5.20	23.00	4.71	3.82	6.19	12.46	14.15	6.95
Coleoptera larvae	0.41	0.94	0.63	4.55	3.85	0.87	1.51	0.88
Others	1.55	7.19	3.30	3.99	5.21	11.42	11.51	6.70
Leucaena + Pigeon pea								
Acari	39.60	22.81	8.55	18.54	24.32	44.37	19.61	23.36
Aranae	1.01	3.80	1.72	1.18	4.55	3.10	4.74	3.93
Collembola	50.07	40.05	84.44	62.02	41.55	25.61	16.38	57.51
Coleoptera	1.09	4.18	0.41	3.43	6.78	4.66	15.95	2.75
Diptera	0.30	5.20	0.52	3.43	7.18	3.36	3.45	1.18
Formicidae	6.48	14.32	2.18	4.12	6.86	12.68	20.26	6.08
Coleoptera larvae	0.09	0.38	0.47	3.05	2.79	1.55	1.29	0.10
Others	1.36	9.25	1.72	4.23	5.98	4.66	18.32	5.10
Acacia + Leucaena								
Acari	35.66	45.31	17.03	23.30	51.65	67.11	40.67	20.09
Aranae	0.33	1.56	1.58	1.69	1.61	1.86	3.50	1.46
Collembola	59.21	21.32	62.27	53.83	27.48	12.72	16.50	62.63
Coleoptera	0.39	4.50	5.18	3.85	3.11	3.73	7.17	2.02
Diptera	0.30	3.65	2.78	4.83	6.21	1.43	4.50	1.91
Formicidae	3.47	17.86	5.93	5.82	4.17	7.68	14.33	8.19
Coleoptera larvae	0.03	0.59	1.58	2.28	2.59	1.10	1.33	0.22
Others	0.61	5.22	3.68	4.40	3.18	4.39	12.00	3.48
Sombrero + Leucaena								
Acari	51.31	19.39	19.87	7.83	10.93	34.42	25.91	13.11
Aranae	0.72	4.21	1.80	1.28	3.77	2.78	7.43	3.64
Collembola	41.09	50.16	57.73	71.48	50.91	43.25	27.54	63.37
Coleoptera	1.23	3.58	5.85	4.56	3.84	3.27	8.15	3.95
Diptera	0.24	4.32	2.97	4.15	10.43	2.58	2.90	1.77
Formicidae	3.39	10.43	5.22	3.64	6.52	8.93	15.76	5.31
Coleoptera larvae	0.15	1.37	1.71	4.52	9.92	0.69	0.54	0.73
Others	1.86	6.53	4.86	2.53	3.69	4.07	11.78	8.12
Acacia + Pigeon pea								
Acari	39.17	24.38	10.84	26.52	23.62	67.27	42.42	56.30
Aranae	0.62	4.75	1.10	1.84	3.04	1.62	4.18	2.91
Collembola	55.91	45.97	79.29	53.57	56.68	16.13	23.74	26.46
Coleoptera	0.54	3.82	1.85	3.77	2.15	3.05	2.86	1.18
Diptera	0.21	3.62	0.88	2.46	4.88	1.81	3.96	1.18
Formicidae	2.57	7.02	2.38	4.44	4.50	3.63	10.33	2.99
Coleoptera larvae	0.05	0.10	0.35	1.40	2.15	0.67	0.66	0.08
Others	0.93	10.33	3.31	5.99	2.98	5.82	11.87	8.90
Control								
Acari	9.39	13.10	20.61	12.90	16.17	16.07	13.76	6.71
Aranae	0.33	1.84	0.81	1.25	3.93	1.90	7.19	2.01
Collembola	75.87	61.96	59.00	72.81	49.44	54.97	30.60	70.20
Coleoptera	0.87	1.91	3.42	1.65	3.08	5.50	9.45	1.34

Table 2. Contd.

Diptera	0.36	1.55	3.29	1.93	6.92	3.38	4.93	1.34
Formicidae	11.90	13.39	8.15	5.12	12.99	12.47	20.74	10.74
Coleoptera larvae	0.15	2.28	1.45	0.50	1.78	0.42	2.67	0.54
Others	1.13	3.97	3.27	3.83	5.70	5.29	10.68	7.11

*Two days before legume pruning.

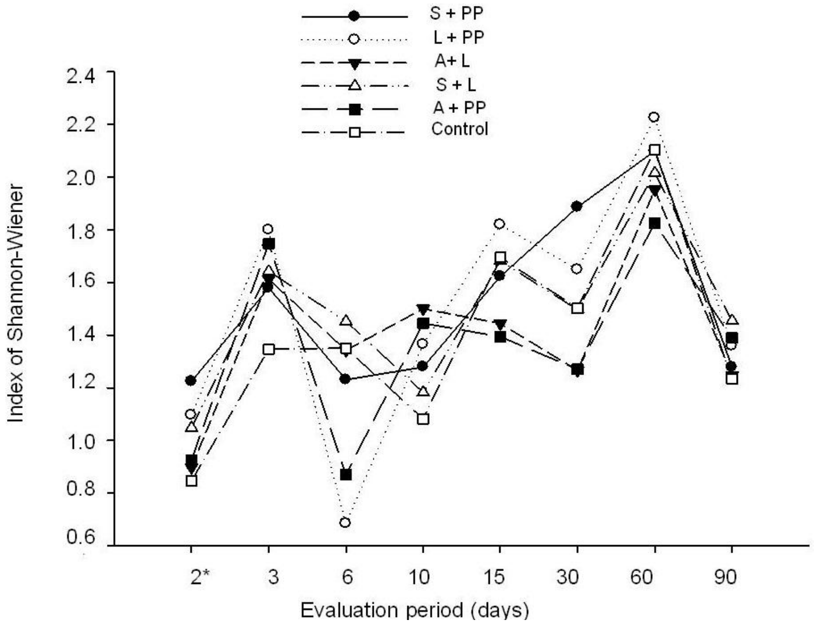

Figure 3. Shannon index of soil fauna in legume combinations in the alley cropping system in different periods of evaluation.

However, the other groups found in the alley cropping are not excluded, because they are also important in the maintenance of the internal regulation in the ecosystem energy flow. The macrofauna plays a key role in the ecosystem by occupying all trophic levels in the food chain from the soil, and to act directly and indirectly in primary production, by forming galleries that facilitate water infiltration, aeration and root penetration into the soil (Silva et al., 2007).

Due to their diversity and magnitude of their functions in the soil environment, some representatives of the macrofauna, such as spiders, beetles, termites, earthworms and ants are considered bioindicators since they are sensitive to environmental changes. Moreover, they are also helpful as disturbed environments restoration agents (Rocha et al., 2011; Ramos et al., 2015; Trifonova et al., 2015).

With respect to the Shannon - Wiener Diversity Index, the treatments showed different results between 6 and 15 dap. The highest value of the Shannon - Wiener Index was recorded at 60 dap for all treatments. This was reflected in a larger evenness in the same period, indicating a higher equitability of the abundance of each group, thus reducing the dominance of some groups such as mites and Collembola (Figures 3 and 4). Such an effect may have been caused by the decomposition rate of each treatment, because the arthropod preference varied with the plant material quality change (Resende et al., 2013).

There was no abrupt changes in the arthropod group diversity in the treatment S + PP (Figure 4), probably due to their higher C/N relationship and the polyphenol amount (Table 1), as few organisms are adapted to directly feed on materials under these conditions (Resende et al., 2013).

The cluster analysis based on the soil arthropod community structure revealed formation of two groups, one represented by the treatments A + PP, and A + L with similarity of approximately 46% (Figure 5). These two treatments had a similar amount of dry matter, besides the same C/N ratio at the beginning and end of the experiment. At the same time, the amount of weeds in these treatments was also lower. A study conducted in the same area showed that the treatments with *Acacia*

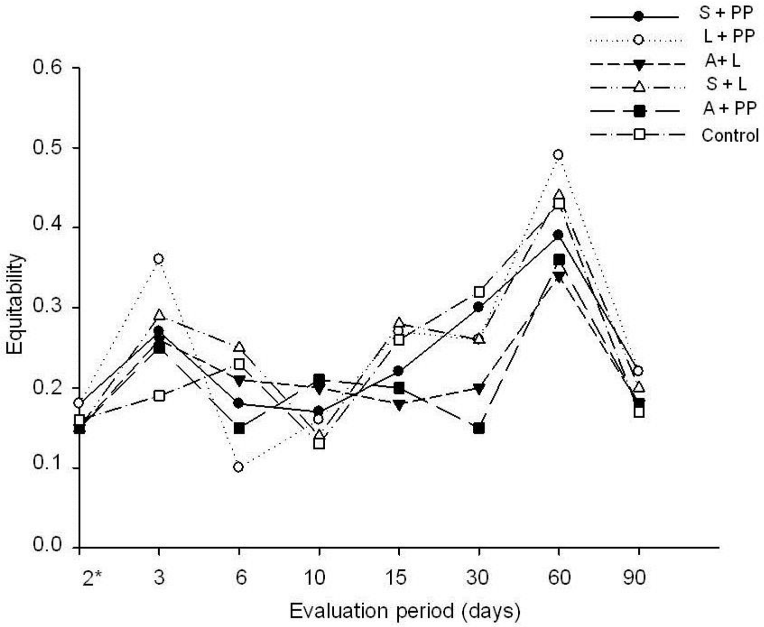

Figure 4. Equitability of soil fauna in legume combinations in the alley cropping system in different evaluation periods.

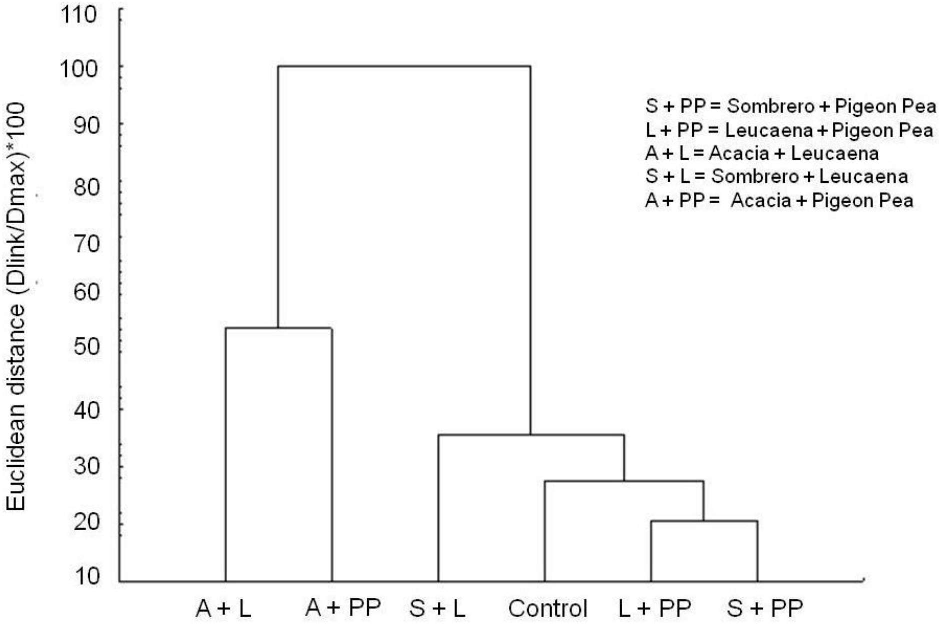

Figure 5. Similarity dendrogram of soil fauna based on Euclidean distance averages in legume combinations in the alley cropping system.

had a higher effect on the weed abundance due to the higher amount and durability of the waste (Moura et al., 2009).

The second group was formed by treatments L + PP, S + PP, S + L and control, and had approximately 64% similarity to each other. The treatments S + PP and L + PP showed 80% similarity, despite that the Sombrero is a legume with low residue quality. No soil fauna preference for the legume combination treatments was observed. However, it was observed that there was high activity in all treatments in search for better food quality and for protection from rain or as refuge by microhabitat complex, provided by the plant material with slower decomposition. This was observed not only for saprophagous groups, but also for various predators present in the system. According to Resende et al. (2013) the soil fauna varies during the plant residue decomposition process and species differ with respect to contrasting decomposition speeds; the polyphenol content is the feature that most affects this behavior.

Conclusion

The soil fauna under different vegetation covers is composed mainly of Aranae, Coleoptera, Diptera, Formicidae, Coleoptera larvae, mites and Collembola, and the latter two are the dominant groups. The soil fauna group richness varies with time of decomposition, with the greatest diversity recorded at 60 days after legume pruning due to the group homogeneity.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Antimicrobial action against of *Macrophomina phaseolina* and control of the grey stem in soybean by homeopathic remedies *Nosode* and *Sulphur*

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The aims of the study were to evaluate the control of botrytis in the soybean stem, spraying homeopathic solutions of *Sulphur* and *Nosode* of *Macrophomina phaseolina* in the dynamizations 6, 12, 24, 36 and 48CH. As additional treatment, we used distilled water and hydroalcoholic solution at 30% ethanol. *In vitro* tests were performed so as to analyze the number of micro-sclerotia and mycelial growth of the fungi, and *in vivo* tests to track the progress of the botrytis stem and the size of the lesion. The experimental design was in randomized blocks, with five replications. For the area under the mycelial growth curve (AUMGC) in the first test, there was no significant effect of *Sulphur* and Nosode of *M. phaseolina*. *In vivo* studies, comparing *Sulphur* with the control treatment, showed a reduction of 14 and 15% for the dynamizations of 12 and 48 CH, respectively. For the amount of micro-sclerotia of *M. phaseolina*, in the first test, Sulphur showed a reduction of up to 50%; *Nosode* of *M. phaseolina* showed no significant reduction of micro-sclerotia. In the second test, *Nosode* was not significant while *Sulphur* caused a reduction of up to 33%. For area under the disease progress curve (AUDPC), in both trials, the drugs proved to be ineffective. These results indicate the potential of these homeopathic remedies in controlling the fungus, *M. phaseolina*.

Key words: Alternative control, *glycine max*, homeopathy.

INTRODUCTION

Brazil is the second largest producer of soybean in the world after the United States, with a production of 98,981.600 tons (Conab, 2016). Over the years and with the increase in cultivated soybean area, is the emergence of diseases that impair productivity. Botrytis stem caused by the fungus *Macrophomina phaseolina* is one of the most important disease, It affects the roots and lower part of the stem; it first causes discoloration and then a dark brown or black coloration. When the weather is favorable, that is, periods of drought, heat and very high temperature, the disease can attack young plants. In mature plants, the infection usually occurs from the middle of the cycle (Almeida et al., 2014). Due to the degree of dangerousness of the disease, it is necessary to control it, which is based on the practice of direct planting and vegetation cover, in order to avoid water stress; chemical and physical soil management; rigorousness at the time of planting; use of recommended varieties for the region; promoting unsuitable environment for the fungus (Almeida et al., 2014), as well as alternative methods of control, such as homeopathic treatment.

Homeopathic medicine is all pharmaceutical form intended to be administered according to the principle of similarity, with preventive and therapeutic purposes, obtained by the method of dilutions followed by succussions and/or successive grindings. The succussion consists of vigorous and rhythmical agitation of dissolved drugs in an appropriate inert ingredient and the boosting results from the process of dilutions followed by succussions and/or successive grindings of the drug, with the purpose of medical power development (Farmacopéia homeopática brasileira, 2011). According to Carneiro et al. (2011), alternative methods of agriculture are modern methods, developed in sophisticated and complex system of agricultural techniques, whose main objective is not the economic exploitation short sighted and inconsequential, but the economic exploitation in the long term, maintaining stable and self-sustaining the agricultural ecosystem. Therefore, this study aimed to develop an alternative method through homeopathy to control *M. phaseolina* in soybean; check the antimicrobial activity of the homeopathic remedies *Nosode* of *M. phaseolina* and *Sepia* against *M. phaseolina*; and control stem botrytis in soybean plants by using these drugs.

MATERIALS AND METHODS

For this study, two experiments were performed *in vivo* and *in vitro*. For the *in vivo* test, the isolated *M. phaseolina* was put in rice medium and liquid medium PD (potato dextrose); and three discs of the *M. phaseolina* colony grown in Petri dish with 1 cm diameter. Containing what media was added to PDA medium (potato, dextrose and agar). For the *in vivo* test of the second experiment, the isolated *M. phaseolina* was put in petri dishes (0,1 cm diameter) with PDA medium and after the fungi present micro-sclerotia, medium with mycelial disks and micro-sclerotia were used for inoculation of the soybean plants in the pots. In both trials, the soybean seeds used in the *in vivo* experiment were from the cultivar NK 412113 (V-MAX convencional). In both trials the following homeopathic medicines were used: *Sulphur* and *Nosode* of *M. phaseolina*, the first being a homeopathic polychrest and the second starting the healing principle by the similar. The *Sulphur* was acquired in homeopathic pharmacy in the 6CH boosting and manipulated to 12, 24, 36 and 48CH as described by the Brazilian Homeopathic Pharmacopoeia (2011), diluted 1: 100 and sucussioning 100 times. The *Nosode* of *M. phaseolina* was obtained from mycelium grown on potato dextrose liquid medium (PD), which was allowed to stir in orbital shaker at 150 rpm for 7days, after filtration was carried out of the the fungus to separate all the culture medium. Three grammes (3 g) of the fungus (*M. phaseolina*) was placed in amber glass together with 27 ml of 70% grain alcohol with the glass encased by aluminum foil and left at rest for 21 days, stirring only once a day in a soft way, producing the mother tincture (Bonato, 2007) and through this, were manipulated as the Brazilian Homeopathic Pharmacopoeia (2011). The dynamizations used were the same of *Sulphur*, that is to say 6, 12, 24, 36 and 48CH.

As additional treatments, we used distilled water and hydroalcoholic solution of 30% ethanol. Water and ethanol were used because they are solvents in the preparation of homeopathic drugs.

To determine the antifungal activity, we used medicines in their due boosting, being incorporated into the culture medium (PDA) still liquid and hot in the Erlenmeyer flask. 0.005% and 5 uL of treatment were used to each 100 ml of PDA culture medium (Bonato, 2007). After, the PDA medium was poured and complete solidification was expected. It was added in the center of each petri dish a disc, removed from the fungal colony, to grow. The dishes were still incubated at room temperature in the dark. Daily measurements were initiated 24 h after the beginning of the experiment and ended when the fungal colonies reached the edges of the petri dish. Such measurements were performed according to the methodology described by Stangarlin et al. (1999) through the method of diametrically opposed measures to evaluate the diameter of the colony. At the end of the daily measurements for determining the area under the mycelial growth curve (AUMGC), we pulled out a known amount of the fungus, standardizing the pickup location and made to count the number of micro-sclerotia in magnifying glass. Through simple rule of three, the total number of micro-sclerotia in each petri dish was obtained.

For both tests *in vivo* tests, 1 liter pots containing the soil mixture were used, along wish sand and organic matter in the proportion 2: 1: 1, autoclaved at 120°C for 1 h. We used the drugs *Sulphur* and *Nosode* of the fungus *M. phaseolina*. The inoculum of *M. phaseolina* for the first test was produced using a rice medium (rice 25 g to 30 ml of water) and in each pot were added two grains of rice colonized with micro-sclerotia of the fungus *M. phaseolina*, in the center of the pot at 1 cm depth. Soybean seeds were sown around the inoculum, at a distance of 2 cm from it and subsequently held the thinning, maintaining three soybean plants per pot. In the first trial, the treatments were administered three days before sowing, in the sowing day, 3, 10 and 17 days after sowing. The application was on the soil in a proportion of 0.1% (100 uL of treatment to 100 ml of distilled water) or 1 uL per pot. We evaluated the drought of the stem giving values from one to four, and admitted one when there was an absence of drought, two in the presence of drought up to 1/3 of the stem, three for the presence of drought up to 2/3 of the stem, and four for the presence of drought in the whole stem. The values were transformed and calculated, the area under the disease progress curve (AUDPC). As for the second test, inoculum of *M. phaseolina* was produced on PDA and was added to each pot three discs containing the fungal mycelium, each of the disks placed in contact with the soybean plant root. This procedure

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Table 1. Area under the mycelial growth curve (AUMGC) of *M. phaseolina* in PDA medium with different dynamizations of the remedies *Sulphur* and *Nosode* of *M. phaseolina.* Data referring to the first test.

Boosting (CH)	*Sulphur*	Average	*Nosode* of *M. phaseolina*	Average
6	20.52 ^{ns}	-	20.16 ^{ns}	-
12	19.78	-	20.76	-
24	20.91	20.58	20.41	20.89
36	19.65	-	20.2	-
48	19.32	-	20.52	-
Average additional treatment hydroalcoholic solution at 30% ethanol				23.31
Average additional treatment distilled water				20.78
Factorial average				20.74
C.V.(%)	3.45	-	2.19	-

^{ns}: Absence of significance between dynamizations of the same remedy or among remedies. Additional treatment: distilled water.

was performed when the plants issued the first trifoliate leaf. In the same day, after the inoculation the soil of the pots was covered with hay.

The treatments were administered in the second test in the soil using spray three days before inoculation, on the day of inoculation, 3, 10 and 17 days after inoculation. Treatments were applied to the soil at a proportion of 0.1% or 1 uL per pot. Growth measurements were taken of the injury on the plant stem, every two days, using graduated scale. With the data obtained, we calculated the area under the disease progress curve (AUDPC). In both tests, the experimental design was a randomized block design with five repetitions, and the Tukey test at 5% probability of error was used to compare means. The factor was 2 x 5 + 2, being 2, the number of drugs (*Sulphur* and *Nosode*), 5 the number of dynamizations that were used, which were: 6, 12, 24, 36 and 48CH, and 2 corresponds to additional treatments, namely water and 30% ethanol. In the absence of a significant difference for the factorial and for the additional treatments, the data were shown in a table, otherwise, graphs were prepared.

RESULTS AND DISCUSSION

As shown in Table 1, for the area under the mycelial growth curve of the first test, there was no significant effect for *Sulphur* and *Nosode* on *M. phaseolina*. Through Figure 1, it is seen that in the second test for the area below the mycelial growth curve of *M. phaseolina* on PDA medium, both drugs showed the same behavior represented by quadratic equations, demonstrating the significance of *Sulphur* and *Nosode* of *M. phaseolina*. For dynamizations 12 and 48CH, *Sulphur* differed from *Nosode* of *M. phaseolina* showing greater reduction in AUMGC. Comparing *Sulphur* with the control there is a reduction of 14 and 15% in the dynamizations 12 and 48CH, respectively. In a work carried out by Toledo et al. (2015), it was found that the mycelial growth of *Alternaria solani* in the presence of *Sulphur* homeopathic preparation in 100 CH, was inhibited by 16.97% compared to the control. In another work, where Sinha and Singh (1983) observed the toxic effect of *Sulphur* on *Aspergillus parasiticus*, had 100% inhibition in mycelial growth using the boosting 200 CH, showing that *Sulphur,* subject to the boosting and on what the fungus will act, can be as effective as chemicals. Since there was no normal data for the amount of micro-sclerotia of *M. phaseolina* from the first test, it was carried out the transformation of the data into root of x+0.5. Through Figure 2, it can be observed that *Sulphur* showed a reduction of 50% in the number of micro-sclerotia, this effect being represented by a second degree equation. As for *Nosode* of *M. phaseolina,* it showed no significant reduction of micro-sclerotia.

For the amount of micro-sclerotia of the second test, as the data did not show any normality, it was carried out the transformation of that data into root of x+0.5. In Figure 3, it can be observed that *Nosode* of *M. phaseolina* did not show significance, while *Sulphur* showed a behavior represented by quadratic equation and provided a reduction of up to 33%, a very important number since the micro-sclerotia are the form of survival of the fungus on the ground, and it contributes to the spread and survival of this for long periods. The reduction of sporulation was also observed with *Sulphur* in the work conducted by Toledo et al., (2015) where it had 53% of reduction for the boosting 30 CH to 63% for boosting 6 CH. In work done by Toledo et al. (2013) seeking to evaluate the inhibition of sporulation of *A. solani* by *Ferrum sulphuricum,* it was found that the dynamizations 6, 12, 18, 21, 24, 27, 30, 48, 66, 69, 72, 75, 78, 81 and 96 CH decreased sporulation and were statistically different from the controls distilled water and hydroalcoholic solution 70%, having the inhibition of 71.6% in the dynamizations 24 and 78 CH and variation of 88.42% in the dynamizations 21 and 96 CH of spore inhibition. Toledo et al. (2015) also found little effect of using isopathy, in the case of *A. solani* both for mycelial growth and also for the number of micro-sclerotia. With regard to the first test, according to Table 2, there was no statistical difference among the treatments and, bearing this in mind, none of the remedies showed themselves

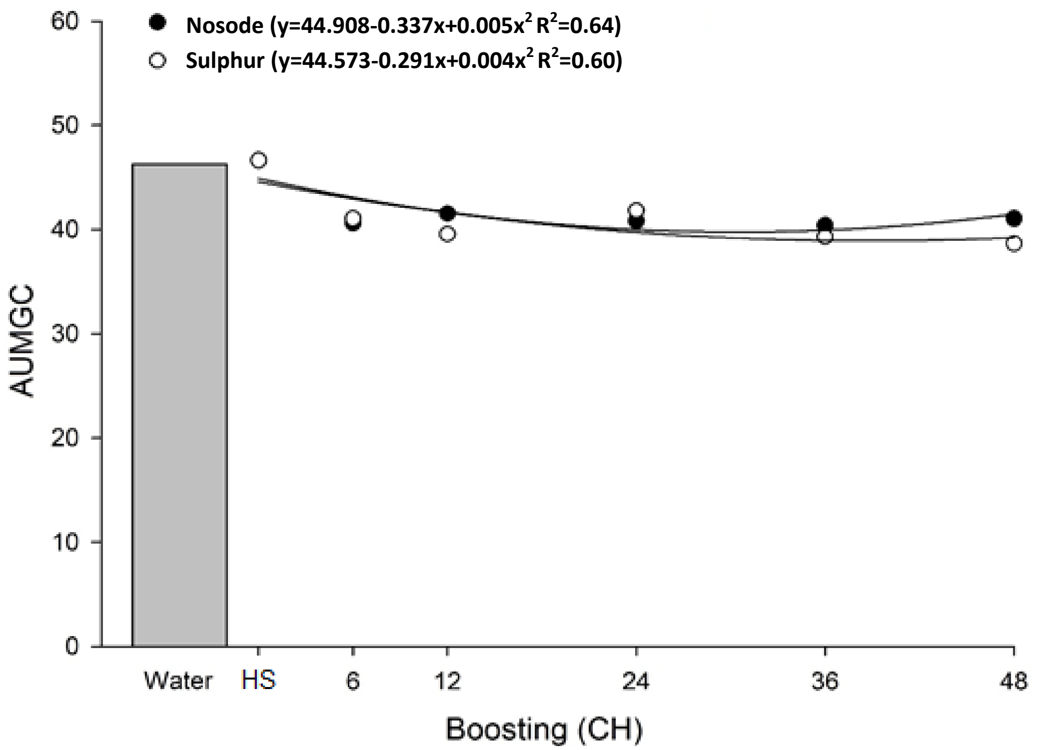

Figure 1. Area under the mycelial growth curve (AUMGC) of *M. phaseolina* in PDA medium with dynamizations of the remedies *Nosode* of *M. phaseolina* and *Sulphur*. HS: Hydroalcoholic solution (30% ethanol). Data referring to the second test.

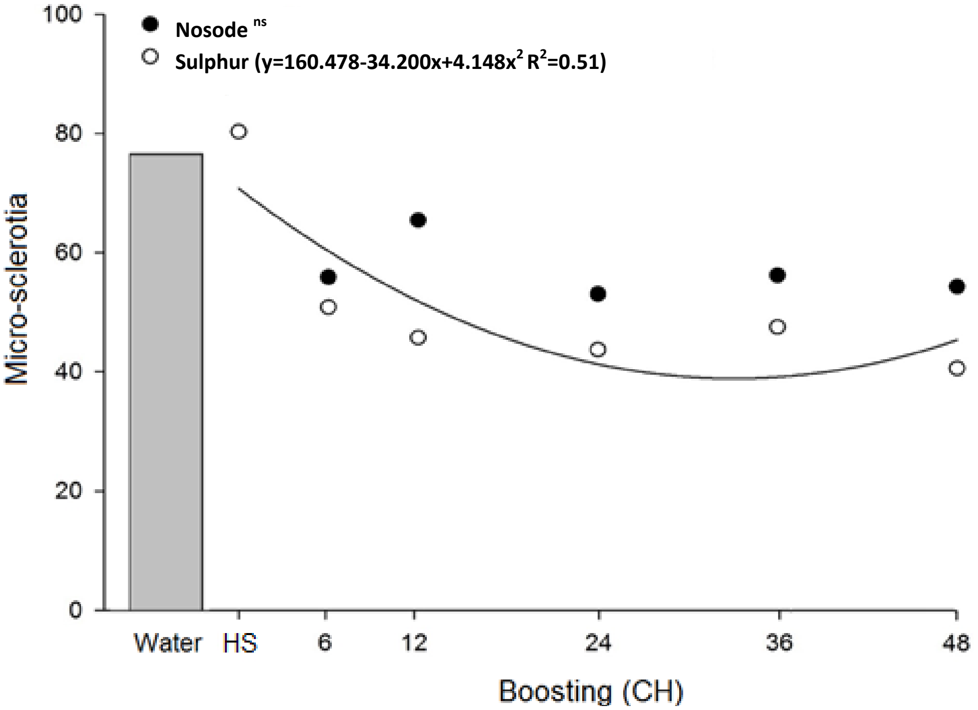

Figure 2. Quantity of micro-sclerotia of *M. phaseolina* in PDA medium with dynamizations of the remedies *Nosode* of *M. phaseolina* and *Sulphur*. Data were transformed into root of x+0,5. ^{ns}: Absence of significance between dynamizations of the same remedy or among remedies. HS: Hydroalcoholic solution (30% ethanol). Data referring to the first test.

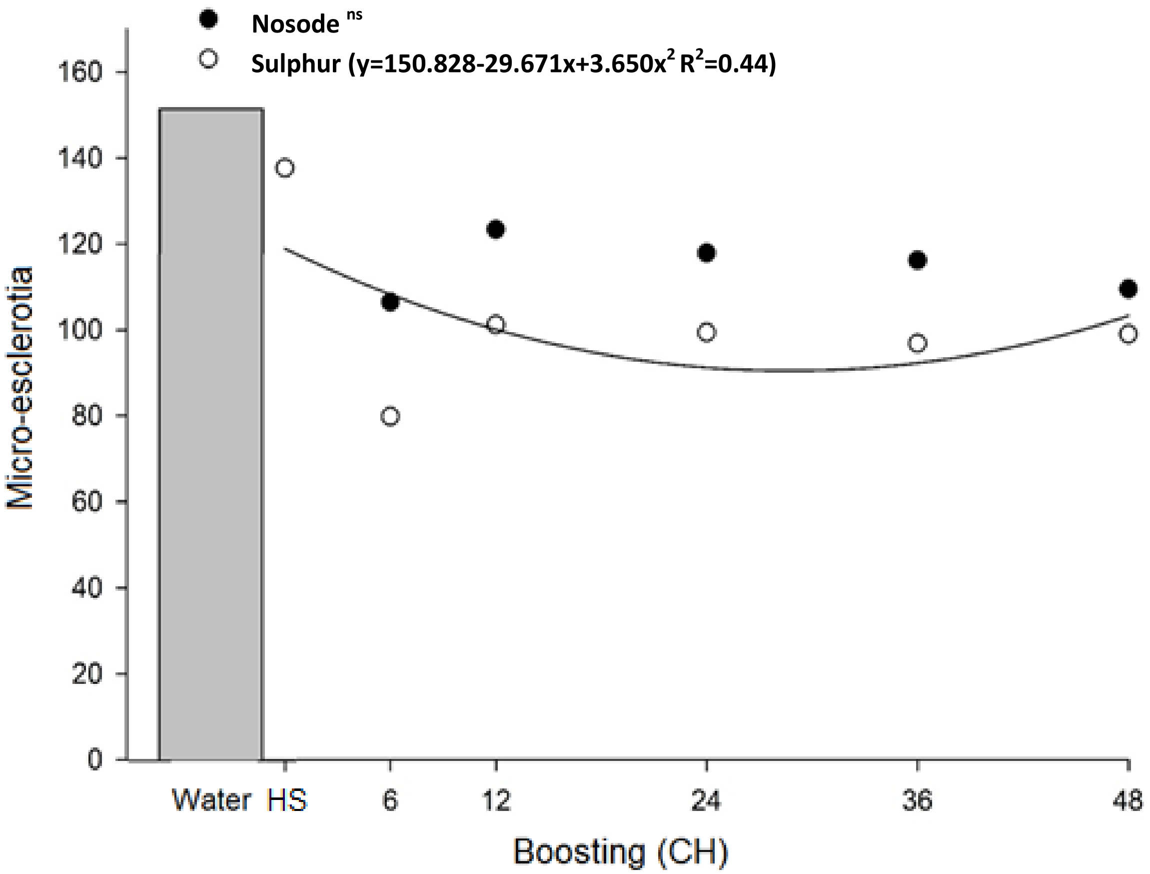

Figure 3. Quantity of micro-sclerotia of *Macrophomina phaseolina* in PDA medium with dynamizations of the remedies *Nosode* of *M. phaseolina* and *Sulphur*. Data were transformed into root of x+0,5. ns: Absence of significance between dynamizations of the same remedy or among remedies. HS: Hydroalcoholic solution (30% ethanol). Data referring to the second test.

Table 2. Area under the disease progress curve (AUDPG) of *M. phaseolina* in soy plants cultivated in a greenhouse and being treated with different dynamizations of the remedies *Nosode* of *M. phaseolina* and *Sulphur.* Data referring to the first test.

Boosting (CH)	*Sulphur*	Average	*Nosode* of *M. phaseolina*	Average
6	727.92^{ns}	940.01	1081.6^{ns}	1025.5
12	706.88		938.34	
24	1511.6		1151.4	
36	970.65		796.44	
48	745.62		1207.4	
Average additional treatment hydroalcoholic solution at 30% ethanol				977.88
Average additional treatment distilled water				2648.30
Factorial average				982.79
C.V. (%)	77.94		77.03	

ns: Absence of significance between dynamizations of the same remedies or among remedies. Additional treatment: distilled water.

efficient to reduce the area under the progress curve for botrytis of the soybean stem in the dynamizations tested.

In Table 3, for the area under the disease progress curve (AUDPC) caused by *M. phaseolina* in soybean plants, in the second test there was also not significance of the treatments. In a study conducted by Toledo et al. (2015), with tomato plants that had black spot, there was a reduction of 34.97% of AUDPC for *Sulphur* medicine in boosting 12CH and reduction of 16.79% for the same drug in boosting 30 CH, this compared to the control of distilled water.

By applying homeopathic solutions in vine for rust

Table 3. Area under the disease progress curve (AUDPG) of *M. phaseolina* in soy plants treated with dynamizations of the remedies *Nosode* of *M. phaseolina* and *Sulphur.* Data referring to the second test.

Boosting (CH)	*Sulphur*	Average	*Nosode* of *M. phaseolina*	Average
6	60.85^{ns}	-	52.88^{ns}	-
12	45.75	-	63.44	-
24	46.71	54.94	45.06	57.85
36	47.51	-	55.17	-
48	48.56	-	50.28	-
Average additional treatment hydroalcoholic solution at 30% ethanol				80.29
Average additional treatment distilled water				52.91
Factorial average				56.39
C.V. (%)	31.73	-	41.53	-

^{ns}: Absence of significance between dynamizations of the same remedies or among remedies. Additional treatment: distilled water.

control, Souza et al. (2006) found that homeopathic treatments have reduced substantially the rust attack (*Phakopsora euvitis*) when compared to the control. Homeopathic solutions Silicea 30 CH, Isophatic 6 CH, 12 CH and 30 CH showed only 7, 17, 9 and 18% of the severity degree presented by the control treatment, which was 100%. Carneiro et al. (2007) found that biotherapic of *A. solani* in the dynamizations 26, 27 and 28 CH reduced the severity of the black spots disease on tomato plants grown in greenhouse. Toledo et al. (2015) evaluated the effect of *Sulphur* and *F. sulphuricum* in the control of the black spots disease on tomato plants, and the results showed that *Sulphur* in 12 and 30 CH minimized the severity of the disease at 10 days after inoculation of the pathogen, and 14 days after inoculation for 6 and 30 CH. Bonato and Silva (2003) confirm that different effects can be seen frequently in homeopathy, depending on the variable analyzed and/or boosting, inhibiting or stimulating the plant. No one knows for sure why this happens, but one possible explanation would be the fact that in nature there are rhythmic movements or the principle of similarity between the organism and the drug (Bonato, 2004).

Conclusion

Although, the homeopathic medicines *Sulphur* and *Nosode* of *M. phaseolina*, in the tested dynamizations have been able to inhibit the mycelial growth and the formation of micro-sclerotia in vitro of *M. phaseolina*, they were not effective to control botrytis in the soybean stem.

Conflict of interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of egg storage temperature and fumigation on hatchability of Cobb 500 and Hubbard broiler strains

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Hatchability of Cobb 500 and Hubbard broiler strain eggs subjected to different levels of egg storage temperature and fumigation was studied at Debre Zeit Agricultural Research Center, Ethiopia. The different egg storage temperature levels employed were 10, 16 and 23°C and fumigation levels employed were fumigated and unfumigated. Fertility and hatchability were tested during the experimental period. Fertility is not dependent on egg storage treatments employed. Egg storage temperature at 16°C and fumigation significantly ($P<0.001$) improved hatchability in both Cobb 500 and Hubbard broiler strains. Cobb 500 broilers had high mean percentage hatchability than Hubbard, but the differences were not significant ($P>0.05$). Egg storage temperature at 23°C resulted in slightly lower mean percentage hatchability than storage at 10°C, but the differences were not significant ($P>0.05$). From the result of the current experiment, it was concluded that fumigation and medium egg storage temperature, 16°C is important for better hatching yield.

Key words: Hatchability, Cobb 500, Hubbard, broiler, strain, temperature, fumigation.

INTRODUCTION

Poultry is an important farm animal species in almost all countries. It is an important source of animal protein and can be raised in situations with limited feed and housing resources. Chickens are ‘waste converters’; they ‘convert’ a scavenged feed resource base into animal protein. They are therefore, one of the most important species for generating income for rural family, especially for developing country like Ethiopia. All over the world, more than 300 breeds of the domestic chicken species (*Gallus domesticus*) exist. Three main categories of chicken breeds are distinguished: pure commercial breeds, hybrid breeds resulting from cross-breeding and local breeds or land races.

Chicken population of Ethiopia is estimated to be 38.3 million (CSA, 2009). To meet food self-sufficiency and poverty reduction, Ethiopia has launched a short and long-term plan program from 1995 onwards. One of the strategies is to exploit poultry resources in the development process. The effort made in improving the poultry industry is one of such strategy that gave more

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emphasis to the introduction of exotic germplasm. At this juncture, broiler production may contribute in meeting the food self-sufficiency for the rapidly increasing Ethiopian human population and to meet the growing demands of animal protein in the country. Their short production cycle, high feed efficiency and high biomass per unit of agricultural land are particularly attractive for Ethiopia where the demand and price for animal protein foods is escalating.

Egg storage is a necessary process in poultry industry to accumulate sufficient number of eggs necessary for each setting. The goal, then, of egg storage is to bring to a standstill embryo development while maintaining their ability to resume development and produce viable and healthy chicks. Hatching eggs are often stored on broiler breeder farms as well as at hatcheries to minimize transportation costs or to provide for enough eggs available to fill the large incubators. Egg storage conditions prior to incubation can influence hatchability and are, thus of considerable concern to commercial hatchery enterprises (Butler, 1991). One of the most important conditions is temperature. Storage conditions should be sufficiently cool to prevent embryonic development during this period. For most bird species, the critical temperature for the initiation of embryonic development appears to be about 25 to 27°C (Drent, 1975). The hatchability of an egg does not necessarily correlate with the quality of chick (Tona et al., 2005). The quality of chick that emerges out of an egg depends on factors such as the age of breeder, length and storage condition of egg before incubation and the incubation conditions (Tona et al., 2005). In the commercial broiler, breeder farms and hatcheries, formaldehyde fumigation is routinely carried out to disinfect hatching eggs (Feras and Beleh, 2008).

Nowadays, new broiler breeds are introduced into the country to solve the scarcity of day old broiler chicks requirement by producers and their by increase the supply of animal protein in the country. However, recommended pre-hatching storage condition of eggs is not well studied. Hence, producers use by adopting information available for commercial layers hatching egg management. In Ethiopia, farmers store eggs at room temperature, but the temperature of the area may vary according to altitude and season. Fumigation of eggs before storing is not also practiced by producers. One of the reasons for not employing proper storage conditions and fumigation could be due to lack of appropriate and locally generated recommendation available as a package with the breed. Thus, it is necessary to make the information available before the distribution of the breed starts. Secondly, the effect of storage condition and hatching egg treatment on hatchability under local condition is not documented. Therefore, knowing the hatchability of Cobb 500 and Hubbard broiler strains subjected to different egg storage temperature and fumigation treatment seems to be very important and timely. The present work was designed to generate data under local condition and improve strategies that realize high percentage hatchability of Cobb 500 and Hubbard broiler strains with the objective of determining the effect of different egg storage temperature, fumigation, breeds and their interaction on hatchability.

MATERIALS AND METHODS

Description of the study area

The experiment investigated the effect of egg storage temperature and fumigation on hatchability of Cobb-500 and Hubbard broiler strain eggs.

The experiment was conducted at Debrezeit Agricultural Research Center (DZARC), Ethiopia. The site is located at an altitude of 1900 m.a.s.l. and 45 km south east of Addis Ababa. The area receives an average annual rainfall of 851 mm and a minimum and maximum temperature of 8.9 and 26.2°C, respectively. The average humidity level of the site is 58.6% (Duguma et al., 2005).

Experimental eggs and their management

A total of 720 freshly laid eggs were collected from Cobb 500 and Hubbard broiler strain breeders. Eggs of Cobb 500 were obtained from Alema Farms Private Limited Company located at Bishoftu and Hubbard were obtained from Debrezeit Agricultural Research Center. All eggs used for the experiment were taken from eggs laid at the same day. At the time of collection, 360 eggs were selected at random from each broiler strain breeders and randomly distributed into two equal groups (180 eggs) and numbered. One group was fumigated with potassium permanganate and formalin at ratio of 1:2 for 15 min and the other group remained unfumigated. To fumigate, the eggs were placed in closed room with 22.5 m^3 volume and 49.5 g of potassium permanganate with 99 ml of formalin, 38% concentration were used. The two groups of eggs from each breeds was further divided in to three groups of 60 eggs at random and exposed to different storage temperature (10, 16 and 23°C) and replicated twice (30 eggs) and stored for 7 days before setting into the incubator. Storage temperature was controlled by adjusting a digital adjustment of cold room, which was originally made for milk storage at 10°C and this room was used for treatment one (T1), egg stored at 10°C. Seed storage room, with average temperature of 16°C was used for treatment two (T2), storing egg at 16°C, for treatment three (T3) ambient temperature of the study area, was used. According to thermometer reading, the average temperature in the storage room during storage was 23°C.

Management of incubator

The eggs were incubated in an incubator of 2592 setter capacity with a ventilation system and an automatic egg turner. The relative humidity and temperature were maintained at 60% and 37°C, respectively. The eggs were placed in an incubator on the same stage with eggs leveled by treatment and replication and arranged horizontally. There were 30 and 60 eggs per replicate and treatment, respectively (Table 4). After 18th day, the eggs were transferred from setter to the hatchery unit with a plastic tray. This was done for two reasons. The eggs are laid on their sides to allow free movement of the chick out of the shell at hatching. It also assists hygiene; large quantities of fluff are generated during hatching and could spread this potential contamination around the hatchery. Hatcher temperature was maintained at 36°C, which is

Table 1. Treatment combinations of the experiment.

Technical interactions	Treatments											
	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12
B1	X	X	X	X	X	X						
B2							X	X	X	X	X	X
T1	X	X					X	X				
T2			X	X					X	X		
T3					X	X					X	X
F1	X		X		X		X		X		X	
F2		X		X		X		X		X		X

Table 2. Two factor interaction.

A, breed (B)* temperature (T) interaction	B, breed (B) * fumigation (F) interaction	C, temperature(T) * fumigation (F) interaction
B 1 * T1	B1 * F1	T1* F1
B1 * T2	B1 * F2	T1 * F2
B1 * T3	B2 * F1	T2 * F1
B2 * T1	B2 * F2	T2 * F2
B2 * T2	-	T3 * F1
B2 * T3	-	T3 * F2

Table 3. Three factor interaction.

Treatment	Interactions
1	B1 *T1 * F1
2	B1 *T1 * F2
3	B1 *T2 * F1
4	B1 *T2 * F2
5	B1 *T3 * F1
6	B1 *T3 * F2
7	B2 *T1 * F1
8	B2 *T1 * F2
9	B2 *T2 * F1
10	B2 *T2 * F2
11	B2 *T3 * F1
12	B2 *T3 * F2

slightly lower than those of the setter to reduce the risk of overheating.

Experimental design

The experiment was arranged in 3*2*2 factorial in CRD (Table 1-3). There were three factors and one of the factors with three levels and the rest with two levels are as follows:

Factor B; Breed (B), levels:

B1 – Egg from Cobb 500 breeder
B2 – Egg from Hubbard breeder

Factor T; Egg storage temperature before incubation for 7 days (T), levels:

T1 – 10°C
T2 – 16°C
T3 – 23°C

Factor F; Fumigation (F), levels:

F1 – Non-fumigated
F2– Fumigated

Hatchability measurement

Candling was conducted on day 8 and 15 to determine fertility. The fertile eggs showed a small dark spot that looked like a “spider”. Infertile eggs were clean and only showed the shadow of the yolk.

Hatchability was calculated on the basis of set and fertile eggs and the number of chicks hatched as depicted in the following formulas.

$$Hatchability\,(\%) = \frac{Number\ of\ chicks\ hatched}{Number\ of\ fertile\ eggs\ placed\ in\ the\ incubator}\ x\,100$$

$$Hatching\ yield\ (\%) = \frac{Number\ of\ chicks\ hatched}{Number\ of\ eggs\ placed\ in\ the\ incubatore}\ x\,100$$

Statistical analysis

The experimental design was ompletely randomized design with

Table 4. Layout of the experiment

Treatment group	Treatment interactions	Replication		Treatment
		R1	R2	
1	B1 *T1 * F1	30	30	60
2	B1 *T1 * F2	30	30	60
3	B1 *T2 * F1	30	30	60
4	B1 *T2 * F2	30	30	60
5	B1 *T3 * F1	30	30	60
6	B1 *T3 * F2	30	30	60
7	B2 *T1 * F1	30	30	60
8	B2 *T1 * F2	30	30	60
9	B2 *T2 * F1	30	30	60
10	B2 *T2 * F2	30	30	60
11	B2 *T3 * F1	30	30	60
12	B2 *T3 * F2	30	30	60
	Total	360	360	720

All eggs were incubated in the same incubator and on the same stare.

factorial structure. The hatchability were analyzed by ANOVA with three levels of egg storage temperature (10, 16 and 23°C), two levels of egg fumigation (fumigated and non-fumigated) and two breeds of broiler strain (Cobb 500 and Hubbard).

All the data were analyzed by using the General Linear model (GLM) procedure of Statistical Analysis Systems for window 9.0 (SAS Institute, Inc., 2002). Least Significant Difference (LSD) was used for mean comparisons. The storage temperature, fumigation and breed are the main effects. The model for the design is given by:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + e_{ijkl}$$

where Y_{ijk} = observation taken at the i^{th} breed, j^{th} temperature, and k^{th} fumigation, μ = overall mean of the population for yijk, α_i = effect due to the i^{th} breed, β_j = effect due to the j^{th} temperature, γ_k = effect due to the k^{th} fumigation, $(\alpha\beta)_{ij}$ = effect due to interaction between the i^{th} breed and the j^{th} temperature, $(\alpha\gamma)_{ik}$ = effect due to the interaction between the i^{th} breed and the k^{th} fumigation, $(\beta\gamma)_{jk}$ = effect due to the interaction between the j^{th} temperature and k^{th} fumigation, $(\alpha\beta\gamma)_{ijk}$ = effect due to the interaction between i^{th} breed, j^{th} temperature and k^{th} fumigation, and e_{ijkl} = random error associated with the observation yijk.

RESULTS AND DISCUSSION

Fertility and hatchability

The main effect of varying levels of egg storage temperature (10, 16 and 23°C); fumigation (fumigated and not-fumigated); broiler strain (Cobb 500 and Hubbard classic) and the interaction effect of these factors on fertility and hatchability are presented in Tables 6 to 7.

Statistical analysis indicated that there was no significant difference (P>0.05) among the treatment groups in fertility. The present result indicated that fertility is not dependent on egg storage treatments employed. The result is expected because fertility mainly depends on sex ratio of the parent stock, season, flock age and other factors in the laying room than storage temperature and fumigation. North (1984) reported that fertility is the result of laying house management rather than hatchery management procedures.

The results of the mean percentage hatchability on fertile eggs from each treatment groups are presented in Tables 5 to 7. Egg storage temperature of 16°C and fumigation (P<0.001) improved hatchability. Cobb 500 broilers had high mean percentage hatchability than Hubbard, but the differences were not significant (P>0.05). Egg storage temperature at 23°C resulted in slightly lower mean percentage hatchability than storage at 10°C, but the differences were not significant (P>0.05). No two way interaction existed for breed by fumigation and temperature by fumigation. However, interaction existed for breed by temperature. Accordingly, both breeds perform significantly better when the egg is stored at 16°C for 7 days. Egg storage at less than 16°C for Cobb 500 and greater than 16°C for Hubbard seems to have negative effect on hatchability. In accordance with the present result, Kirk et al. (1980) confirmed that the shorter the storage period, the higher the optimum storage temperature for best hatching results. The findings of the present experiment was in agreement with those of Das and Ali (1999) who reported that fertility and hatchability of eggs produced in summer and early spring (when storage temperature is high) was low. Wilson (1991) reviewed literature reporting optimum storage temperature and concluded that storage temperature decreases as length of storage increased. In general, the suggested temperatures by Wilson (1991), based on literature review were: 20 to 25°C when storing eggs for less than four days; 16 to 17°C for four to seven days; and 10 to 12°C for storage of eggs for more than seven

Table 5. Mean values for main effects of breed, egg storage temperature and fumigation on fertility and hatchability of fertile eggs and total eggs set.

Main effect		Fertility (%)	Hatchability on fertile eggs (%)	Hatchability on set eggs (%)
B	B1	91.94	83.33	76.39
	B2	89.09	81.96	73.89
F	F1	88.81	80.06^{b}	71.66^{b}
	F2	92.22	85.24^{a}	78.61^{a}
T	T1	90.41	80.55^{b}	72.92^{b}
	T2	91.55	87.37^{a}	80.42^{a}
	T3	89.58	80.02^{b}	72.08^{b}
	LSD	*4.52*	*3.28*	*3.7*

$^{(a, b)}$Means within a column with different superscript under the same main effect are significantly (P<0.05) different.

Table 6. Mean values for two factor interaction effects of breed, egg storage temperature and fumigation on fertility and hatchability of fertile eggs and total eggs set.

Two factor interaction effect		Fertility (%)	Hatchability on fertile eggs (%)	Hatchability on set eggs (%)
B*F	B1*F1	90	81.44	72.78
	B1*F2	93.89	85.22	80
	B2*F1	87.62	78.67	70
	B2*F2	90.56	85.26	70.55
	LSD	*5.22*	*3.65*	*77.22*
B*T	B1*T1	90.83	$79.71b^{c}$	72.5^{b}
	B1*T2	92.5	86.4^{a}	79.16^{a}
	B1*T3	92.5	83.87^{ab}	77.5^{ab}
	B2*T1	90	81.4^{b}	73.33^{b}
	B2*T2	90.59	88.34^{a}	81.67^{a}
	B2*T3	86.67	76.16^{c}	66.66^{c}
	LSD	*6.39*	*4.65*	*5.24*
T*F	T1*F1	88.33	77.28	68.33
	T1*F2	92.5	83.83	77.5
	T2*F1	88.93	85.3	76.66
	T2*F2	94.17	89.44	84.17
	T3*F1	89.16	77.59	70
	T3*F2	90	82.44	74.17
	LSD	*6.39*	*4.65*	*5.24*

$^{(a, b, c)}$Means within a column with different superscript are and under the same factor interaction significantly (P<0.05) different.

days. Egg storage temperature used in the current experiment, which yielded better hatchability agreed with this earlier works.

There was significant (P<0.01) difference in mean percent hatchability on fertile eggs between treatments with fumigated groups showing higher mean percent hatchability as compared to non- fumigated groups. This result is also the same for mean percent hatchability on total set eggs (P<0.01). The present result showed the necessity of pre-incubation fumigation under our case. The findings of this study were comparable with the findings of Proudfoot and Stewart (1970), who reported that pre-storage and pre-incubation fumigation with potassium permanganate and formalin resulted in higher hatchability than with eggs not fumigated, but the difference in their study only approached statistical significance. The present findings did not agree with Clarenburg and Romijn (1954), who reported no

Table 7. Mean values for three factor interaction effects of breed, egg storage temperature and fumigation on fertility and hatchability of fertile eggs and total eggs set.

Three factor interaction effect		Fertility (%)	Hatchability on fertile eggs (%)	Hatchability on set eggs (%)
B*T*F	B1*T1*F1	88.33	77.29	68.33
	B1*T1*F2	93.33	82.14	76.67
	B1*T2*F1	88.33	84.9	73.33
	B1*T2*F2	96.67	87.91	85
	B1*T3*F1	93.33	82.14	76.67
	B1*T3*F2	91.67	85.61	78.33
	B2*T1*F1	88.33	77.27	68.33
	B2*T1*F2	91.67	85.51	78.33
	B2*T2*F1	89.52	85.71	80
	B2*T2*F2	91.67	90.98	83.33
	B2*T3*F1	85	73.04	63.33
	B2*T3*F2	88	79.27	70
	LSD	9.04	6.57	7.42

significant difference in hatchability between the unfumigated and fumigated with formaldehyde at a concentration produced by 30 ml formalin added to 20 g $KMnO_4$ per m^3 (that is, 400 mg released formaldehyde per m^3) groups as well as the result reported by Turk (1968), who used 10 g of paraformaldehyde per m^3 (that is, 600 mg released formaldehyde per m^3) and found similar result with Clarenburg and Romijn (1954).

Conclusion

In Ethiopia, now a days, new broiler breeds are introduced in to the country to solve the scarcity of day old broiler chicks requirement by producers and their by increase the supply of animal protein in the country. However, the recommended pre-hatching storage handling of eggs is not well studied. In poultry production, it is very important to store the eggs in suitable conditions before hatching. The experiments were conducted by using 360 eggs from each Cobb 500 and Hubbard breeders for hatchability experiment at the DebreZeit Agricultural Research Center for 28 days.

Eggs from the two breeds were stored for seven days at 10, 16 and 23°C before set into the incubator, each group was divided into two equal groups, one group fumigated with formaldehyde and the other group was not fumigated. There were three factors and one of the factors with three levels the rest two factors with two levels. The experimental design was completely randomized design with factorial structure. The parameters considered were fertility and hatchability on set and fertile eggs.

There was no significant (P>0.05) difference among the treatment groups in fertility. Egg stored at 16°C and fumigation showed significantly (P<0.001) higher mean percentage hatchability both on fertile and total set eggs basis. The highest hatchability was obtained from the interaction of 16°C egg storage temperature with fumigation.

Therefore, under the condition of the current experiments, storing egg at an average of 16°C if the egg storage period is one week and fumigation with formaldehyde before set into the incubator is recommended to gate high yield of hatchability.

Scope for future work

The fumigation level on this experiment was limited to fumigated and not fumigated; hence, the effect of fumigation at different concentration of fumigant has to be looked into. The present study should also be conducted during different seasons under varied climatic conditions of the country since season and climate may affect hatchability.

Conflict of Interests

The authors have not declared any conflict of interests.

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Abbreviations

ANOVA, Analysis of variance; **AOAC,** Association of Official Analytical; **ATVET,** Agricultural Technical Vocational; **B,** breed; **CRD,** completely randomized design; **CSA,** Central Statistical Authority; CV, coefficient of variation; **DZARC,** Debre Zeit Agricultural Research Center; **EARO,** Ethiopian Agricultural Research Organization; F, fumigation; **FAO,** Food and Agricultural Organization; **Fr,** fertility; **GLM,** general linear model; **HFE,** hatchability on fertile eggs; **HSE,** hatchability on set eggs; **LSD,** least significant difference; **MOA,** Ministry of Agriculture; **MoARD,** Ministry of Agriculture and Rural Development; **PBMC,** Poultry Breeding and Multiplication Centers; SAS, Statistical Analytical System; SPSS, Statistical Program for Social Sciences.

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Full Length Research Paper

Irrigation under different soil surface wetted areas and water depths for banana cv. Grand Naine

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The use of different water depths and soil surface soil surface wetted areas by micro-sprinkler irrigation systems results different wetted soil volumes and evapotranspiration conditions, which may cause changes in fruit production quality and quantity. The objective of this study was to evaluate yield, fruit physical characteristics and leaf area of banana cv. Grand Naine under different irrigation depths and soil surface wetted areas in Northern Minas Gerais State, Brazil. The experiment was conducted in the period 2003 to 2006, involving three production cycles of 'Grand Naine' banana with planting spacing of 3.0 m × 2.7 m irrigated by micro-sprinklers. The experimental design was a randomized block with four replicates in a split-plot arrangement with three soil surface wetted areas in the plot and five irrigation depths as subplots. The irrigation levels were taken as fractions of crop evapotranspiration (ETc): 0.70; 0.85; 1.00; 1.15 and 1.30 ETc, and the soil surface wetted areas (Wa) were: Wa 1 of 10.17 m^2, with emitter of 20 L h^{-1} and radius of throw of 1.8 m; Wa 2 of 23.74 m^2, with emitter of 63.6 L h^{-1} and radius of throw of 2.7 m and Wa 3 of 28.26 m^2, with emitter of 60 L h^{-1} and radius of throw of 3.0 m. Central fruit diameter and mean weight, leaf area and yield of 'Grand Naine' banana were not influenced by irrigation depths. On the other hand, smaller soil surface wetted area causes reduction in central fruit length and weight, leaf area and yield of 'Grand Naine' banana.

Key words: *Musa spp*., irrigation management, soil surface wetted area.

INTRODUCTION

Brazil is in the fifth position in the global ranking of banana production and, according to FAOSTAT (2015), in 2014, the production was 6,946,567 tons, with emphasis for the northeast and southeast regions, which account for 66.91% of the production (IBGE-SIDRA, 2016). The state of Minas Gerais is the second largest

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producer in the southeast region, with 47.48% of the production concentrated in its northern portion (IBGE-SIDRA, 2016), a semi-arid region, recently identified by the trademark “Região do Jaíba”, constituted for characterization as an area of geographic indication for the production of quality fruits.

In the Brazilian semi-arid region, the mean annual rainfall is lower than 800 mm, with irregularity of spatial and temporal distribution and aridity index between 0.2 and 0.5. Since the water requirement of the banana crop is higher than the natural rainfall and with regular distribution, the use of irrigation becomes necessary to fulfill water needs during the periods of water deficit in the soil even in humid regions (Vanhove et al., 2012; Ravi et al., 2013; Muthusamy et al., 2014; Kissel et al., 2015). However, it is necessary to attempt for precision of irrigation mainly in semiarid regions of tropics and subtropics more subjected to climate changes (Surendar et al., 2013, 2015).

Micro-sprinkler irrigation has been predominant in the localized irrigation of banana in the production centers of the semi-arid region. There are different micro-sprinklers available in the market, in terms of both structure and nominal flow rate. Flow rates are related to the radius of throw and, consequently, the generated soil surface wetted area. The soil surface wetted area is associated with the region of root development; the higher it is, the greater the lateral expansion of the root system. However, larger soil surface wetted diameters also imply greater areas under evaporation, with reduction of application efficiency. Rocha (2009) evaluated the effect of the percentage of soil surface wetted area on physiological, production and fruit quality variables of ‘Tahiti’ lime (transpiration, stomatal conductance and leaf temperature) and observed no differences in these aspects for the evaluated soil surface wetted area percentages.

The knowledge on the water requirement of the banana crop has increased in the last years and results have been found for different climate conditions (Coelho et al., 2013; Silva; Bezerra, 2009; Montenegro et al., 2008; Teixeira et al., 2002) for different cultivars in different physiographic regions. However, considering micro-sprinkler irrigation as the trickle system most used in the production centers of irrigated banana in Brazil, studies that associate levels of irrigation water and soil surface wetted area for water application by micro-sprinklers are scarce.

The emitter radius of throw determines soil surface wetted area, which is dependent upon its flow rate and pressure. The emitter precipitation intensity, in turn, depends on their physical characteristics. The wetted area on the soil surface due to the application of water is a determinant factor in the mean moisture content of the wetted volume and in its dimensions, with implications on root distribution, on water and nutrient uptake and also on soil water losses through evaporation and percolation. Farmers usually do not know which emitter to choose for optimal production and market offers types with different flow rates. Moreover, morphological, production and fruit quality factors of the banana crop may be influenced by the soil surface wetted area, in isolation or in interaction with the applied water depths. This study aimed to evaluate the effect of different irrigation water depths and soil surface wetted areas applied by a micro-sprinkler system on yield, fruit physical characteristics and on leaf area of ‘Grand Naine’ banana during three production cycles in Northern Minas Gerais, Brazil.

MATERIALS AND METHODS

The experiment was carried out in the Northern Unit of the Agricultural Research Company of Minas Gerais - EPAMIG, in the municipality of Nova Porteirinha, Minas Gerais State, Brazil (Figure 1). The area is inserted in the Brazilian semi-arid region, at the geographical coordinates of 15° 46' 38.98"S, 43 17' 22.06" W and altitude of 537 m, and its climate is Aw, according to Köppen’s classification. The soil of the experimental area was classified as dystrophic Red Yellow Latosol and its physical-hydraulic characteristics are presented in Table 1.

The experiment was conducted from 2003 to the beginning of 2006, comprehending three production cycles of ‘Grand Naine’ banana, with planting spacing of 3.0 m × 2.7 m under micro-sprinkler irrigation, maintaining the soil covered by the straw of the plants. The experimental design was randomized blocks with four replicates, in a split-plot arrangement, with three soil surface wetted areas in the plots and five irrigation depths in subplots.

Irrigation water depths were determined by the ETc fractions of 0.70, 0.85, 1.00, 1.15 and 1.30 of ETc, considering the efficiency of the irrigation system of 0.85, with daily irrigations. Crop evapotranspiration (ETc) between two irrigations was obtained based on the potential evapotranspiration (ETo) determined by the Class-A pan method and on crop coefficients (Kc) established as a function of those suggested by Allen et al. (1998). The wetted area on the soil surface was determined by the radius of throw of the micro-sprinklers, according to their flow rates, through water collectors positioned in a grid (0.50 × 0.50 m) in an area with four plants (5 m × 4 m), and the emitter in the center. The soil surface wetted area 1, with 10.17 m^2, was obtained using emitter with flow rate of 20 L h^{-1} and radius of throw of 1.8 m; the soil surface wetted area 2, with 23.74 m^2, was obtained using emitter with flow rate of 63.6 L h^{-1} and radius of throw of 2.7 m, and the soil surface wetted area 3, with 28.26 m^2, was obtained using emitter with flow rate of 60 L h^{-1} and radius of throw of 3.0 m.

The process of soil surface wetted area determination was also used to obtain the mean precipitation intensity, based on the mean water depth of the collectors divided by the time (h) of the test, which was performed periodically. The mean precipitation intensity was used in the determination of irrigation time. Irrigation depths and soil surface wetted areas were differentiated in the controller through valves corresponding to each one of the factors, totaling 15 sub-main lines. Rainfall and class A pan evaporation were measured in a conventional weather station, installed close to the experiment.

Soil water status was evaluated through soil water tension, measured with a tensiometer using an analog tensimeter, before irrigations. Leaf area was evaluated based on the length and width of the third leaf during flowering period. Yield (t ha^{-1}) and the variables of fruit physical quality (mean length, weight and diameter of the central fruit from the second hand) were evaluated at harvest. Distance and effective depth of the root system were observed by opening soil pits in the plots, between the plant and the micro-

Figure 1. Experimental area located at Nova Porteirinha County in the Northern of Minas Gerais, Brazil.

Table 1. Soil physical-hydraulic characteristics: Texture, density and water contents corresponding to the potentials obtained in the soil water retention curve (Nova Porteirinha-Minas Gerais, Brazil).

Layer (m)	Sand	Silt	Clay	Soil density	Soil moisture (cm^3cm^{-3}) at tension (kPa)				
		($g\ kg^{-1}$)		($Mg\ m^{-3}$)	-10	-33	-100	-500	-1500
0-0.20	516	202	293	1.71	0.239	0.230	0.218	0.205	0.195
0.20-0.40	444	210	346	1.63	0.260	0.248	0.235	0.212	0.209
0.40-0.60	343	186	471	1.66	0.309	0.299	0.287	0.269	0.261

sprinkler, and by removing the roots from the soil in monoliths at the distances of 0.25, 0.50, 0.75 and 1.00 m from the plant and along the soil profile from the surface to 0.80 m, every 0.10 m. The images were processed according to Sant'ana et al. (2012), allowing the determination of root length at each distance and soil depth between the plant and the micro-sprinkler. Distance and effective depth of the roots corresponded to those with 80% of the cumulative total length from the plant and from soil surface (Sant'ana et al., 2012).

The data of mean length, weight and diameter of the central fruit of the second hand, leaf area and yield were submitted to analysis of variance in each cycle. The means of dependent variables were compared by Tukey test at 0.05 probability level for the independent variable soil surface wetted area. Regression analysis evaluated depended variables as a function of irrigation depths. Regression models were also fitted to the data of cumulative root length as a function of the distance from the plant and soil depth, referring to each soil surface wetted area.

RESULTS

Climatic attributes were not similar during the three crop cycles. Irrigation water depths applied in each treatment (fraction of ETc) were different for each cycle (Table 2), because of the variation in the maximum evapotranspiration (ETo) and crop evapotranspiration (ETc). The lowest irrigation water depth value recorded in cycle 1 was above 800 mm and, in cycles 2 and 3, above 990 mm and for the treatment 0.85 ETc, the irrigation water depths in all cycles were higher than 997 mm. These depths of water corresponded to values near to the ones observed by Bassoi et al. (2004) for maximum yields in the semi-arid of Petrolina, Pernambuco State whose aridity indexes were smaller than the ones of the Nova Porteirinha.

According to the analysis of variance (Table 3), there was no interaction between the factors soil surface wetted area x water depth during the three cycles for the evaluated dependent variables of 'Grand Naine' banana. There was effect of soil surface wetted area on central fruit length (CFL) in cycles 1 and 3, central fruit diameter (CFD) in cycle 2, central fruit weight (CFW) in cycle 3, total leaf area (TLA) in cycles 1 and 3 and yield (Y) in the three cycles. The irrigation depths influenced, independently, only central fruit length (CFL) in cycle 3.

The mean length of the central fruit of the second hand was the highest for the soil surface wetted area of 23.74 m^2 in cycle 1 (Table 4), and the lowest for the soil surface wetted area of 10.17 m^2 in cycle 3. The irrigation water depths did not influence mean diameter and weight of the

Table 2. Rainfall, crop evapotranspiration and total water depths required by the plants, according to the applied treatments (Nova Porteirinha-MG, Brazil).

Cycle	Rainfall (mm)	ETc (mm)	0.70ETc (mm)	0.85ETc (mm)	1.00ETc (mm)	1.15ETc (mm)	1.30ETc (mm)
1	819	1,108	821	997	1,173	1,349	1,525
2	1,163	2,097	1,543	1,813	2,083	2,353	2,624
3	344	1,466	991	1,204	1,416	1,629	1,841

central fruit in any of the cycles. The mean diameter of the central fruit remained constant as irrigation depth increased, with mean values of 35.0, 36.0 and 35.2 mm in the cycles 1, 2 and 3, respectively (Table 4), which are above 32 mm, thus classified within the extra category for Cavendish bananas. The mean fruit weight in cycle 3 for the soil surface wetted area of 23.74 m^2 was similar to that of the soil surface wetted area of 28.2 m^2 and higher than that of the soil surface wetted area of 10.17 m^2 (Table 4). Irrigation water depth has affected central fruit length (F test) but any regression model did not relate these variables. Based on fruit length classification (PBMH; PIF, 2006) the largest soil surface wetted area resulted fruits of length within the class of length greater than 22 cm and smaller than 26 cm, with mean of 24.30 cm. The smallest soil surface wetted area led to fruits within the class of length greater than 18 cm and smaller than 22 cm in the third cycle.

'Grand Naine' banana showed lower leaf area for the smallest soil surface wetted area (10.17 m^2) in cycles 1 and 3 (Table 5), as well as lower yield for this wetted area in all production cycles. Means of leaf area from larger soil surface wetted areas, 23.74 and 27.18 m^2, were not different between themselves for all cycles. The mean yields for these same conditions differed only in the first cycle (Table 5). Irrigation water depths did not influence both leaf area and yield in the range of 990 mm (0.7 ETc) to equivalent to 1840 mm (1.30 ETc).

The increase of soil surface wetted area was equal to 133% from 10.17 to 23.74 m^2 and to 18% from 23.74 to 28.26 m^2. These wetted volumes allowed greater effective lateral distance from plant and depth of roots (Figure 3). Effective distance from plant and effective depth were 0.84 and 0.53 m, respectively for soil surface wetted area of 10.17 m^2. The effective distances were 1.11 and 1.36 m and the effective depths were 0.53 and 0.58 m for the areas of 23.7 and 28.2 m^2, respectively (Figure 3), demonstrating that the wetted areas on the soil surface promote larger volume of soil for the distribution of roots.

DISCUSSON

The results indicate that the soil surface area wetted influences the physical quality of fruits (F test), with evidence for mean fruit length, whose influence repeated for two of the three cycles evaluated, while the mean fruit weight was only influenced in cycle 3. Fruit dimensions such as length, diameter as well as fruit weight, are important attributes for genetic improvement and especially for market, because they interfere with the preference of the consumer and affect the yield of the fruit (Oliveira et al., 2013).

Fruits produced under the three soil surface wetted areas showed diameter values above 32 mm that is considered as the extra category for Cavendish bananas. These results do not agree with those reported by Figueiredo et al. (2006), who did not observe influence of soil surface wetted area, using one and two lateral lines of drippers, on the length of the central fruit of the second hand of 'Prata-Anã' banana. The influence of soil surface wetted area upon fruit length 'should be related to water and nutrient uptake, since water depth influenced it only on the third cycle in which means were close each other (Table 5). Therefore, the lateral root expansion due to the soil surface wetted area explains better the result.

Results of the range of mean diameter above 32 mm and weight of the central fruit above 180.36 g in all cycles, regardless the irrigation depths agree and disagree with others authors (Figueiredo et al., 2006; Coelho et al., 2006) due to factors not considered as sources of variation in the statistical model. Despite the statistical influence of soil surface wetted area on some physical attributes for one or two crop cycles, the results are not enough to conclude that soil surface wetted area and irrigation water depth affects all attributes of physical quality of banana fruits for general purposes.

Irrigation water depth did not influence leaf area and yield because the range of irrigation water depths from 0.70 to 1.30 ETc corresponded to the one in which the yield rate begins to decrease as irrigation depth increases. Larger yield rate reduction occurred for irrigation water depths in between 1.0 and 1.25 ETc, as observed in studies that evaluated banana yield as a function of irrigation depths (Costa et al., 2014; Coelho et al., 2006; Figueiredo et al., 2006). In addition, the non-effect of the irrigation water depth on leaf area and yield may be due to the range of irrigation water depths close to or higher than 0.85 ETc, considering cycles 2 and 3. Mean water contents varied in this range from 80% (-27 kPa) to 88% (-18 kPa) with minimum from 67% (-70 kPa) to 75% (-37 kPa) of available water in the layer of 0.00 to 0.20 m during part of the cycles 2 and 3 (Figure 2). A

Table 3. Analysis of variance of the studied variables.

Source of variation	DF	CFL cycle 1			CFL cycle 2			CFL cycle 3		
		MS	F	Sig	MS	F	Sig	MS	F	Sig
Block	3	2.516	2.03	0.1271	2.374	1.98	0.1350	6.834	2.20	0.1047
Area	2	7.723	6.23	0.0048	0.0339	0.03	*****	19.959	6.43	0.0041
Error A	6	1.240			1.202			3.104		
WD	4	0.193	0.20	*****	1.118	1.04	0.3991	5.075	2.70	0.0456
WD*Area	8	1.094	1.12	0.3763	0.7639	0.71	*****	2.477	1.32	0.2652
Residual	36	0.981			1.0731			1.877		
CV			3.9245			4.127			5.799	

Source of variation	DF	CFD cycle 1			CFD cycle 2			CFD cycle 3		
		MS	F	Sig	MS	F	Sig	MS	F	Sig
Block	3	0.0178	1.82	0.1603	0.00361	0.20	*****	0.05044	1.85	0.1558
Area	2	0.00889	0.91	*****	0.06358	3.55	0.0391	0.00334	0.12	*****
Error A	6	0.00976			0.01789			0.02728		
WD	4	0.00516	0.51	*****	0.01534	0.72	*****	0.00658	0.26	*****
WD*Area	8	0.00537	0.53	*****	0.01160	0.55	*****	0.00945	0.37	*****
Residual	36	0.01015			0.02116			0.02543		
CV			2.9124			4.1135			4.6517	

Source of variation	DF	CFW cycle 1			CFW cycle 2			CFW cycle 3		
		MS	F	Sig	MS	F	Sig	MS	F	Sig
Block	3	631.854	1.25	0.3077	290.490	0.95	*****	1271.503	1.68	0.1885
Area	2	876.209	1.73	0.1922	81.5557	0.27	*****	2638.897	3.49	0.0413
Error A	6	507.376			305.388			756.7063		
WD	4	59.0762	0.19	*****	129.034	0.34	*****	943.2189	2.12	0.0981
WD*Area	8	316.565	1.02	0.4373	148.229	0.39	*****	386.6066	0.87	*****
Residual	36	309.618			383.917			444.3803		
CV			9.5067			10.356			12.750	

Source of variation	DF	TLA cycle 1			TLA cycle 2			TLA cycle 3		
		MS	F	Sig	MS	F	Sig	MS	F	Sig
Block	3	14.2674	3.83	0.0178	44.260	5.07	0.0050	12.538	6.43	0.0013
Area	2	63.9263	17.14	0.0000	16.4275	1.88	0.1670	28.661	14.70	0.0000
Error A	6	3.72986			8.72839			1.9502		
WD	4	1.24283	0.42	*****	7.33638	1.39	0.2562	3.3582	1.31	0.2833
WD*Area	8	2.75924	0.93	*****	4.56882	0.87	*****	2.6019	1.02	0.4402
Residual	36	2.98092			5.26966			2.555		
CV			13.522			17.534			19.972	

Source of variation	DF	Y cycle 1			Y cycle 2			Y cycle 3		
		MS	F	Sig	MS	F	Sig	MS	F	Sig
Block	3	167.74	2.17	0.1088	147.854	2.79	0.0546	1279.404	9.11	0.0001
Area	2	718.87	9.29	0.0006	246.06	4.64	0.0161	1030.749	7.34	0.0021
Error A	6	77.39			53.051			140.455		
WD	4	6.89	0.24	*****	41.806	1.21	0.3233	227.674	1.95	0.1227
WD*Area	8	11.697	0.41	*****	12.666	0.37	*****	44.497	0.38	*****
Residual	36	28.274			34.539			116.548		
CV			12.60			15.014			22.170	

WD, Water depth; DF, degrees of freedom; CV, coefficient of variation; MS, mean square; Sig, significance; CFL, central fruit length; CFD, central fruit diameter; CFW, central fruit weight; TLA, total leaf area; Y, yield.

Table 4. Mean central fruit length (CFL), diameter (CFD) and weight (CFW) of fruits for the different soil surface wetted areas and under different irrigation water depths for the three evaluation cycles.

Wetted areas	Central fruit length (mm)			Central fruit diameter (mm)			Central fruit weight (g)		
	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3
A1	24.62 B	24.98	22.25 B	34.56	36.00 A	34.19	176.49	189.62	149.35 B
A2	26.10 A	25.22	24.47 A	34.84	35.15 B	34.26	193.00	191.80	174.56 A
A3	25.00 B	25.11	24.14 A	34.38	34.94 B	34.40	185.78	186.18	172.11 A
% ETc	**Cycle 1**	**Cycle 2**	**Cycle 3***	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 1**	**Cycle 2**	**Cycle 3**
0.70	25.17	25.36	22.20	34.28	35.09	33.15	183.76	191.22	144.27
0.85	25.07	24.79	23.99	35.04	34.91	35.18	186.11	181.69	175.31
1.00	25.07	24.92	23.90	34.43	35.64	34.04	180.36	189.56	171.81
1.15	25.41	25.27	24.12	34.80	36.05	34.78	190.00	196.08	169.60
1.30	25.47	25.17	23.90	34.41	35.15	34.27	185.21	187.46	165.71

Means followed by equal uppercase letters in the column do not differ by Tukey test at 0.05 probability level.

Table 5. Leaf area and yield for the different wetted areas and under different irrigation water depths for the three evaluation cycles.

Wetted area (m^2)	Leaf area (m^2)			Yield (t ha^{-1})		
	Cycle 1	Cycle 2	Cycle 3	Cycle 1	Cycle 2	Cycle 3
10.17	10.60^B	11.95	6.48^B	35.60C	35.13^B	39.55^B
23.74	14.37^A	14.07	8.80^A	48.69^A	42.96^A	53.27^A
24.18	13.33^A	13.25	8.73^A	42.28^B	39.34^{AB}	53.27^A
% ETc	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 1**	**Cycle 2**	**Cycle 3**
0.70	12.86	14.19	7.67	41.36	41.05	44.55
0.85	12.56	12.07	7.81	37.33	42.28	50.19
1.00	12.75	13.01	8.60	38.43	42.07	52.87
1.15	12.13	13.05	8.30	38.96	42.33	49.20
1.30	13.54	13.14	7.64	39.64	43.24	46.68

Means followed by equal uppercase letters in the column do not differ for each cycle by Tukey test at 0.05 probability level.

20% depletion of soil water availability is the limit for beginning stress for banana crop (Robson and Bower, 1987).

The yields obtained in cycle 3 for the soil surface wetted area of 23.74 m^2 were similar to the 'Grand Naine' yields reported by Goenaga and Irizarry (1986), who observed maximum estimated value of 47.9 t ha^{-1} for the water depth correspondent to 1.0 of class A pan evaporation. On the other hand, even with lower leaf area in cycle 3, the yield was higher than in the other cycles, suggesting the existence of other factors that may have influenced the increase in yield. The values of leaf area in cycles 1 and 2 are similar to those found by Coelho et al. (2006) for 'Grand Naine' banana. An exception occurred for leaf area in cycle 3, which showed the lowest value (8.00 m^2). However, this value is similar to that obtained by Oliveira et al. (2013), who reported maximum leaf area of 9.35 m^2 for 'Grand Naine' banana, 10 months after planting, with an estimated irrigation depth of 1,276 mm $cycle^{-1}$, in the Coastal Plains of Cruz das Almas, Bahia.

The higher values of leaf area and yield of 'Grand Naine' banana, cultivated under irrigation configurations with the greater soil surface wetted areas, 23.74 and 28.26 m^2, are associated with the larger wetted volume of soil to which these superficial soil surface wetted areas corresponded. Fifteen percent of roots were at distance of 0.15 m and 100% of roots at 1.36 m from plant for surface wetted area of 10.17 m^2 while less than 20% of roots were at 0.15 m from plant and 100% of roots was also at 1.36 m for 28.2 m^2 (Figure 3). A hundred percent of roots were found at depth of 0.75 m for surface wetted area of 10.17 m^2 while for 28.2 m^2 they were found at 0.90 m depth (Figure 3). Larger expansion of the root system as in distance or in depth represents more nutrients and water uptake per unit of soil volume. Therefore, it increases nutrient in plants (Donato et al., 2010), promotes higher vigor to the plants (Donato et al., 2013) contributing to the increment of fruit physical

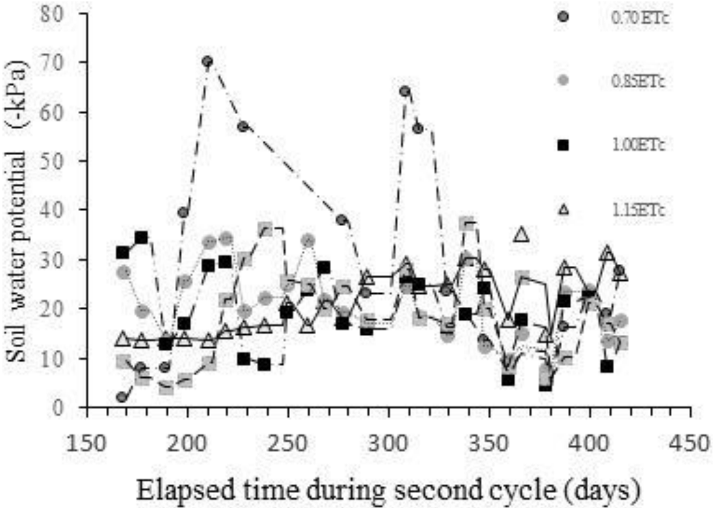

Figure 2. Soil water tension referring to the different water depths applied through irrigation during the second cycle.

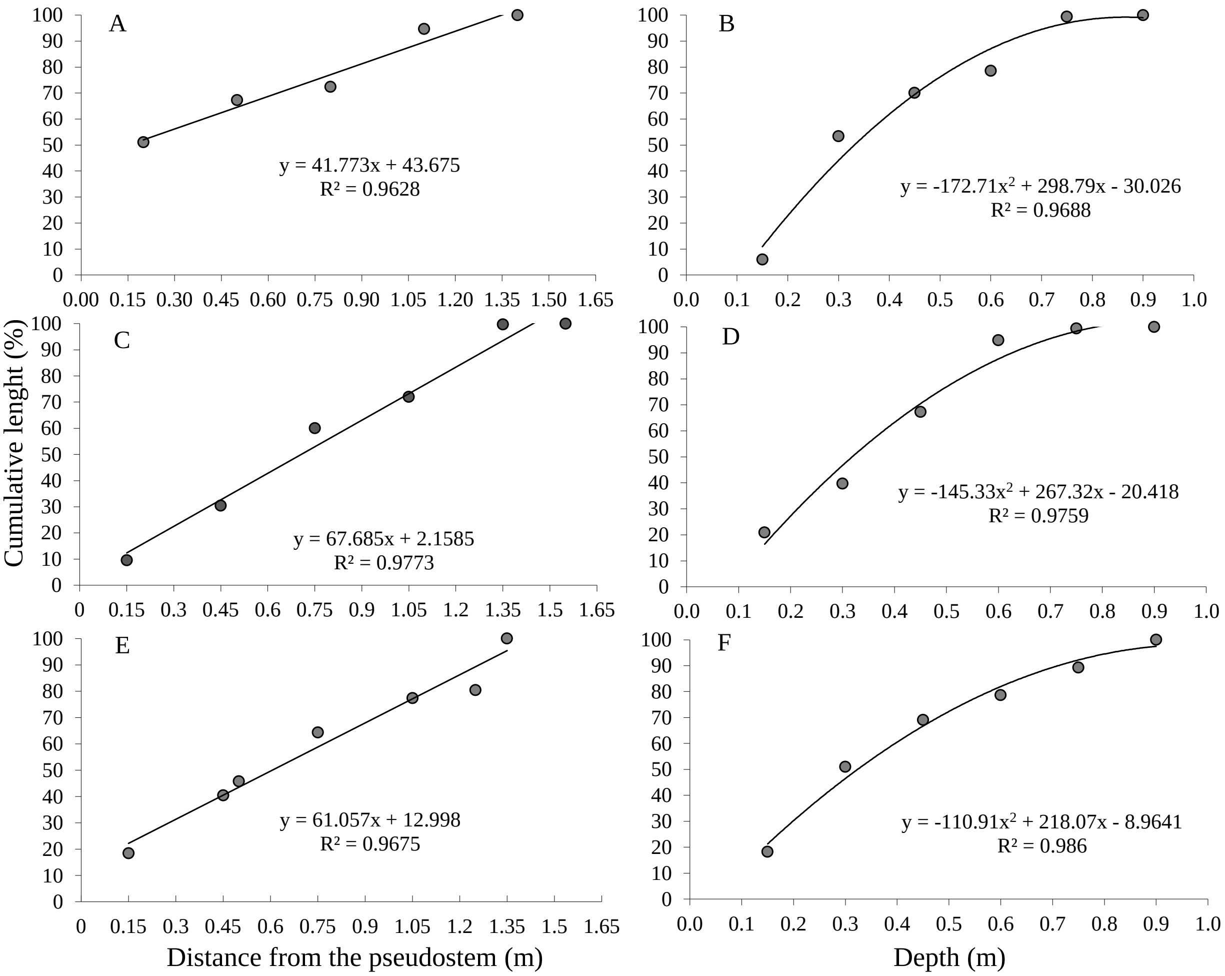

Figure 3. Cumulative root length (%) as a function of the distance from the plant (A) and soil depth (B) for the soil surface wetted area of 10.17 m^2, distance (C) and depth (D) for the soil surface wetted area of 23.7 m^2 and distance (E) and depth (F) for the soil surface wetted area of 28.2 m^2. Nova Porteirinha-MG, Brazil.

quality and yield of banana crop as observed in the present study.

Conclusions

1. Central fruit diameter and weight, leaf area and yield of 'Grand Naine' banana are not altered by irrigation depths from 821 to 1,525 mm for a total evapotranspiration in the cycle of 1,108 mm, as well as for irrigation depths equal to or higher than 991 mm and total crop evapotranspiration in the cycle equal to or higher than 1,466 mm;
2. Larger soil surface wetted area promotes greater expansion of the root system, higher leaf area, higher fruit length and higher yield in 'Grand Naine' banana;
3. The use of micro-sprinklers with greater radius of throw, equal to or higher than 2.70 m, promoted wetted volume with better moisture conditions for the production of 'Grand Naine' banana, considering fractions of the required water depths between 0.85 and 1.15 of ETc or water depths between 897 and 1,349 mm for 1,108 mm of ETc during the cycle, between 1,204 and 1,629 mm for 1,466 mm of ETc during the cycle and between 1,813 and 2,353 mm for 2,097 mm of ETc during the cycle.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Field assessment of baits for frugivorous flies (Tephritidae and Lonchaeidae)

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Hydrolyzed proteins are used as attractive agents in McPhail traps for monitoring of fruit flies (Tephritidae). There has been no defined role for monitoring of insects belonging to the Lonchaeidae family. Currently, there is a great concern in using most efficient and low-cost attractive materials. Thus, this study aimed at assessing the attractiveness of solid and liquid baits in capturing of frugivorous flies (Tephritidae and Lonchaeidae). Therefore, we carried out four trials in coffee plantations (*Coffea arabica* L.) during two different periods (May/ 2013 and July/ 2014). A randomized block design with four treatments and five replications was used in the first period, and ten treatments with four replications the following year. Two distinct experiments were carried out, one using baits in solid and another in liquid form, which consisted of applying 10 g for trap (solid) or 200 mL solution of the same compounds diluted in water (5%: p/ v). In 2013, we tested yeast extract with and without sugar, brewer's yeast, citrus pulp and hydrolyzed protein as control. In 2014, five additional baits were tested: açai, plum and grape flours, passion fruit fiber and poultry feces. In all experiments, a 5% hydrolyzed protein solution was used as control. Eight days after being set, traps were assessed. Even the yeast extract, with and without sugar, and the brewer's yeast, in solid form, were as attractive as control treatment in capturing flies. The poultry feces and yeast extract, with and without sugar in solution form, can be used to replace hydrolyzed protein in capturing tephritids. Lonchaeids are barely attracted by the hydrolyzed protein. Additionally, yeast extract and poultry feces can be used for monitoring and biodiversity studies of the Lonchaeidae fauna.

Key words: Fruit growing, monitoring, trap, protein.

INTRODUCTION

The term frugivorous flies is used to indicate all flies belonging to the Tephritidae and Lonchaeidae families, while fruit flies refers only to the Tephritidae family (Zucchi, 2000). Tephritids are major economic pests of fruit plantations worldwide, being responsible for yield losses due to damages on fruit that make them unavailable for *in natura* consumption, as well as having importance as quarantine pests (Aluja and Mangan, 2008;

Jenkins et al., 2011). The Lonchaeidae family has been long overlooked by researches because of a lack of taxonomic knowledge; however, there has been an increasing interest in studying such insects since lonchaeids have been collected during tephritids' monitoring. In addition, these insects have also been assigned as primary pest in *Malpighia punicifolia* L. (Araújo and Zucchi, 2002), *Citrus reticulada* Blanco (Lopes et al., 2008), *Passiflora edulis* f. *Flavicarpa* (Aguiar-Menezes et al., 2004) and *Manihot esculenta* (Lourenção et al., 1996; Gistoli and Prado, 2011).

Four genera of the Tephritidae family are found in Brazil: *Rhagoletis* Loew, 1862, *Bactrocera* Macquart, 1835, *Ceratitis* MacLeay, 1829 and *Anastrepha* Schiner, among which the two latter have most importance (Zucchi, 2000, 2008). Whereas the Lonchaeidae family is represented by the genera *Lonchaea* Fallén 1847, *Dasiops* Rondani 1856 and *Neosilba* McAlpine 1962 (Zucchi, 2008; Strikis et al., 2011).

Coffee plants are considered preferred hosts for fruit flies, mainly for the species *C. capitata* (Wiedemann, 1824) and *Anastrepha fraterculus* (Wiedemann, 1830), since this plant provides shelter during periods of low availability of hosts in the field (Montes et al*.,* 2012). The coffee tree has also major importance for the maintenance of frugivorous fly populations, even though these insects are not taken as main pests for this crop. However, these insects may threaten a few fruits commercially grown *in natura*, becoming their primary pest (Souza Filho et al., 2003).

Fruit fly monitoring is an important tool for decision-making in pest control managements and consists of using Jackson's traps based on sexual pheromone as well as McPhail traps, which contain 5% corn hydrolyzed protein (Carvalho, 2005). The use of traps and standard attractive increase monitoring operation costs for small farmers; therefore, alternative materials such as plastic bottles, fruit juice or sugarcane molasses are often employed in samplings.

A capture system has not been established yet for monitoring of lonchaeids, which are usually collected through the same attractive traps used for tephritids (Raga et al., 2006), since there are still few studies on such group of flies.

Researches using new compounds as attractive bait for fruit fly capturing have been developed for several authors (Fontellas-Brandalha and Zucoloto, 2004; Feitosa et al., 2008; Weldon and Taylor, 2011; Piñero et al., 2015).

In recent years, there has been an increased concern to find efficient and low-cost attractive materials. As well, some studies have indicated good prospects for solid baits (Conway and Forrester, 2007; Epsky et al., 2011; Lasa et al., 2014), which have shown some advantages in water use and less time for trap supply, which can be used in monitoring and biodiversity studies.

The current study aimed at assessing the attractiveness of solid and liquid baits in capturing of frugivorous flies (Tephritidae and Lonchaeidae), which may be further indicated in pest management programs and biodiversity studies.

MATERIALS AND METHODS

The studies were carried out in coffee plantations (*Coffea arabica* L.) of "Catuaí Amarelo" and "Catuaí Vermelho" varieties. The plantations are located in Santa Fé farm (14º 44' 8.7" S; 40º 26' 06" W), in the city of Planalto-BA, Brazil. The treatments consisted of baits in solid and liquid form making two different and sequential experiments. The experiments were performed under a randomized block design. Four treatments (baits) and five replications (traps) were tested in 2013, and 10 treatments with four replications in 2014, in a total of 25 and 40 plots, respectively (Table 1). The plots were composed of McPhail traps with each attractive material, being set on plants at 1.50 m height from soil and 20-m equidistant, with a 10-m border. Ten grams of each product was weighed and then distributed to the base of traps. Hydrolyzed protein was used as a control treatment for all experiments. 10 g was used for each trap (solid) or 200 mL solution of the same compounds diluted in water (5%: p/v) (liquid), as per the manufacturer's recommendations.

The compounds were selected based on their commercial composition. Therefore, compounds with a predominance of proteins (yeast extract - Bionis®, brewer's yeast and corn hydrolyzed protein), of carbohydrates and fibers from fruit (açaí, plum and grape flours, citrus pulp and passion fruit fiber), plus poultry feces, which are considered important sources of protein for fruit flies in nature was used (Christenson and Foote, 1960).

The evaluations were made eight days after traps were set for all experiments, which is considered a trap attractive refill period when using hydrolyzed protein in orchards under official monitoring. The flies captured in field traps were sorted, counted and divided according to genus and/ or species.

The identification of the *C. capitata* species was made based on descriptions of Zucchi (2000). For *Anastrepha*, we have solely used females, identifying them by a apical spine pointing outward, with the aid of a stereomicroscope (40x) and biological microscope (100x), according to the method described by Zucchi (2000). Yet the lonchaeids were identified at genus level by morphological characters in the chest and abdomen.

Statistics

The statistical analysis was carried out for data of the most abundant fly species. The data under non-normal distribution were submitted to non-parametric mean comparisons using the Friedman's test ($p > 0.05$); the remaining data underwent variance analysis and means were compared by the Tukey's test at 5% probability, using ASSISTAT 7.7 beta.

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Table 1. Treatments used in the field experiments on the attractiveness of baits to frugivorous flies.

Experiment*	Treatment
2013	T1 = Bionis® with sugar; T2 = Bionis® without sugar; T3 = Dehydrated citrus pulp; T4= Brewer's yeast; T5 (Control) = Hydrolyzed protein**
2014	T1= Bionis® with sugar; T2 = Bionis® without sugar; T3 = Dehydrated citrus pulp; T4= Brewer's yeast; T5 = Plum flour; T6 = Açaí flour; T7 = Passion fruit fiber; T8 = Grape flour; T9 = Poultry feces; T10 (Control) = Hydrolyzed protein

*Two subsequent experiments in each year, being the first with solid baits and then with liquid ones; **All experiments in solution at 5%.

RESULTS AND DISCUSSION

In 2013, 1.611 flies were caught, being 84 (5.2%) with solid compounds and 1,527 (94.7%) with 5% solutions (Table 2). Tephritids prevailed in all collections, making 98.8% of solid treatments and 94.0% of liquid ones. The most abundant species was *C. capitata,* representing 95.2 and 96.0% of flies caught in solid and liquid experiments, respectively (Table 2). The genus *Anastrepha* was represented by the species *A. fraterculus* (2.4% in solid and 3.2% in liquid) and *A. consobrina* (Loew, 1873) (1.2%). Among the lonchaeids, only representatives from the genus *Neosilba* were captured, contributing in 1.2 and 0.8% of flies captured with solid and liquid baits, respectively (Table 2). In absolute terms, hydrolyzed protein was the most attractive treatment for tephritids, being responsible for 39.2% of tephritid capture in solid experiments and 38.3% in liquid ones. For lonchaeids, the product Bionis, with and without sugar, was most attractive, collecting 92.3% of the flies in both experiments, demonstrating thus a low attractiveness of proteins to these flies.

Both Bionis® (with - T1, and without sugar - T2) and brewer's yeast (T4), in solid form, showed an attractiveness similar to the hydrolyzed protein (control - T5) for female and total (male plus female) captures of the *C. capitata*, among which citric pulp had the lowest attractiveness (Table 3). Regarding the evaluations of the same products, in liquid form, the results were similar for female collections; however, no significant difference was seen for total captures. Male captures were less expressive compared to female ones for all treatments (Table 3). Adults belonging to the *C. capitata* species, particularly females at sexual maturity had greater preference for protein-based materials, which was ingested according to the foraging behavior and mating of these insects (Cohen and Voet, 2002).

The population of *A. fraterculus* captured was low. Moreover, solid treatments did not take any specimen of this species, except for control (Table 4). The Bionis in solution, with and without sugar, did not differ significantly from the hydrolyzed protein to the total number of adults captured. The yeast extract, with and without sugar, and the brewer's yeast were as attractive as the hydrolyzed protein for females. However, these treatments did not differ as to the males, except for citrus pulp that had the worst performance when collecting adults of *A. fraterculus*.

The hydrolyzed protein has shown to be a highly attractive lure to tephritids. This compound is similar or slightly higher than several others, e.g. guava juice (Azevedo et al., 2012), syrup (Raga et al., 2006), corn steep liquor and sugarcane molasses (Montes and Raga, 2006), 25% grape juice (Scoz et al., 2006), vinegar (Monteiro et al., 2007), hydrolyzed enzymatic protein and ammonium acetate and putrescine (Lasa et al., 2014), and yeast (Santos et al., 2010). Few studies demonstrate lower attractiveness by hydrolyzed protein relative to other baits. For instance, Epsky et al. (2011) carried studies that showed compounds based on mixture of ammonium acetate and putrescines are most attractive.

Some studies have shown that yeasts are attractive lures to tephritids, with higher than or similar to different corn hydrolysate baits (Santos et al., 2008) as observed for 25% grape juice in this study (Monteiro et al., 2007).

An amount of 14,382 flies were caught in 2014, among which 2,109 (14.6%) in solid baits and 12,273 (85.3%) in the same compounds diluted in water at 5% (Table 5). Again, tephritids were predominant, reaching 99.6% in studies with solid baits and 99.7% with liquid ones. The species *C. capitata* has also prevailed, accounting for 87.9 and 96.6% of all captured flies in solid and liquid baits, respectively (Table 5). The genus *Anastrepha* was represented for the species *A. fraterculus* (11.7 and 3.1%) and *A. manihoti* Lima, 1934 (0.04%). Among lonchaeids, solely specimens belonging to the *Neosilba* genus were taken, representing 0.4 and 0.3% in studies using solid and liquid baits, respectively (Table 2).

Bionis® (com - T1, and without sugar - T2) and Brewer's yeast (T4), in solid form, were as attractive as hydrolyzed protein (control - T5) (Table 6). Studies on yeasts (Torula) indicated upper attractiveness of this compound when compared to Biolure, which is based on ammonia and putrescine to capture flies of the species *Anastrepha ludens* (Loew, 1873) (Conwany and Forrester, 2007).

Not all liquid baits differed from hydrolyzed protein, except for grape flour that was less attractive to *C. capitata* (Table 6). Although not significant, sugarless yeast extract and poultry feces showed the highest

Table 2. Number and percentage (%) of frugivorous flies captured by solid and liquid baits in a coffee plantation in the city of Planalto - BA, Brazil. May of 2013.

Treatment	Solid baits								Liquid baits					
	C. capitata		*A. fraterculus*		*A. consobrina*		*Neosilba* spp.		*C. capitata*		*A. fraterculus*		*Neosilba* spp.	
	Nº	%	Nº	%	Nº	%	Nº	%	Nº	%	Nº	%	Nº	%
T1 (Yeast extract with sugar)	15	18.7	0	-	0	-	1	100.0	210	14.4	12	24.5	7	58.4
T2 (Yeast extract without sugar)	18	22.5	0	-	0	-	-	-	360	24.5	13 (9M)*	26.5	4	33.3
T3 (Citrus pulp)	0	-	0	-	0	-	-	-	69	4.7	1 (1M)*	2.0	0	-
T4 (Brewer's yeast)	17	21.2	0	-	0	-	-	-	263	17.9	2	4.0	0	-
T5 Control (Hydrolyzed protein)	30	37.6	2	100.0	1	100.0	-	-	564	38.5	21 (4M)*	42.9	1	8.3
Total	**80**	**100.0**	**2**	**100.0**	**1**	**100.0**	**110**	**0.0**	**1.466**	**100.0**	**49**	**100.0**	**12**	**100.0**
Overall total							**84**	**5.2**					**1.527**	**94.7**

Table 3. Average number (± standard deviation) of captured *C. capitata* in solid baits, in a coffee plantation in the city of Planalto - BA, Brazil. May of 2013.

Treatments	Solid			Liquid		
	Females	Males	Total	Females	Males	Total
T1 (Yeast extract with sugar)	1.8 ±1.1^{ab}**	1.0 ± 0.5^{a}**	2.8±1.2^{ab}**	38.4±3.2^{ab}**	8.8±2.1^{a} *	47.2±3.8^{a}*
T2 (Yeast extract without sugar)	1.8 ±0.1^{ab}	1.6 ±0.3^{a}	3.4 ±0.2^{ab}	65.8±1.9^{a}	16.4±1.5^{a}	82.2±2.4^{a}
T3 (Citrus pulp)	0.0 ±0.0^{b}	0.0 ±0.0^{b}	0.0 ±0.0^{b}	18.7±1.5^{b}	2.6±0.6^{a}	17.6±1.5^{a}
T4 (Brewer's yeast)	2.0±0.4^{ab}	1.4 ±0.5^{a}	3.4 ±0,4^{ab}	45.6±1.2^{ab}	8.0±1.0^{a}	53.4±1.3^{a}
T5 Control (Hydrolyzed protein)	3.4±1.0^{a}	1.2±0.5^{a}	4.6 ±1.0^{a}	96.4±2.2^{a}	17.2±1.2^{a}	113.6±1.3^{a}
CV (%)					56.6	31.1

*Means followed by the same letter within a column do not differ from each other by the Tukey's test at 5% probability. The data were transformed into log x+1. ** Means followed by the same letter do not differ from each other by the non-parametric Friedman's test (p>0.05).

average of captures for *C. capitata* compared to control. The attractiveness of odor released by the baits to adults of *C. capitata* may be influenced by its nutritional status, that is, protein-deficient adults may associate the odor as being a protein source by means of olfactory receptors (Manrakhan and Lux, 2008).

Among solid baits, the hydrolyzed protein remained most attractive to *A. fraterculus*. However, yeast extract (T1 and T2), citric pulp (T3), beer yeast (T4), passion fruit fiber (T7) and poultry droppings (T9) had no difference with control for collections of *A. fraterculus* (Table 7); thus, they still deserve more attention. Studies on protein-based commercial baits have shown a high efficiency in capturing *Anastrepha* spp. flies (Raga et al., 2006), as well protein is regarded as an important nutrient for fruit flies, directly influencing the insect longevity and sexual performance in adults (Oviedo et al., 2011).

Differently, the results for liquid form baits demon-strated a greater attractiveness of plum flour against other treatments. The release of volatile substances by compounds might have been responsible to attract adults of *A. fraterculus*. For Kendra et al. (2005), the response of *Anastrepha supensa* (Loew, 1862) females to the releasing of volatile compounds as ammonia, for example, is related protein intake period.

A fewer specimens of lonchaeids were found

Table 4. Average number (± standard deviation) of *A. fraterculus* captured in solid and liquid baits, in a coffee plantation in the city of Planalto - BA, Brazil. May of 2013.

Treatments	**Solid**			**Liquid**		
	Females	**Males**	**Total**	**Females**	**Males**	**Total**
T1 (Yeast extract with sugar)	0.0 ±0.0^{b}*	0.0 ± 0.0^{a}*	0.0±0.0^{b}*	3.2±0.6^{ab}*	0.6±0.7^{ab} *	3.8±0.7^{ab}*
T2 (Yeast extract without sugar)	0.0 ±0.0^{b}	0.0 ±0.0^{a}	0.0 ±0.0^{b}	3.0±0.7^{ab}	1.4±0.5^{a}	4.4±0.8^{a}
T3 (Citrus pulp)	0.0 ±0.0^{b}	0.0 ±0.0^{a}	0.0 ±0.0^{b}	0.0±0.0^{b}	0.2±0.4^{ab}	0.2±0.4^{b}
T4 (Brewer's yeast)	0.0±0.0^{b}	0.0 ±0.0^{a}	0.0 ±0.0^{b}	0.2±0.4^{ab}	0.0±0.0^{b}	0.2±0.4^{b}
T5 Control (Hydrolyzed protein)	0.4±0.3^{a}	0.0±0.0^{a}	0.4 ±0.3^{a}	4.2±0.1^{a}	0.6±0.5^{ab}	4.8±0.7^{a}

*Means followed by the same letter do not differ from each other by the non-parametric Friedman's test (p>0.05).

Table 5. Number and percentage (%) of frugivorous flies captured by solid and liquid baits in a coffee plantation in the city of Planalto - BA, Brazil. July of 2014.

Treatments	**Solid baits**								**Liquid baits**					
	C. capitata		***A. fraterculus***		***A. manihoti***		***Neosilba* spp.**		***C. capitata***		***A. fraterculus***		***Neosilba* spp.**	
	Nº	**%**	**Nº**	**%**	**Nº**	**%**	**Nº**	**%**	**Nº**	**%**	**Nº**	**%**	**Nº**	**%**
T1 (Yeast extract with sugar)	157	8.5	31(15M)*	12.6	0	-	3	33.3	1.111	9.4	59 (20M*)	15.5	13	39.5
T2 (Yeast extract without sugar)	179	9.6	82(24M)*	33.3	1	100.0	6	66.6	2.593	21.9	89 (91M)	23.5	2	6.1
T3 (Citrus pulp)	36	1.9	1	0.4	0	-	0	-	1.269	10.7	7 (18M)*	1.8	-	-
T4 (Brewer's yeast)	207	11.2	(1M)*	1.2	0	-	0	-	635	5.3	1 (6M)*	0.2	3	9.1
T5 (Plum flour)	52	2.8	0	-	0	-	0	-	1.266	10.7	50 (34M)*	13.2	1	3.0
T6 (Açaí flour)	38	2.1	0 (1M)*	-	0	-	0	-	811	6.8	9 (19M)*	2.4	1	3.0
T7 (Passion fruit fiber)	91	4.9	5 (5M)*	0.8	0	-	0	-	915	7.7	23 (17M)*	6.1	1	3.0
T8 (Grape flour)	17	0.9	0	-	0	-	0	-	113	0.9	1	0.2	-	-
T9 (Poultry feces)	142	7.7	19 (10M)*	7.7	0	-	0	-	2.066	17.4	29 (12M)*	7.6	11	33.3
T10 Control (Hydrolyzed protein)	935	50.4	105(74M)*	42.7	0	-	0	-	1.081	9.1	112(11M)*	29.5	1	3.0
Total	**1.853**	**100.0**	**246**	**-**	**1**	**100.0**	**9**	**-**	**11.860**	**100.0**	**380**	**100.0**	**33**	**100.0**
Overall total							**2.109**	**14.6**					**12.273**	**85.3**

*M = Number of male flies belonging to the genus Anastrepha caught in traps at different treatments.

compared to tephritids, with hydrolyzed protein showing low or even null attractiveness to the species *Neosilba* sp. (Tables 2 and 3). Yeast extract with and without sugar, in both solid and in liquid form, plus the bird feces in liquid form enabled the capturing of the vast majority of insects. These baits should be indicated for biodiversity studies as well as monitoring of this group of flies. The genus *Neosilba* comprises species of great economic interest; therefore, its population monitoring is of upmost importance, once they affect commercial fruits (Strikis et al., 2011).

In solid form, yeast extract and beer yeast have potential as alternatives to the use of hydrolyzed

Table 6. Average number (± standard deviation) of *C. capitata* captured by solid and liquid baits in a coffee plantation in the city of Planalto - BA, Brazil. July of 2014.

Treatments	Solid			Liquid		
	Females	Males	Total	Females	Males	Total
T1 (Yeast extract with sugar)	29.5 ±1.6^{bcd}*	9.7 ± 0.8^{ab}*	39.2±1.2^{abcd}*	164.5±1.1^{a}*	115.0±2.0^{a}*	277.7±2.1^{ab}*
T2 (Yeast extract without sugar)	36.2 ±0.5^{abc}	10.0 ±1.0^{ab}	46.2 ±1.8^{abc}	491.5±1.9^{a}	183.5±4.8^{a}	675.0±7.4^{a}
T3 (Citrus pulp)	7.2 ±1.4^{cde}	1.7 ±0.8^{b}	9.0 ±0.8^{cde}	195.0±6.2^{a}	83.7±3.7^{ab}	278.7±7.4^{ab}
T4 (Brewer's yeast)	45.0±1.5^{ab}	7.0 ±0.3^{ab}	52.0±1.3^{ab}	110.7±3.6^{ab}	58.7±3.7^{ab}	169.5±4.4^{ab}
T5 (Plum flour)	9.5±1.1^{de}	3.5± 0.8^{ab}	13.0±1.7^{bcde}	203.5±0.2^{a}	113.0±3.7^{ab}	316.5±5.5^{ab}
T6 (Açaí flour)	7.2 ±1.1^{bcd}	1.7 ±0.7^{b}	9.0 ±1.3^{de}	171.5±9.4^{ab}	69.5±7.1^{ab}	241.0±11.8^{ab}
T7 (Passion fruit fiber)	22.7 ±0.6^{bc}	5.7±0.4^{ab}	28.5 ±1.1^{bcd}	158.4±6.1^{ab}	64.5±5.0^{ab}	222.7±7.8^{ab}
T8 (Grape flour)	3.7±1.7^{e}	0.5 ± 0.4^{b}	4.2± 0.7^{e}	19.7±1.1^{b}	8.5±1.5^{b}	28.2±1.5^{b}
T9 (Poultry feces)	29.2±1.7^{bcd}	6.2± 0.9^{ab}	35.5 ±1.9^{bcd}	392.7±5.8^{a}	108.2±1.4^{ab}	501.0±5.2^{a}
Control (Hydrolyzed protein)	205.7±4.1^{a}	28.0±1.7^{a}	233.7 ± 4.4^{a}	212.7±1.2^{a}	57.5±1.8^{ab}	270.2±1.1^{ab}
CV (%)	22.0	49.0	21.9	16.8	48.5	40.6

*Means followed by the same letter within a column do not differ from each other by the Tukey's test at 5% probability. The data were transformed into log x+1.

Table 7. Average number (± standard deviation) of *A. fraterculus* captured in solid and liquid baits in a coffee plantation in the city of Planalto - BA, Brazil. July of 2014.

Treatments	Solid			Liquid		
	Females	Males	Total	Females	Males	Total
T1 (Yeast extract with sugar)	7.0 ±0.3^{ab}**	4.0 ±0.7^{ab}**	11.0±0.6^{ab}**	13.7±1.2^{ab}*	6.5±0.7^{ab}**	20.2±1.2^{ab}*
T2 (Yeast extract without sugar)	17.7 ±0.6^{ab}	8.7 ±0.8^{ab}	26.5±0.9^{ab}	23.7±1.1^{a}	9.5±1.4^{a}	33.2±2.0^{a}
T3 (Citrus pulp)	0.2 ±0.5^{ab}	0.0 ±0.0^{b}	0.2 ±0.5^{ab}	2.0±1.1^{bc}	1.5±0.5^{ab}	3.5±1.1^{bc}
T4 (Brewer's yeast)	0.7 ±0.2^{ab}	0.2 ±0.5^{ab}	1.0 ±0.4^{ab}	1.5±0.5^{bc}	0.7±0.5^{ab}	2.2±0.2^{bc}
T5 (Plum flour)	0.0±0.0^{b}	0.0± 0.0^{b}	0.0 ±0.0^{b}	12.5±2.2^{abc}	6.5±1.1^{ab}	19.0±2.4^{ab}
T6 (Açaí flour)	0.0±0.0^{b}	0.2 ±0.5^{b}	0.2 ±0.5^{ab}	2.2±1.0^{bc}	1.5±0.7^{ab}	3.7±1.2^{bc}
T7 (Passion fruit fiber)	1.2 ±0.5^{ab}	1.2±0.6^{ab}	2.5 ±0.8^{ab}	6.5±1.8^{abc}	2.0±1.1^{ab}	8.5±7.8^{abc}
T8 (Grape flour)	0.0 ±0.0^{b}	0.0 ± 0.0^{b}	0.0± 0.0^{b}	0.2±0.5^{c}	0.0±0.0^{b}	0.2±0.5^{c}
T9 (Poultry feces)	4.5±0.4^{ab}	3.2± 0.5^{ab}	7.7 ±1.2^{ab}	12.5±1.4^{abc}	3.0±0.7^{ab}	15.7±5.2^{ab}
Control (Hydrolyzed protein)	32.2±2.8^{a}	13.2±1.5^{a}	45.7 ±3.2^{a}	12.0±0.6^{ab}	33.0±0.4^{ab}	15.0±0.7^{ab}
CV (%)				29.2		43.7

* Means followed by the same letter within a column do not differ from each other by the Tukey's test at 5% probability. The data were transformed into log x+1. ** Means followed by the same letter do not differ from each other by the non-parametric Friedman's test (p>0.05).

protein for *C. capitata* and *A. fraterculus*. In liquid form, all baits had an increase in attractiveness, except for grape flour, which was less attractive to both species of flies. It is also noteworthy mention that poultry feces were attractive, especially in liquid form, for the capture of both species of flies. Females seem to be showing a greater selectivity for baits than males do. Good catches provided by poultry liquid material might be derived from ammonium release when decaying, being attractive to the flies. Such attractiveness of poultry droppings have been reported in a few species as the case of *Rhagoletis pomonella* (Wash, 1867) (Prokopy et al., 1993a) and *A. suspensa* (Epsky et al., 1997). For *C. capitata*, this attractiveness varies with the source and excrement conditions. Droppings of birds and lizards are most attractive than mammal feces, since the first two show uric acid decomposition that is more attractive than the urea decomposition (Prokopy et al., 1993b). The rates of decomposition and ammonium release to the atmosphere could vary with interactions between biotic and abiotic factors as microbial activities, temperature and rainfall (Mazor, 2009).

From an economic point of view, the use of yeast extract (Bionis, with or without sugar) would be most expensive since this product costs around US$ 8.26 per kilo (Biogirin, 2014), while a liter of hydrolyzed protein (Bio Anastrepha®) costs US$ 2.77, excluding transportation expenses. Poultry feces would probably have much lower costs; however, the lack of suppliers with standardized products could hinder this process.

Conflict of interests

The authors have not declared any conflict of interests.

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The efficiency of wheat yields by nitrogen dose and fractionation

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The biomass productivity and wheat grains efficiency is determined by nitrogen dose adjustment (full or fractioned), environmental conditions, and cropping system. The aim of this study was to improve the efficiency of N-fertilizer usage on wheat to maximize the biomass productivity and grain yield by adjusting the full or fractioned nitrogen dose in favorable and unfavorable year conditions, in succession systems with high and reduced N-residual release. In this study, two experiments were conducted between 2012 and 2014. One was to quantify the biomass productivity rate and another to determine grain yield. The experimental design was a complete randomized block, with four replications, in a 4 × 3 factorial scheme to N fertilizer rates (0, 30, 60 and 120 kg ha^{-1}) and supply forms of the nutrient [full dose (100%) in the V_3 phenological stage (third expanded leaf); fractioned (70 and 30%) at the V_3 and V_6 phenological stages (third and sixth expanded leaf, respectively) and; fractionated (70 and 30%) at the V_3 and E phenological stages (third expanded leaf and early grain filling),] respectively, in soybean/wheat and maize/wheat cultivation systems. The nitrogen supply in wheat through single dose or fraction indicates linear tendency over the productivity biomass daily rate-1 with the increase of N-fertilizer, regardless of a favorable and unfavorable year and system of a succession of the high and reduced N-residual release. However, in favorable years, the use of full dose on V_3 stage is indicated. In the maize/wheat system, the full dose at V_3 stage is more efficient, especially with higher doses of the nutrient. For grain yield, the N-fertilizer fractioning was adjusted in intermediate cropping years, while the full dose became suitable at the V_3 stage in favorable years. However, in unfavorable years, nitrogen investments should be minimized, regardless of the supply form and succession system.

Key words: *Triticum aestivum* L., succession system, optimization, regression.

INTRODUCTION

The supply of N-fertilizer for plants depends, among other factors, on the amount of soil organic matter, the decomposition of plant residues and yield expectation, which interact with each other in cropping systems (Costa et al., 2013; Mantai et al., 2015a). The management technologies and weather conditions act under the nitrogen use efficiency in productivity (Benin et al., 2012; Mantai et al., 2015a). Therefore, the climatic conditions of each year (favorable or unfavorable) and the succession systems, with high or reduced N-residual release, can alter the nitrogen use efficiency in wheat yield (Arenhardt et al., 2015).

The quantity and the proper time of nitrogen application should be better exploited since high doses and/or applications in early/late crop development stages may be too little advantageous (Arenhardt et al., 2015; Ma et al., 2010), in addition to the environmental losses caused by leaching and volatilization (Ma et al., 2010; Mantai et al., 2015b). Therefore, nitrogen fertilization should not be characterized by its high cost, but by the efficient use to provide productivity and sustainability (Costa et al., 2013). In this context, the possibility of splitted application of N fertilizers with adjusted doses can result in increased utilization efficiency by wheat (Espindula et al., 2010). This management can be better understood and feasible, taking into account the environmental conditions and succession systems with the high and reduced release of N-residual.

The aim of this study is to improve the N-fertilizer use efficiency of wheat to maximize the biomass productivity and grain yield by dose adjustment for wheat plant development under conditions of favorable and unfavorable years of cultivation, and crop rotations with high and reduced N-residual release.

MATERIALS AND METHODS

The field experiments were conducted in the years 2012, 2013 and 2014, at the municipality of Augusto Pestana (28° 26' 30" South and 54° 00' 58" West), Rio Grande do Sul, Brazil. The soil of the experimental area is classified as typical dystrophic red latosol and the climate is classified as Cfa, according to Köppen classification, with hot summer and without a dry season. Soil analysis was carried out ten days before the sowing date and subsequently in the average of the years was identified with the following chemical characteristics: i) maize/wheat system (pH= 6.5, P= 23.6 mg dm^{-3}, K= 295 mg dm^{-3}, OM= 2.9%, Al= 0 cmol$_c$ dm^{-3}, Ca= 6.8 cmol$_c$ dm^{-3}, and Mg= 3.1 cmol$_c$ dm^{-3}) and; ii) soybean/wheat system (pH= 6.1, P=49.1 mg dm^{-3}, K= 424 mg dm^{-3}, OM= 3.0%, Al= 0 cmol$_c$ dm^{-3}, Ca= 6.3 cmol$_c$ dm^{-3} and Mg= 2.5 cmol$_c$ dm^{-3}). The sowing was carried out according to the wheat technical indications, mechanically, with experimental units using 5 rows of 5 m long and spaced 0.20 m apart, totaling 5 m^2. The quantity of 60 and 50 kg ha^{-1} of P_2O_5 and K_2O, respectively, was applied during sowing based on the P and K levels in the soil, considering the expected grain yield of 3 t ha^{-1} and urea nitrogen form to contemplate the proposed dose in this study.

The seeds were submitted to a germination and vigor test in the laboratory in order to provide the desired density of 300 viable seeds per m^{-2}. During vegetation period, plants were protected against diseases by FOLICUR® EC fungicide at the dose of 0.75 L ha^{-1}. In addition, the weeds were controlled with named ALLY® used, which is known to have reduced stature, early cycle, resistance to lodging, commercial type "bread" and high yield potential. The cultivar is the standard biotype commonly desired by wheat farmers in southern Brazil.

In each cultivation system with high and low N-residual release (soybean/wheat and maize/wheat systems), two experiments were conducted. One was to quantify the biomass productivity rate (DB, kg ha-1) by cuts in every 30 days to physiological maturity, and the other to estimate grain yield (GY, kg ha-1). The experimental design used for all the experiments was a randomized block with four replications, in a factorial 4 × 3 scheme for N-fertilizer rates (0, 30, 60 and 120 kg ha-1) and for nitrogen supply ways [one rate (100%) in the V3 phenological stage (third expanded leaf); fractionated (70 and 30%) in the V3 and V6 phenological stages (third and sixth expanded leaf); and fractioned (70 and 30%) in the V3 and E phenological stages (third expanded leaf and early grain filling)], respectively.

The harvest of wheat for estimations of the biomass productivity and grain yield was performed manually by cutting the three central rows of each experimental unit, close to harvest stage (125 days after sowings), with approximately 15% moisture content of grain. The harvest of grains is also defined as the last cut in the experiment directed for analyzing biomass productivity. The plants designed for grain harvest were threshed and dried to 13% grain moisture, and estimating the grain yield (GY, kg ha^{-1}). The plants for biomass analysis were dried in the kiln at 65°C until constant weight for weighing and estimating biomass productivity (DB, kg ha^{-1}).

After checking the assumptions of normality and homogeneity using Bartlett test, analysis of variance for detection of the main and interaction effects was carried out. Based on this information, the adjustment was made using the linear equation (DB= b0 ± bix) to estimate the daily biomass production rate^{-1} ha^{-1} and averages by the Scott and Knott test in the analysis of grain yield in each dose and N-fertilizer supply condition. In conditions where there was a significant quadratic effect ($GY= b_0 \pm b_1x \pm b_2x^2$), the estimated maximum technical efficiency ($MTE = -[(b_1)/(2b_2)]$) of nitrogen use for grain yield was obtained. On the other hand, when there was a significant linear effect ($GY=b_0 \pm b_ix$) the grain yield was obtained by N-fertilizer technical recommendation accordingly with the succession of culture for the estimated 3 t ha^{-1}. All statistical procedures were performed using the Genes software.

RESULTS AND DISCUSSION

In 2012, the maximum temperatures observed in the beginning of wheat development was higher (± 27°C) in relation to 2013 and 2014 (Figure 1). The condition improved faster elongation and decreased the stimulus to the production of new tillers, a determinant component for biomass productivity and grain yield. After fertilization, variations of temperature were observed close to flowering time. Although rainfall was less in comparison with historic average (Table 1), the association between meteorological information and reasonable productivity

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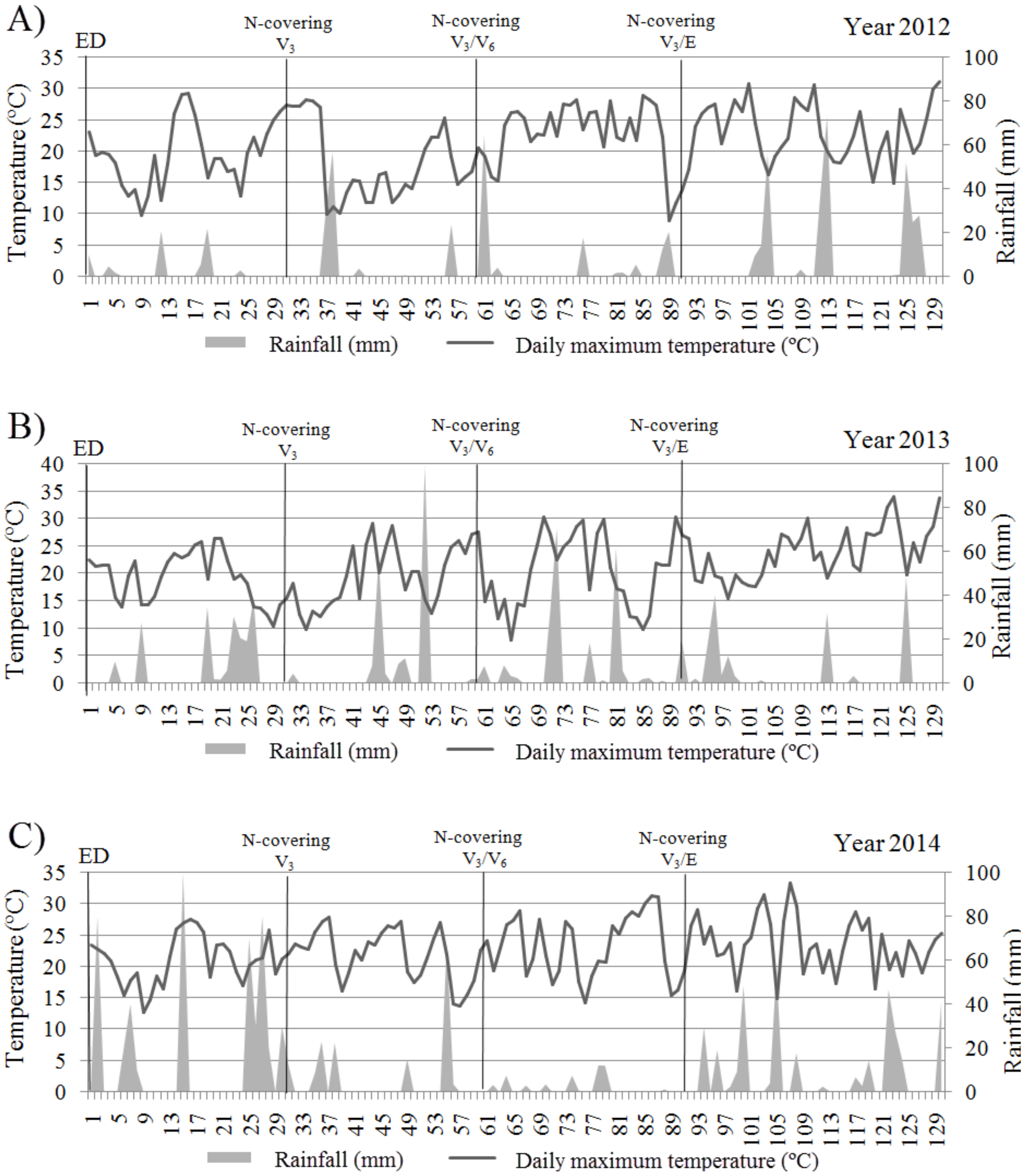

Figure 1. Rainfall and daily maximum temperature in the wheat crop cycle with the days of nitrogen application. ED= emergency date: 2012 (27 June); 2013 (17 June); 2014 (25 June). DAE= days after emergency. V_3= full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; and V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling.

obtained characterize 2012 as an intermediate year (IY) of cultivation.

In 2013, the maximum temperatures observed at the moment of N-fertilizer application was around of 15°C, and with favorable conditions of soil moisture for rain that occurs before fertilizing (Figure 1). According to Table 1, the total volume of rain was similar to historic average, indicating the adequate distribution of rainfall along the cycle (Figure 1). These conditions were decisive for a higher average of grain yield, characterizing 2013 as a

Table 1. Temperature, rainfall per month and average productivity.

Year	Month	Temperature (ºC)			Rainfall (mm)		$GY_{\bar{x}}$ (kg ha^{-1})	Class
		Minimum	Maximum	Average	Historical average*	Occurred		
2012	May	11.1	24.5	17.8	149.7	20.3	2441	IY
	June	9.3	19.7	14.5	162.5	59.4		
	July	7.4	17.5	12.4	135.1	176.6		
	August	12.9	23.4	18.1	138.2	61.4		
	September	12.0	23.0	17.5	167.4	194.6		
	October	15.0	25.5	20.2	156.5	286.6		
	Total	-	-	-	909.4	798.9		
2013	May	10.5	22.7	16.6	149.7	100.5	3358	FY
	June	7.9	18.4	13.15	162.5	191.0		
	July	8.3	19.2	13.75	135.1	200.8		
	August	9.3	20.4	14.85	138.2	223.8		
	September	9.5	23.7	16.6	167.4	46.5		
	October	12.2	25.1	18.65	156.5	211.3		
	Total	-	-	-	909.4	973.9		
2014	May	10.8	23.6	17.2	149.7	412.0	1414	UY
	June	8.6	19.0	13.8	162.5	412.0		
	July	9.7	21.8	15.8	135.1	144.0		
	August	8.8	23.7	16.2	138.2	77.8		
	September	13.33	23.6	18.5	167.4	274.8		
	October	16.02	27.5	21.8	156.5	230.8		
	Total	-	-	-	909.4	1551.4		

*= Average rainfall obtained the months from May to October 1989-2014; IY= intermediate year; FY= favorable year; UY= unfavorable year; $GY_{\bar{x}}$= average grain yield.

favorable year (FY) of cultivation. In 2014, the moment of N-fertilizer application indicated maximum temperature next to 23°C (Figure 1). Although there were adequate conditions of soil moisture due to rains that occurred before fertilizing, the moment of nutrient supply was characterized by significant rain volume (30 mm), allowing a high loss of nitrogen for leaching. In addition, the big frequency and rain volume were observed between 90 days after an emergency and the harvest date. This period coincides with low light and high temperatures, these conditions reduced the efficiency photosynthesis. The elevated rainfall in relation to historic average and the reduced productivity obtained in this crop season (Table 1) characterize 2014 as an unfavorable year of cultivation.

One way to improve the nitrogen absorption by plants is the mutation of soil humidity. The nitrogen supply depends on humidity, aeration, and temperature that interrelate with each other in cropping systems (Rocha et al., 2008; Silva et al., 2015). The rainfall is the main meteorological variable that affects the productivity of cultivated species (Benin et al., 2012; Battisti et al., 2013). In this sense, stress caused by lack of water affects plant development negatively with direct effect in productivity (Guarientiet al., 2005; Arenhardt et al., 2015).

The soil and weather variability alter the nitrogen disponibility and demand of plant, thereby restricting productivity (Simili et al., 2008). Weather favorable to wheat is described as more mild temperatures and of solar radiation quality, improving tillering and grain filling, and without high volume and intense rainfall, but one that improves the adequate supply of soil moisture (Guarientiet al., 2004; Valério et al., 2009). Mild temperatures improve the number and filling of grains, while high temperatures on tillering cause infertility of spikelets, which lead to low productivity (Ribeiro et al., 2009).

In the analysis of the variation source of the main effects of nitrogen doses, the condition of supply, cultivate years, and the significant triple interaction was obtained on daily biomass productivity rate^{-1}, total biomass and grain yield (not shown); justifying the way of table presentation in interaction developments. The soybean/wheat system with the high liberation of N-residual, in 2012 (intermediate year) indicated that fractionation condition promotes expressive values on daily biomass productivity rate^{-1}, total biomass and grain yield (Table 2). The dose of 30 kg of N ha^{-1} was more

Table 2. Linear regression equation of dry biomass and wheat average grain yield by dose and nitrogen fractionation in the soybean/wheat system.

Dose	Condition of N	Equation	R^2	P	Average (kg ha^{-1})	
(N)	Stage (DAE)	DB= $b_0 \pm b_i x$	(%)	($b_i x$)	DB	GY
		2012 (IY)				
0	-	1371+68x	80	*	3730	1607
30	V_3 (30)	1134+68x	75	*	4021 a	2256 b
	V_3/V_6 (60)	1811+83x	83	*	4432 a	2570 a
	V_3/E(90)	1614+77x	61	*	4190 a	2273 b
60	V_3(30)	1570+78x	68	*	4349 a	2330 b
	V_3/V_6(60)	1307+74x	73	*	4283 a	2453 b
	V_3/E(90)	1763+82x	72	*	4401 a	2686 a
120	V_3 (30)	1434+75x	74	*	4194 b	2875 a
	V_3/V_6 (60)	1327+78x	75	*	4562 a	2638 a
	V_3/E(90)	2244+85x	83	*	4172 b	2846 a
		2013 (FY)				
0	-	1977+71x	95	*	3352	1930
30	V_3 (30)	1823+73x	99	*	3686 a	2860 a
	V_3/V_6 (60)	2805+82x	96	*	3342 a	2990 a
	V_3/E(90)	2393+77x	86	*	3393 a	2763 b
60	V_3 (30)	1908+84x	91	*	4412 a	3952 a
	V_3/V_6 (60)	2179+84x	93	*	4193 a	3591 b
	V_3/E(90)	2019+75x	97	*	3653 b	3450 c
120	V_3 (30)	1903+95x	91	*	5268 a	4501 a
	V_3/V_6 (60)	2754+108x	88	*	5355 a	4676 a
	V_3/E (90)	2351+88x	99	*	4306 b	4438 a
		2014 (UY)				
0	-	442+53x	67	*	3560	1069
30	V_3 (30)	701+68x	67	*	4402 b	1345 a
	V_3/V_6 (60)	882+80x	56	*	5163 a	1514 a
	V_3/E(90)	1968+81x	86	*	3715 c	1376 a
60	V_3 (30)	843+77x	59	*	4954 b	1798 a
	V_3/V_6 (60)	1161+90x	57	*	5611 a	1566 a
	V_3/E(90)	1005+75x	69	*	4656 b	1549 a
120	V_3 (30)	1021+86x	69	*	5500 a	1613 a
	V_3/V_6 (60)	1027+91x	62	*	5844 a	1536 a
	V_3/E(90)	851+86x	64	*	5780 a	1665 a

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = Fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); DB= dry biomass (kg ha^{-1}); R^2= determination coefficient; P ($b_i x$)= significance probability of slope line; *= significant at 5% probability level. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

efficient when fractionation was employed in V_3/V_6 stages. However, 60 kg dose of N ha^{-1} indicated that the fractionating in V_3/E stages was more responsive. In elevated nutrient dose, the V_3/V_6 fractionating indicated more efficiency, similar to the reduced condition of N-fertilization.

In 2013 (favorable year), the fertilizing in V_3 stage showed more significant results with all doses of N-fertilizing. Although the V_3/V_6 condition can increase the daily biomass productivity rate^{-1}, the total biomass productivity and grain yield was inferior or similar to the full dose provided. As a result, one single application in nitrogen management in the field became more advantageous, reducing the production costs and work time by using machinery. In 2014 (unfavorable year), the condition of N-fertilizing use in full dose or fractionated raised questions, mainly, in years of rain becoming more intense close to harvest (Table 2). In doses of 30 and 60 kg of N ha^{-1}, the fractioned condition showed more interest on daily biomass productivity rate^{-1} and total biomass, however, it does not occur differences on grain yield. This suggests that when seeking maximum productivity straw for summer crops in the no-tillage system, it is indicated with the fractioning shown. On the other hand, at the higher dose of N-fertilizer, a single application promoted similar results on grain yield and biomass. While analyzing only the grain yield, the use of full dose stands out as the most appropriate management, regardless of nutrient dose.

The maize/wheat system, with reduced N-residual release, in the year 2012 (intermediate year) showed advantages over nitrogen use in full dose in the condition of 30 and 60 kg N ha^{-1} (Table 3). Only in the highest condition of N-fertilizer the V_3/E fractioning proved advantageous on grain yield. In 2013 (favorable year), the nitrogen management in full dose also showed positive results in grain yield, regardless of N-fertilizer dose. It may represent a reduction of time and costs in the machinery used for soil fertilization.

The doses of 60 and 120 kg N ha^{-1} may increase the straw productivity in the field when fractionated in V_3/V_6 growth stages, in comparison with the single dose at V_3 growth stage (Table 3). In the year 2014 (unfavorable year), the full dose condition in this system also showed more effective results on daily biomass productivity rate^{-1}, total biomass and grain yield. The results of conjoint analysis of biomass productivity and grain yield indicated that, in the high N-residual condition (Table 2), the intermediate year (2012) and unfavorable year (2014) suggested the use of N fractionation. However, in the favorable year (2013) the use of full dose is the most indicated. In the condition of high C/N ratio (Table 3), the results suggest that the lower N-residual release for corn straw requires the need for the most intensive use of N-fertilizer, with direct application of full dose at V_3 stage.

The favoring of cultivation year is decisive on the productivity potential, due to the volume and rainfall distribution, temperature, and solar radiation (Benin et al., 2012). Nitrogen deficiency reduces the uptake of solar radiation by wheat, with direct effects on the biomass production and grain yield (Heinemann et al., 2006). The N-fertilizer stimulates the vegetative and root growth, affecting the absorption of nutrients and productivity (Flores et al., 2012). The description of N-fertilizer dose in wheat is realized according to the soil organic matter content, the species cultivated previously, and the yield expectations (Siqueira-Neto et al., 2010). The correct use of nitrogen in favorable weather conditions can increase the grains productivity, overcoming the expected yield by nitrogen dose. On the other hand, it can also facilitate the lodging, with negative effects on productivity and grain quality (Bredemeier et al., 2013; Arenhardt et al., 2015). The appropriate time for N-fertilizer supply in coverage focuses on plant phenology associated with the scarcity period of the nutrient (Bredemeier et al., 2013). For wheat, the biggest scarcity of nitrogen is defined between the period of emission of the third and sixth leaf (Arenhardt et al., 2015; Rissini et al., 2015). Nitrogen fractionation in wheat has been suggested to provide greater efficiency in the assimilation of nutrient, especially when soil moisture conditions are not appropriate at the moment of N application (Sangoi et al., 2007). Therefore, the fractioning can reduce leach losses in wet years and volatilization in dry years (Costa et al., 2013; Mantai et al., 2015b). In addition, the biochemical composition of the waste affects the dose and timing of nitrogen supply in relation to the nutrient release in soil and decomposing tissues (Siqueira-Neto et al., 2010).

The expression of grain yield by the maximum technical efficiency of nitrogen use and nutrient dose, for productivity expectation of 3 t ha^{-1}, in different growing conditions (unfavorable year, favorable year and intermediate year), are presented in tables 4 and 5. Thus, in linear behavior conditions, grain yield estimate for the expectation of 3 t ha^{-1} was obtained according to the wheat recommendations and the nutrient dose in function of succession system (soybean/wheat = 60 kg de N ha^{-1}; maize/wheat = 90 kg de N ha^{-1}). Considering the soybean/wheat system in the year 2012 (intermediate year), only the fractioned condition showed a quadratic behavior with 90 to 100 kg N ha^{-1} for the maximum grain yield of 2809 and 2932 kg ha^{-1}, respectively (Table 4). In this condition, the dose to the expectation of 3 t ha^{-1} showed the highest yields in fractioned condition. In an intermediate year, the reduction of N-fertilizer from optimum estimated dose of 60 kg N ha^{-1} showed great benefits. Among these benefits is the drastically reduced dose, close grain yield values, and reduction of production costs and environmental damages.

In 2013 (favorable year), the linear behavior was obtained either by full or fractioned N-fertilizer dose. In this year, the dose of 60 kg N ha^{-1} expressed greater values than the expectation of 3 t ha^{-1}, especially in full dose condition of the nutrient. In 2014 (unfavorable year), the fractionated condition showed similar behavior to the year 2012 (intermediate year), however, with low efficiency of N-fertilizer use. It is noteworthy that the nutrient optimal doses of 80 and 112 kg N ha^{-1} indicated maximum productivity of 1685 and 1702 kg ha^{-1}, respectively. Furthermore, the dose of 60 kg N ha^{-1} for the expected yield of 3 t ha^{-1} indicated mean grain yield approximately 1500 kg ha^{-1}. These facts reinforce that nitrogen use efficiency can be high or low depending on the weather conditions of the environment. Moreover, it shows that the N-fertilizer investment in restrictive conditions of cultivation must be minimized.

Considering the maize/wheat system in 2012 (intermediate year), only the fractioned condition in V_3/V_6 stages indicated a quadratic behavior, with an optimum nutrient dose of 118 kg N ha^{-1} for the expected 2918 kg

Table 3. Linear regression equation of dry biomass and wheat average grain yield by dose and nitrogen fractionation in the maize/wheat system.

Dose	Condition of N	Equation	R^2	P	Average (kg ha^{-1})	
(N)	Stage (DAE)	DB= $b_0 \pm b_i x$	(%)	($b_i x$)	DB	GY
		2012 (IY)				
0	-	1322+50x	91	*	2474	918
30	V_3 (30)	1734+74x	69	*	3858 a	1745 a
	V_3/V_6 (60)	2214+75x	84	*	3448 b	1912 a
	V_3/E(90)	1765+67x	83	*	3297 b	1764 a
60	V_3 (30)	2714+93x	86	*	4260 a	2237 a
	V_3/V_6 (60)	2543+84x	88	*	4165 a	2357 a
	V_3/E(90)	1754+73x	77	*	3740 b	2197 a
120	V_3 (30)	2288+87x	84	*	4239 a	2782 b
	V_3/V_6 (60)	2220+85x	77	*	4203 a	2795 b
	V_3/E(90)	2167+83x	79	*	4077 a	3211 a
		2013 (FY)				
0		1350+43x	95	*	1938	1262
30	V_3 (30)	2608+76x	97	*	3162 a	2892 a
	V_3/V_6 (60)	2600+76x	93	*	3165 a	2265 b
	V_3/E(90)	2927+80x	94	*	3100 a	2243 b
60	V_3 (30)	2432+75x	98	*	3203 b	3083 a
	V_3/V_6 (60)	3449+97x	94	*	3848 a	3077 a
	V_3/E(90)	2573+73x	95	*	2969 b	2392 b
120	V_3 (30)	2735+92x	88	*	4206 b	3871 a
	V_3/V_6 (60)	3355+108x	96	*	4760 a	3939 a
	V_3/E(90)	3030+95x	94	*	4155 b	3448 b
		2014 (UY)				
0	-	577+34x	87	*	1974	647
30	V_3 (30)	968+58x	76	*	3430 a	1133 a
	V_3/V_6 (60)	733+46x	76	*	2744 b	1027 a
	V_3/E(90)	745+39x	86	*	2236 c	944 a
60	V_3 (30)	641+62x	72	*	4024 a	1343 a
	V_3/V_6 (60)	1187+66x	75	*	3769 a	1476 a
	V_3/E(90)	744+43x	73	*	2499 b	1075 b
120	V_3 (30)	1116+71x	81	*	4211 a	1432 a
	V_3/V_6 (60)	1184+63x	85	*	3580 b	1483 a
	V_3/E(90)	1065+57x	90	*	3237 b	1457 a

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); DB= dry biomass (kg ha^{-1}); R^2= determination coefficient; P ($b_i x$)= significance probability of slope line. *= significant at 5% probability level. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

ha^{-1} (Table 5). In this condition, the dose employed for 3 t ha^{-1} (90 kg N ha^{-1}) promoted 2809 kg ha^{-1}. Therefore, it considerably reduced the nitrogen use and maintained similar productivities. In 2013 (favorable year), similar behavior was obtained in full and fractioned dose. The expected dose for 3 t ha^{-1} (90 kg N ha^{-1}) promoted approximately 4 t ha^{-1} in the full dose condition at V_3 stage. Moreover, although the years 2012 and 2014 showed the same behavior, the optimal nutrient dose of 93 kg N ha^{-1} in 2014 promoted expected productivity of 1535 kg ha^{-1}, with the similar expectation of 3 t ha^{-1}. These results support the proposal that in unfavorable years, investments with fertilizer should be reduced, noting the cost and benefit. However, the behavior observed in the soybean/wheat and maize/wheat systems on the N-fertilizer efficient use was similar with the

Table 4. Summary of regression variance analysis in the estimate of wheat grain yield by dose and nitrogen fractionation in the soybean/wheat system.

Condition (N) Stage (DAE)	Source of variation	Equation $GY = b_0 \pm b_1x \pm b_2x^2$	P (b_ix)	R^2 (%)	$N_{(MTE)}$ (kg ha^{-1})	$GY_{(MTE)}$ (kg ha^{-1})	$N_{(3\ t\ ha^{-1})}$ (kg ha^{-1})	$GY_{(3\ t\ ha^{-1})}$ (kg ha^{-1})
2012 (IY)								
V_3 (30)	L	1821+9x	*	94	-	-	60	2361 b
	Q	$1761+13.1x-0.03x^2$	^{ns}	95	-	-		
V_3/V_6 (60)	L	1936+7.1x	*	54	-	-	60	2683 a
	Q	$1675+25.2x-0.14x^2$	*	83	90	2809		
V_3/E(90)	L	1797+10.2x	*	80	-	-	60	2712 a
	Q	$1542+27.9x-0.14x^2$	*	99	100	2932		
2013 (FY)								
V_3 (30)	L	2276+20.4x	*	91	-	-	60	3500 a
	Q	$1999+39.4x-0.14x^2$	^{ns}	98	-	-		
V_3/V_6 (60)	L	2131+22.1x	*	97	-	-	60	3457 a
	Q	$1956+34.3x-0.1x^2$	^{ns}	99	-	-		
V_3/E(90)	L	1988+21.4x	*	97	-	-	60	3272 b
	Q	$1814+33.5x-0.1x^2$	^{ns}	99	-	-		
2014 (UY)								
V_3 (30)	L	1292+3.7x	*	50	-	-	60	1514 a
	Q	$1140+14.2x-0.08x^2$	^{ns}	83	-	-		
V_3/V_6 (60)	L	1177+4x	*	48	-	-	60	1641 a
	Q	$981+17.6x-0.11x^2$	*	93	80	1685		
V_3/E(90)	L	1169+4.7x	*	85	-	-	60	1567 a
	Q	$1075+11.2x-0.05x^2$	*	99	112	1702		

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); R^2= determination coefficient; P (b_ix) = inclination significance probability; *= significant at 5% probability level; ^{ns}= non-significant; L= linear equation; Q= quadratic equation; $N_{(MTE)}$= maximum technical efficiency of nitrogen use; $GY_{(MTE)}$= grain yield by the maximum technical efficiency of nitrogen use; $N_{(3\ t\ ha^{-1})}$= expected nitrogen dose for 3 t ha^{-1} of grain yield; $GY_{(3\ t\ ha^{-1})}$= grain yield obtained with the expected nitrogen dose for 3 t ha^{-1}. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

suffering of major changes by agricultural year conditions. The interaction between the climate and nitrogen use results in grain yield variations in wheat from year to year, being that water availability is the most decisive factor (Benin et al., 2012). Favorable weather conditions and cultivation techniques act on N-fertilizer efficient use, which is reflected in grain yield (Arenhardt et al., 2015). Nitrogen fertilization should be performed in order to provide adequate plant nutrition, with a possible increase in productivity components (Carvalho et al., 2001; Rissini et al., 2015). Independent of the application season, the increase up to 120 kg N ha^{-1} has positive effects on productivity (Teixeira Filho et al., 2010). The maximum nitrogen use efficiency in wheat ranged from 90 to 120 kg ha^{-1}, being that higher doses showed no significant responses in grain yield in favorable growing conditions (Penckowski et al., 2009). In irrigated wheat, a positive response was obtained with up to 156 kg N ha^{-1}, with grain yield of 6472 kg ha^{-1} (Heinemann et al., 2006). In oats, favorable growing conditions showed maximum nitrogen efficient use with 66 kg ha^{-1}, with grain yield of 3874 kg ha^{-1}. On the other hand, in unfavorable conditions, the maximum use efficiency was obtained with 92 kg N ha^{-1} with grain yield of 3172 kg ha^{-1}. These results show that favorable growing conditions associated with the optimum nitrogen dose can provide higher grain yield than expected (Mantai et al., 2015b). The fractionation of nitrogen fertilization in conditions of high rainfall can favor the increased wheat productivity and reduce losses by leaching (Espindula et al., 2010). This fractionation in wheat favors the biomass production, but not satisfactory in the expression of grain yield (Yano et al., 2005). According to Barbosa Filho et al. (2005), applying nitrogen two or three times results in significantly higher grain yield than when done at a single time. In the same sense, Sangoi et al. (2007) found that nitrogen

Table 5. Summary of regression variance analysis in the estimate of wheat grain yield by dose and nitrogen fractionation in the maize/wheat system.

Condition (N)	Source of variation	Equation	P	R^2	$N_{(MTE)}$	$PG_{(MTE)}$	$N_{(3\ t\ ha^{-1})}$	$PG_{(3\ t\ ha^{-1})}$
Stage (DAE)		$GY= b_0 \pm b_1x \pm b_2x^2$	(b_ix)	(%)	(Kg ha^{-1})		(Kg ha^{-1})	
		2012 (AI)						
V_3 (30)	L	$1109+15.2x$	*	91	-	-	90	2477 b
	Q	$886+30.5x-0.12x^2$	ns	99	-	-		
V_3/V_6 (60)	L	$1243+14.5x$	*	87	-		90	2809 a
	Q	$973+33x-0.14x^2$	*	99	118	2918		
V_3/E(90)	L	$1070+18.2x$	*	98	-	-	90	2708 a
	Q	$981+24.4x-0.04x^2$	ns	99	-	-		
		2013 (AF)						
V_3 (30)	L	$1700+20.1x$	*	81	-	-	90	3833 a
	Q	$1304+47x-0.21x^2$	ns	94	-	-		
V_3/V_6 (60)	L	$1471+21.9x$	*	95	-	-	90	3442 b
	Q	$1235+38.2x-0.13x^2$	ns	99	-	-		
V_3/E(90)	L	$1520+16.1x$	*	95	-	-	90	2969 c
	Q	$1460+20.3-0.03x^2$	ns	95	-	-		
		2014 (AD)						
V_3 (30)	L	$891+5.9x$	*	91	-	-	90	1422 a
	Q	$797+12.4x-0.05x^2$	ns	99	-	-		
V_3/V_6 (60)	L	$774+7.4x$	*	76	-	-	90	1534 a
	Q	$580+20.5x-0.11x^2$	*	98	93	1535		
V_3/E(90)	L	$687+7.2x$	*	95	-	-	90	1335 a
	Q	$566+11.3x-0.03x^2$	ns	98	-	-		

*DAE= days after emergence; IY= intermediate year; FY= favorable year; UY= unfavorable year; V_3= full condition (100%) of the nitrogen dose in the third expanded leaf; V_3/V_6 = fractioned condition (70 and 30%) of the nitrogen dose in the third and sixth expanded leaf; V_3/E= fractioned condition (70 and 30%) of the nitrogen dose in the third expanded leaf and early grain filling; GY= grain yield (kg ha^{-1}); R^2= determination coefficient; P (b_ix) = inclination significance probability; *= significant at 5% probability level; ^{ns}= non-significant; L= linear equation; Q= quadratic equation; $N_{(MTE)}$= maximum technical efficiency of nitrogen use; $GY_{(MTE)}$= grain yield by the maximum technical efficiency of nitrogen use; $N_{(3\ t\ ha^{-1})}$= expected nitrogen dose for 3 t ha^{-1} of grain yield; $GY_{(3\ t\ ha^{-1})}$= grain yield obtained with the expected nitrogen dose for 3 t ha^{-1}. Means followed by the same letter do not differ in the 5% error probability level by Scott & Knott test.

supply in divided doses acts significantly in grain yield. On the other hand, Silva et al. (2008) found no difference in wheat productivity when submitted to full or fractioned nitrogen dose. Coelho et al. (1998) contradict the advantageous effects of fractionation, reporting that this practice can be significant if there are losses of nitrogen in the application in full dose due to heavy rains.

Conclusions

To improve the nitrogen use efficiency by the conjoint analysis of the biomass productivity and grain yield in the soybean/wheat system, both unfavorable and intermediate years of cultivation suggest the utilization of fractioned nitrogen fertilization. However, during favorable years, the use of full dose in V_3 stage is more suitable. In the maize/wheat system, the full dose of N-fertilizer at V_3 stage is more efficient, especially at higher doses of nutrient. For grain yield, the nitrogen fertilizer fractioning is adjusted during the intermediate years of cultivation, while the full dose in V_3 stage is indicated in favorable years. During unfavorable years, nitrogen investments should be minimized regardless of the supply form and succession system.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Technological parameters and economic analysis of sugarcane cultivated under irrigation depths for ethanol production in Santa Maria-RS, Brazil

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This study aimed to perform economic analysis and evaluate the effect of technological parameters on plant and ratoon sugarcane under irrigation depths for ethanol production. Treatments were irrigation of 30, 60, 90, and 120% of ET_c and a control treatment (no irrigation). The experimental design was a randomized block with six repetitions. We used a drip irrigation system with management based on crop evapotranspiration, according to the methodology proposed by FAO. In rainfed and under irrigation plant cane, the variable cost represented 54.40 and 66.81% and the fixed cost represented 45.60 and 33.19%, respectively. The difference in the cost of production in rainfed and irrigated was 27.23 and 57.20%, for the plant cane and ratoon, respectively. Moreover, we presented the economic viability, which for sugarcane grown in rainfed is 60% of ET_c, with differences in the cost of production and net profit of 53.94 and 52.20%, and financial return in the year of implementation and 4 years and 4 months, respectively. The irrigation increased technological parameters for ethanol production. For plant cane, the only variable that showed no statistically significant difference was the fiber, and for ratoon cane the technological parameters did not have statistically significant difference.

Key words: *Saccharum*, drip irrigation, financial indicators, ratoon cane, plant cane, dryland.

INTRODUCTION

In Brazil, sugarcane has played an important role in the formation of economic, political, and social bases since its introduction on 22 January, 1532 (Miranda, 2008), and as a defining agent of production factors, especially in the use of agricultural areas (Castilho, 2000).

In addition to the importance of Brazil in the sugar

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processing, after the decade of 1970, sugarcane gained importance as a source of energy due to an increase in oil prices (1973 to 1979), and for offering a product able to generate clean energy. In this period, the ethanol production triggered relevant socioeconomic impacts such as increasing rural income, employment generation, reducing dependence on foreign oil, and the increase of Brazilian balance of trade (Negrão and Urban, 2005).

After the decade of 1990, with the opening of the Brazilian economy, the sugarcane sector faced important changes, passing to act in a free market environment that required greater competitiveness and effectiveness of all involved agents in order to remain in the activity (Melo and Esperancini, 2012).

In 2013, the Brazilian state of Rio Grande do Sul used one billion liters of ethanol and its production (six to eight million liters per year) is only 2% of the ethanol used, being produced in the main ethanol plant, the Cooperative of Sugarcane Growers Porto Xavier Ltda (COOPERCANA), in Porto Xavier (Prestes, 2013). The ethanol prices have never been so high, even equal or higher than gasoline because of transportation costs (away from ethanol plants located in São Paulo), where 70% of Brazilian ethanol is produced (Colussi, 2011).

Currently, Brazil is the greatest worldwide sugarcane producer, with 9,004.50 thousand hectares of area and production of 642.10 million tons of stalk (average yield of 71.31 t ha^{-1}) (CONAB, 2014). Over 56% of production was used to produce ethanol (28.66 billion liters) and 47.72% for sugar (36.36 million tons). Furthermore, sugarcane production has been increasing annually due to the construction of new ethanol plants and selection of more productive varieties. Thereby, the commercialization of sugar and ethanol has represented an important part of the Gross Domestic Product (GDP) of the national agribusiness (Silva et al., 2012).

Despite the great expansion of sugarcane fields, environmental problems such as water deficit due to irregular rainfall and an increase of below-normal rainfall in the months where it is more required, causing more damage when occurring during vegetative stages have been observed (Dias, 1999; Rolim et al., 2007).

The soil and climate conditions in the new sugarcane fields require the use of irrigation. Abreu et al. (2013) and Teodoro et al. (2009, 2015) found that in the cycle where occurred greater water deficit, the agricultural and agro-industrial production were significantly affected. Sugarcane responds positively to irrigation and it may be used as a key factor for implementing irrigation systems in sugarcane fields. Moreover, it increases yield and lifetime of sugarcane fields (Demétrio, 1978; Matioli, 1998; Neto et al., 2006; Dalri and Cruz, 2008; Farias et al., 2008a; Farias et al., 2008b; Oliveira et al., 2009; Silva et al., 2011; Silva et al., 2014).

However, in view of the great need of water during the production cycle and the lack of water resources, proper irrigation water management has fundamental importance for achieving greater yield, quality, cost reduction, and rational water use (Padrón et al., 2015a), such as drip irrigation system (Parkes et al., 2010; Boas et al., 2011; Martins et al., 2011). Moreover, Gava et al. (2011) investigating drip irrigation system in three sugarcane varieties obtained, on average, 20% increase in plant cane and 28% in ratoon cane.

Irrigation is one of the most influential factors in yield and production cost of sugarcane (Teodoro et al., 2013). Thus, the management of this agricultural technique requires special attention, since the farmer must use the amount of water that provides a maximum economic return (Fernandes, 2003). Thereby, the localized irrigation arises as a path of linking irrigation productivity gains with higher savings of water and electricity, becoming a technique with increasing use in Brazil and worldwide.

Analyzing the economic feasibility of the implementation of this specific method of irrigation on the current Brazilian agricultural and economic situation becomes increasingly important. The crop yield response regarding different irrigation depths is essential to enable and disseminate the exploitation of irrigated crop in a given region (Frizzone, 1993).

Assessing technological quality of sugarcane has fundamental importance. It will define sugarcane potential as a feedstock for the production of sugar and ethanol in the various stages of industrialization (Stupiello and Fernandes, 1984). The production of sugar and ethanol from irrigated sugarcane depends on several factors, such as the amount of water applied by irrigation, variety, soil type, and the climate of the region (Neto et al., 2006). Therefore, this study aimed to perform the economic analysis and evaluate the effect of technological parameters of sugarcane cultivated for ethanol production under different irrigation depths, using a drip irrigation system.

MATERIALS AND METHODS

This experiment was carried out at the experimental area of the Polytechnic School of the Federal University of Santa Maria located at 29°41’25”S, 53º48’42"W, and altitude of 110 m, during the growing seasons of 2013-2014 and 2014-2015. The predominant soil in the region is Paleudalf, frank texture, according to Soil Taxonomy (USDA, 1999). According to the Köppen-Geiger climate classification, the climate of the region is humid subtropical (Cfa). During both growing seasons, relative air humidity (ranged from 69.50 to 86.80%), insolation (ranged from 134 to 286.20 h), and evapotranspiration (ranged from 41.50 to 175.20 mm; Table 1) were greater in the first growing season. The rainfall, maximum, average, and minimum temperatures are presented in Figure 1. In the 2013-2014 and 2014-2015 growing seasons, minimum, average, and maximum temperatures were -0.6; 21.20; 40°C and 0.1; 20.50; 37.20°C, respectively, showing greater variation in the first growing season. In the 2013-2014 growing season, maximum rainfall occurred in November and June, and the minimum rainfall in December. In the second growing season, maximum and minimum rainfall occurred in December and November, respectively.

Treatments (30, 60, 90 and 120% of crop evapotranspiration)

Table 1. Monthly climatic data of the experimental area with relative air humidity, insolation, and evaporation cumulative during the 2013-2014 and 2014-2015 growing seasons.

Months	Relative humidity mean (%)			Insolation (hour)			Evaporation (mm)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
Jan.		73.10	78.30		219.20	235.80		158.50	148.70
Feb.		73.80	79.70		211.20	207.20		138.20	122.10
March		76.80	77.60		212.60	229.40		113.70	118.60
April		78.20	77.00		219.80	207.20		86.50	81.90
May		83.40	82.50		142.80	146.90		49.10	52.50
June		86.80	80.90		199.80	145.80		41.50	34.80
July		80.60	86.20		176.40	89.60		53.20	41.70
Aug.		75.80			188.50			76.50	
Sept.		76.40			134.00			101.20	
Oct.		73.40			161.00			146.80	
Nov.	71.60	71.00		229.20	173.10		144.30	131.60	
Dec.	69.50	76.10		286.20	211.00		175.20	142.10	

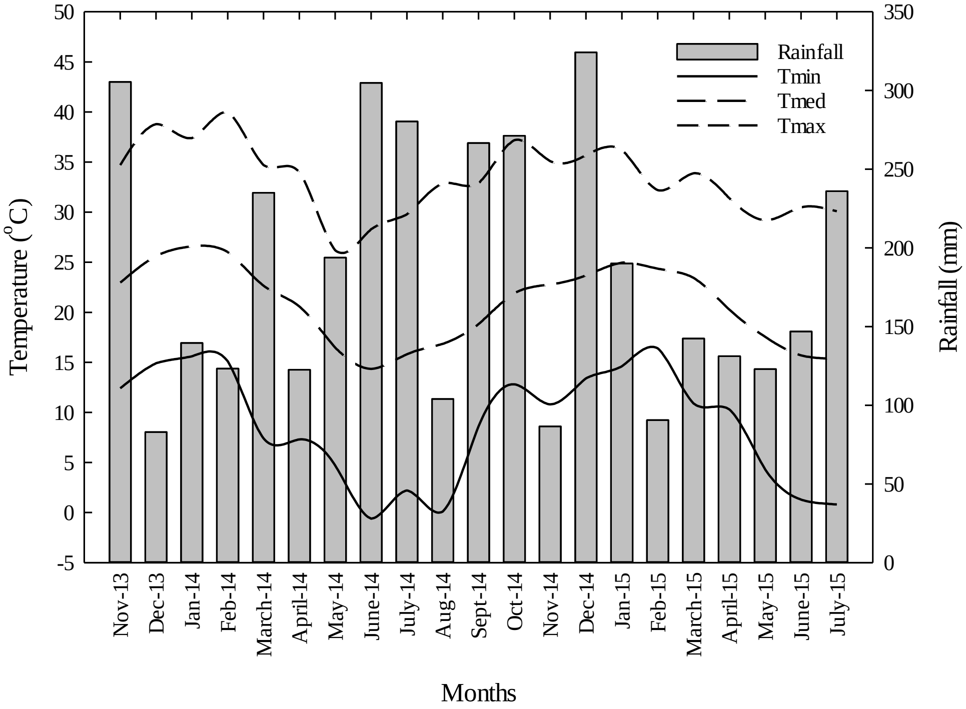

Figure 1. Climograph of the experimental area, during the 2013-2014 and 2014-2015 growing seasons.

and a control treatment (rainfed) were arranged in a randomized block design with six repetitions. Each experimental unit was formed by 20 m^2 (4x5 m), and 600 m^2 of total experimental area, without plants on the border. The sugarcane (RB93-5581 variety) was planted on 14 November 2015, with a spacing of 1 m between rows, and continuous distribution of stalks (3-4 buds per stalk, and 18 buds per meter) into the furrow. The harvest occurred on 20 July 2014 (first growing season) and 8 June 2015 (second growing season). In order to reduce experimental errors and maintain homogeneity, sugarcane stalks were divided into the top, middle, and bottom parts, and each part was planted in two blocks. A drip irrigation system, with drippers spaced 0.2 m and a flow rate of 0.8 L h^{-1} was used. One spherical gate and one pressure control valve were installed in each experimental unit in order to control irrigation time and obtain regular pressure, respectively. Moreover, the uniformity distribution of the irrigation system was assessed and wetted soil volume tests were performed following the results reported by Padrón et al. (2015b). From day one up to 29 days after

Table 2. Average soil attributes of the experimental area.

Soil layers (m)	Bulk density (g cm^{-3})	Field capacity (m^3 m^{-3})	Wilting point (m^3 m^{-3})	Water content (m^3 m^{-3})	Infiltration (mm h^{-1})	Texture
0-0.2	1.42	0.31	0.14	0.18	15	Loam
0.2-0.4	1.38	0.34	0.17	0.17		Clay-loam
0.4-0.6	1.36	0.37	0.23	0.13		Clay

Source: Pádron et al. (2015b).

planting, water management was performed based on 100% of evapotranspiration for all treatments to ensure sprouting and planting uniformity. Afterwards, the irrigation treatments were started and performed every seven days up to one month before each harvest.

The reference evapotranspiration was based on the methodology of Penman-Monteith/FAO (Equation 1), and the crop evapotranspiration at a standard condition was based on Equation 2 (Allen et al., 1998). Climate data were obtained from the weather station of the Federal University of Santa Maria, linked to the National Institute of Meteorology, localized approximately 2000 m from the experimental area. Rainfall (mm), maximum and minimum temperature (°C), maximum and minimum relative air humidity (%), insolation (hours), and wind speed (m s^{-1}) were collected daily.

$$\mathrm{ET_o} = \frac{0.408\ \Delta \times (Rn - G) + \gamma \times \left(\frac{900}{\mathrm{T} + 273}\right) \times U_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 \times U_2)} \quad (1)$$

Where ETo is the reference evapotranspiration (mm day^{-1}), Rn, G, and T are net radiation value at crop surface (MJ m^{-2} day^{-1}), soil heat flux density (MJ m^{-2} day^{-1}), and daily mean air temperature at 2 m height (°C), respectively. Also, U_2 ,es, ea, (es - ea), Δ, and γ represent wind speed at 2 m height (m s^{-1}), saturation vapor pressure (kPa), actual vapor pressure (kPa), saturation vapor pressure deficit (kPa), slope of the saturation vapor pressure curve (kPa°C^{-1}), and psychrometric constant (kPa°C^{-1}), respectively.

$$ET_c = k_c \times ET_o \quad (2)$$

Where ET_c stands for crop evapotranspiration (mm), ET_o is the reference crop evapotranspiration (mm), and kc is the single crop coefficient. The following single crop coefficient values were used:

K_{cini}=0.40; K_{cmed}=1.25 andK_{cfin}=0.75 (Allen et al., 1998).

The soil texture, apparent density, field capacity, infiltration test, and chemical analysis were performed according to Padrón et al. (2015b) (Table 2). Furthermore, fertilizers were applied according to the soil chemical analysis and crop requirements (expected yield of 80 to 100 t ha^{-1}). In order to correct soil pH, 3.5 t ha^{-1} of lime was broadcasted on the soil surface and incorporated with a disk harrow.

The economic analysis was carried out for each study period (plant cane and ratoon cane). The value of sugarcane commercial production in each period was calculated based on the average value of the study locality and from the Cooperative of Sugarcane Growers Porto Xavier Ltda (COOPERCANA) (the main sugarcane processing cooperative of Rio Grande do Sul), establishing R$ 55,00 for each t ha^{-1} for the five years of analysis. The production system cost (fixed and variable costs) for each period of upland sugarcane (including all operations involved and the necessary inputs for the production: number of machine hours, tractor daily rate, number of men day^{-1}, soil preparation, seedlings, planting, herbicides, insecticides, cutting, loading, transport, and manual harvesting) were also calculated by the average value of the study locality and with the average value of COOPERCANA. For irrigated sugarcane the costs are from the drip irrigation system. Considering an initial investment of R$ 10,000.00 and without including land and water value for irrigation, but adding labor and electricity costs, we estimated the unit cost of water depth (R$ 1.56 mm^{-1} ha^{-1}). It should be noted that the average values of the expenditure were determined for the first two years. In the subsequent periods, the values were calculated from a forecasted value of the services plus a cumulative adjustment of the second year, considering a rate of 7.2% per year according to (Vieira et al., 2014). Likewise, the yield was determined for the first two years, being the coming years estimated from the second year. There is a tendency in reducing yield after a time, ranging from 12 to 15% per year (Pereira et al., 2015). However, the price per ton also presents annual increments, which can be equivalent to productivity losses. Thereby, both were considered constant after the third year. The net profit of the production system was determined by Equation 3.

$$L_{(x)} = P_y\ y - P_x\ x - c \quad (3)$$

Where: onde: $L_{(x)}$ = net profit (R$ ha^{-1}); P_y = production value (R$ t^{-1}); Y = yield (t ha^{-1}); P_x = irrigation water price (R$ mm^{-1}); x = irrigation depth (mm); c = production system costs (R$ ha^{-1}).

A second order polynomial regression analysis between the dependent variable (net profit) and the independent variable (irrigation depth) was used to obtain the net income function (Equation 4). In addition, the point of maximum technical efficiency was determined, where the irrigation depth maximized net profit (Equation 5).

$$y = a + bx + cx^2 \quad (4)$$

Where: y= net profit (R$); x= applied irrigation depth (mm); a, b, c= equation parameters.

$$Xmax = -b/2c \quad (5)$$

From the projection of cash flows associated with each studied production systems, we carried out economic analysis using the following criteria: net present value (NPV), internal rate of return (IRR), relative benefit cost (B/C), equilibrium point (EP), *payback* (PB), and discounted *payback* (PBD). It is important to highlight a peculiar feature of rainfed treatment compared to the others, which there was no need for initial investment in irrigation equipments. This fact directly affected the determination of the IRR, which presupposes a relationship between the investment value (cash outflow) and the value resulting from the cash flows. Thereby, it was not possible to determine IRR because all flows over the five years of analysis were positive. Moreover, to establish a comparative basis in relation to other treatments, we calculated the rate of return

Table 3. Production costs of plant and ratoon cane under irrigation and rainfed.

Variable	Plant cane				Ratoon cane			
	Rainfed		Under irrigation		Rainfed		Under irrigation	
	(R\$ ha^{-1})	(US\$ ha^{-1})	(R\$ ha^{-1})	(US\$ ha^{-1})	(R\$ ha^{-1})	(US\$ ha^{-1})	(R\$ ha^{-1})	(US\$ ha^{-1})
Soil preparation	504.00	144.00	504.00	144.00	-	-	-	-
Plantation	2,030.00	580.00	2,030.00	580.00	-	-	-	-
Cultural tract	820.00	234.30	820.00	234.30	638.00	182.30	638.00	182.30
Supplies	927.00	264.90	927.00	3,122.00	927.00	264.90	1,927.00	550.60
Harvest	350.00	100.00	350.00	100.00	350.00	100.00	350.00	100.00
Services	180.00	51.40	1,980.00	565.70	180.00	51.40	1,980.00	565.70
Cost total	4,811.00	1,374.60	6,611.00	1,888.90	2,095.00	598.60	4,895.00	1,398.60
Fixed costs	2,194.00	626.90	2,194.00	626.90	150.00	42.90	1,200.00	342.90
Variable costs	2,617.00	747.70	4,417.00	1262.00	1,945.00	555.70	3,695.00	1,055.70

in each year (comparing the net result with the expenses). Then, the cumulative rate of the analyzed period (five years) and its annual equivalent were determined. The analysis considered a minimum rate of attractiveness (14.25%) based on Brazil interest rate.

Samples of technological parameters evaluated in this study were obtained from the central rows by collecting six industrial stalks per plot at the end of the growing cycle. The total soluble solids (°Brix), the sugarcane fiber (Fiber = 0.08×WBM+0.876; where WBM = wet bagasse mass), the apparent sucrose of the sugarcane juice (Pol%$_{\text{sugarcane juice}}$ = (1.0078×Sacch.reading+ 0.0444)×(0.2607–0.009882×°Brix; where Sacch.reading = reading of the saccharimeter), the apparent sucrose of the sugarcane (Pol%$_{\text{sugarcane}}$ = Pol%$_{\text{sugarcane juice}}$×(1–0.01×fiber)×C) and (C = 1.0313–0.00575×Fiber; where C is the sugarcane juice transformation coefficient), the purity of sugarcane (Purity = Pol%$_{\text{sugarcane}}$÷Brix%$_{\text{sugarcane}}$×100) and (Brix$_{\text{sugarcane}}$ = Brix%×(1–0.01)×C), the sugarcane total reducing sugars (TRS%$_{\text{sugarcane}}$ = TRS%$_{\text{sugarcane juice}}$×(1–0.01×fiber)×C), (TRS%$_{\text{sugarcane juice}}$ = (Pol%$_{\text{sugarcane juice}}$/0.95)+RS%$_{\text{sugarcane juice}}$), and (RS%$_{\text{sugarcane juice}}$ = 3.641–0.0343×Purity; TRS%$_{\text{sugarcane juice}}$ = the total reducing sugars in the juice; (RS%$_{\text{sugarcane juice}}$) = the reducing sugars of the sugarcane juice, the recoverable total sugar (RTS = 10×IC×1.0526×0.905+10×RSS×0.905) and (10×IC = inches per ton of sugarcane; 1.05263 = stoichiometric coefficient for the conversion of sucrose into reducing sugars; 0.905 = recovery coefficient for an industrial loss of 9.5%; 10×RSS = reducing sugar per ton of sugarcane), and the estimation of ethanol production (Ethanol = TRS%$_{\text{sugarcane juice}}$×10×0.6475) were calculated. The value of 100% ethanol was later transformed to 85% ethanol, considering the efficiency of the fermentation process. The determination of the parameters evaluated followed the methodology of the Instruction Manual provided by the Council of Sugarcane, Sugar, and Alcohol Producers of São Paulo State (CONSECANA, 2006). Statistical analysis was performed using the SPSS software package (SPSS V17.0).

RESULTS AND DISCUSSION

The crop cycles during the growing seasons of 2013-2014 and 2014-2015 were 237 days and 323 days, respectively, with a difference of 86 days. Evapotranspiration, rainfall, and irrigation days were greater in the 2014-2015 growing season, with a difference of 312 and 147 mm, and 7 days, respectively. These differences were possibly influenced by the period of the crop cycle and climatic conditions of the region, but the irrigation depths applied were similar in both growing seasons.

The production cost for plant and ratoon cane under irrigation and rainfed are shown in Table 3. In plant cane (rainfed condition), planting was the variable that had the highest cost, with 42.19% of the total cost, followed by supplies with 19.27%. Moreover, in plant cane under irrigation, input planting for 30.71%, followed by services (29.95%). For rainfed ratoon cane, input was the variable that had the supplies cost (44.24%), followed by cultural practices (30.45%). In ratoon cane under irrigation, service and supplies costs were those with the highest cost (40.45 and 39.37%, respectively). For plant cane, in rainfed and under irrigation, the variable cost (54.40 and 66.81%, respectively) and the fixed cost represented 45.60 and 33.19%, respectively. For rainfed ratoon cane, the variables cost and fixed cost accounted for 92.84 and 7.16%, and under irrigation, 75.49 and 24.51%, respectively. The difference in production cost for plant cane in rainfed and under irrigation was 27.23%, and for ratoon cane was 57.20%.

Irrigation depth, yield, the gross profit and the total cost are shown in Table 4. There was no significant difference between yield and treatments in both growing seasons. The 60% ET$_c$ treatment had the best yield in plant and ratoon cane, differing from rainfed with an increase of 10.73 and 7.11%, respectively. The largest gross profit occurred in treatments under irrigation, being 60% ET$_c$ the greatest, with an increase of 7.79%, compared to rainfed. In addition, the higher total cost was in the irrigated treatment (120% of ET$_{c)}$, with a difference (56.46%) compared to rainfed. The net profit in terms of irrigation rate five-year analysis is shown in Figure 2. The rainfed treatments had the greatest net profit and the treatments under irrigation presented a decreased net profit. In relation to rainfed, the lower net profit occurred

Table 4. Treatments, irrigation depths (ID), yield, gross proft and the total cost in the cultivation of sugarcane for five years of study.

Treatment (% ET_c)	Plant cane		Ratoon cane		Gross proft		Total cost	
	ID (mm)	Yield (t ha^{-1})	ID (mm)	Yield (t ha^{-1})	(R$ ha^{-1})	(US$ ha^{-1})	(R$ ha^{-1})	(US$ ha^{-1})
0	-	158.80	-	176.50	47,564.00	13,589.71	17,039.33	4,868.38
30	126.60	168.60	125.70	183.60	49,665.00	14,190.00	35,922.05	10,263.44
60	253.20	177.90	251.50	190.00	51,584.50	14,738.43	36,993.46	10,569.56
90	379.80	176.30	377.20	187.90	51,034.50	14,581.29	38,064.18	10,875.48
120	506.40	171.60	503.00	185.90	50,336.00	14,381.71	39,135.59	11,181.60

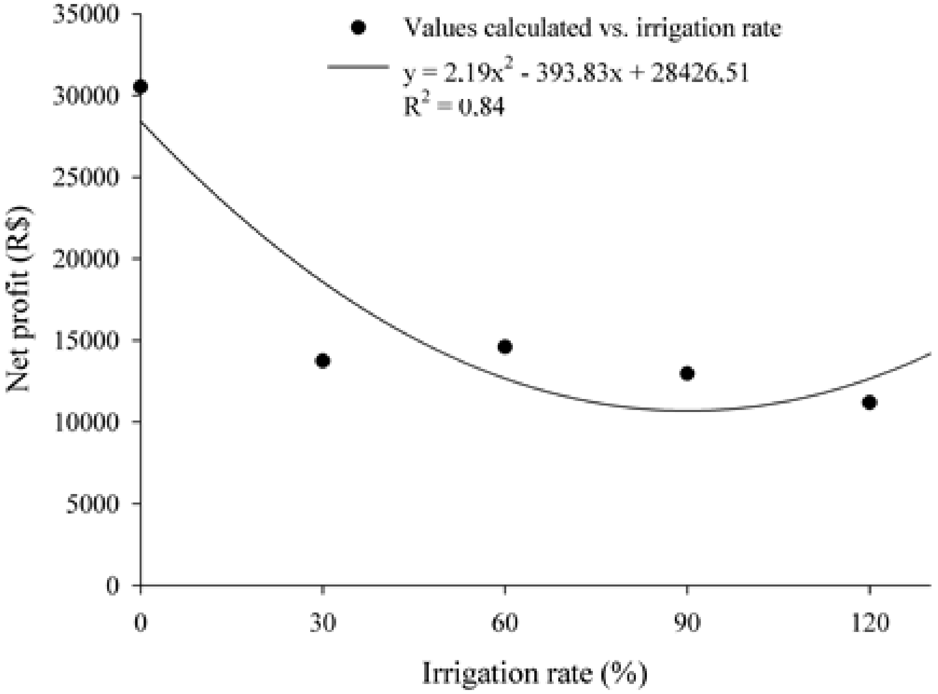

Figure 2. Net proft in terms of irrigation for sugarcane crop for five years of analysis.

with 120% da ET_c, with decrease of 63.30%, the lowest decrease was in 60% da ET_c, with 52.20%, and the minimum technical efficiency was in 90.04% da ET_c.

The financial indicators are shown in (Table 5). In rainfed condition, because no there was a need for initial investment it was not possible to determine the IRR. The all flows over the five years of analysis were positive, being possible to calculate the rate of return within each year through the determination of the cumulative rate for the period of five years and their annual equivalent (288.73%). In the treatments under irrigation, the only treatment that presented favorable financial indicators was 60% ET_c, with *paybacks* giving a financial return before the end of the reported period, without covering initial investment of R$ 10,000.00. However, further studies with greater amount of planted land, more production cycles, different genotypes, and irrigation systems are necessary.

The results showed financial viability in rainfed treatments. The only irrigated treatment that showed viability was 60% ET_c. In the first year of cultivation, the balance of rainfed treatment matched with the average state productivity, which is approximately 55 t ha^{-1} (CONAB, 2014). Similarly, Pereira et al. (2015) studied the production cost of sugarcane in the state of Mato Grosso do Sul and found that the sugarcane industry demands high initial investment and farmer's decision making is linked to the collection of real information about profitability. Moreover, the authors concluded that the economic viability of implementation of a sugarcane field is not feasible when the area is smaller than 1,700 hectares and the maximum value for implementation and

Table 5. Treatments, the net present value (NPV), internal rate of return (IRR), the equilibrium point (EP), benefit cost (B/C), p*ayback* (PB), and discounted *payback* (PBD) for sugarcane crop for five years of study.

Treatment	VPL	TIR	(B/C)	EP 1º year	EP 2º year	EP 3º year	EP 4º year	EP 5º year	*Payback*	*PayBack* discounted
(% ET_c)	NPV R$	IRR (%)	(B/C)	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	PB year	PBD year
0	20,513.64	-	-	56.96	3.41	4.22	4.68	5.20	-	-
30	-217.23	13.23	0.98	76.18	34.41	57.09	68.29	83.57	2.96	4.81
60	402.76	16.12	1.04	73.72	33.75	54.45	64.54	78.03	2.74	4.34
90	-687.73	10.93	0.93	73.26	33.96	55.27	65.69	79.72	3.08	5.21
120	-1,913.92	4.63	0.81	74.98	34.16	56.09	66.86	81.45	3.60	6.62

maintenance of ratoon cane is of R$ 5,500 ha^{-1} and R$ 900 ha^{-1}, respectively. Costa (2012) studied growth, yield, and economic viability of sugarcane under different irrigation levels in the region of Penápolis-SP, using RB855453 and RB965902 varieties. The author concluded that the unique situation that presented positive result of R$ 210.23 ha^{-1}, with an increase of 24.45 t ha^{-1} (RB85545 variety), with a maximum economic efficiency irrigation depth of 1,024.53 mm (75% ET_c) and generated a yield of 182.15 t ha^{-1}. Farias (2006), in the study on optimizing the water and zinc use in sugarcane in Paraiba coastal board, stated that the application of 25% ET_c results in a negative gross profit (loss) of R$ 9.64 t^{-1}. Yet, with 50 and 75% ET_c generated an average gross profit of R$ 4.92 t^{-1}, and with 100% ET_c, combined with the application of 2.39 kg ha^{-1} of zinc had a gross profit of R$ 19.60 t^{-1}. Furthermore, Cintra et al. (2008) claimed from several authors' conclusions that a supplementary irrigation in the initial stages of development of sugarcane is crucial for increasing yield, especially in ratoon cane. Furthermore, the importance of further research on the responsiveness and production function of sugarcane varieties to irrigation in several production locations was emphasized. Amorim et al. (2007) investigated irrigation costs in sugarcane, carrying out a study with several irrigation systems in Juazeiro-BA, demonstrated that the best irrigation system evaluated by the variables yield per hectare and cost per hectare is dripping irrigation. It is the most viable system, besides its high efficiency in water application by crop utilization, being around 90 to 95%. However, it requires a high initial investment, yet the authors asserted that the expansion of agribusiness depends on the favorable evolution of the Brazilian and world scenario and in particular of macroeconomic and trade policies. The reform of public policy presupposes the provision of equal opportunities for Brazilian producers in relation to their competitors in developed countries, in isonomic conditions of competition.

The technological parameters of plant and ratoon cane under different irrigation management levels are shown in Table 6. In plant cane, irrigation had significant effect on all parameters (ºbrix, Pol%$_{\text{sugarcane juice}}$, Pol%$_{\text{sugarcane}}$, Purity, TRS%$_{\text{sugarcane}}$, RTS, and Ethanol), except fiber. In ratoon cane, parameters did not have significant statistical difference, demonstrating different behavior regarding to plant cane, and fiber had the same behavior in both growing seasons. Irrigation influenced on the parameters evaluated in plant cane, agreeing to Silva et al. (2014), who also found differences in performance among the parameters evaluated only in plant cane. Regarding the treatments applied in both seasons, the variables had showed the highest values in the treatments under irrigation.

Moreover, as Assis et al. (2004) studied the response of technological parameters of sugarcane under different irrigation depths and fertilization. They found significant effect (°Brix, fiber, Pol%$_{\text{sugarcane juice,}}$ and TRS%$_{\text{sugarcane}}$) in plant cane and for ratoon cane, and irrigation had no significant effect on all traits, which agrees with the results of this study. Dalri and Cruz (2008) investigated subsurface drip irrigation on sugarcane yield and quality, demonstrating that irrigation did not affect the technological traits in plant cane, disagreeing with the results obtained in this work. Simões et al. (2015) evaluated different irrigation systems and reported that there was no influence on the technological quality of sugarcane. Neto et al. (2006) studied the response of first ratoon sugarcane to irrigation levels and topdressing. They affirmed that only the variable Pol%$_{\text{sugarcane juice}}$ responded significantly to the irrigation system. Conversely, Simões et al. (2015) and Neto et al. (2006) found different results.

Fibers in the plant cane cycle were lower (10%) and for ratoon cane they were within recommended. Fernandes (2003) and Oliveira et al. (2009) reported mean values among 10.5 and 12.5%, which are recommended for energetic maintenance of sugarcane processing industries. In addition, Barbosa et al. (2007), regarding the ideal amount of fiber, asserted that it has to be between 12 and 13%. For ethanol production, the lower fiber content benefits the process of sugarcane juice extraction and the increase in fiber content hinders the extraction process. Moreover, greater fiber content can

Table 6. Treatments, ˚brix, fiber, Pol%$_{\text{sugarcane juice}}$, Pol%$_{\text{sugarcane}}$, Purity, TRS%$_{\text{sugarcane}}$, RTS and Ethanol for plant and ratoon sugarcane subjected to different levels of irrigation management.

Treatment (% ET$_c$)	Plant cane							
	˚Brix	Fiber	Pol$_{\text{\%sugarcane juice}}$	Pol$_{\text{\%sugarcane}}$	Purity	TRS$_{\text{\%sugarcane}}$	RTS (kg t^{-1})	Ethanol (L t^{-1})
0	17.20^{b}	10.00	14.60^{b}	12.80^{b}	77.00^{b}	14.30^{b}	130.80^{b}	89.90^{b}
30	17.20^{b}	9.90	14.60^{b}	12.80^{b}	77.30^{a}	14.30^{b}	131.00^{b}	89.90^{b}
60	17.80^{a}	10.00	15.10^{a}	13.30^{a}	77.40^{a}	14.80^{a}	135.20^{a}	92.90^{a}
90	18.00^{a}	10.00	15.30^{a}	13.40^{a}	77.00^{b}	15.00^{a}	136.60^{a}	93.80^{a}
120	17.20^{b}	10.00	14.60^{b}	12.80^{b}	77.30^{a}	14.30^{b}	130.90^{b}	89.90^{b}
CV%	2.09	1.37	2.03	2.15	4.17	1.37	1.38	1.25
Sig	P<1%	P>5%	P<1%	P<1%	P<1%	P<1%	P<1%	P<1%
				Ratoon cane				
0	17.20	10.60	15.50	12.70	81.60	14.90	135.70	94.40
30	17.30	10.80	15.50	12.70	80.60	14.90	135.90	94.60
60	17.50	11.00	15.60	12.80	80.20	15.00	136.20	95.20
90	17.50	10.90	15.80	12.80	81.30	15.10	137.80	96.10
120	17.20	10.80	15.80	12.70	82.90	15.10	137.50	95.80
CV%	2.49	2.50	2.380	2.45	4.79	1.57	1.58	1.50

assist sugarcane lodging resistance.

Apparent sucrose (Pol$_{\text{\%sugarcane juice}}$ and Pol$_{\text{\%sugarcane}}$) had the same ˚brix behavior, which are correlated. Under irrigated condition, Pol$_{\text{\%sugarcane juice}}$ and Pol$_{\text{\%sugarcane}}$ had the greatest values compared to rainfed condition and probably irrigation contributed increasing these parameters. According to CONSECANA (1998), the sucrose content values above 12.26% correspond to a sugarcane-standard. In terms of quality, Ripoli and Ripoli (2004) found that sugarcane with values greater than 14% would be able to be industrialized. Moreover, sugarcane will be considered mature when presenting Pol$_{\text{\%sugarcane}}$ ranging from 14.4 to 15.3% (Fernandes 2000).

Treatments under irrigation demonstrated the highest purity values. The raw materials quality standards designed by CONSECANA (2006) establish that the industrial plants could only refuse shipments with purity below 75%. Franco (2003) and Fernandes (2003) reported that the state of São Paulo has a minimum purity reference of 80% at the beginning and 85% in the course of the harvest season in order to recommend sugarcane industrialization.

The study of sugar contents in sugarcane is important because lower values of total reducing sugars (TRS$_{\text{\%sugarcane}}$) indicate lower industrial yield in production of sugar or alcohol. Moreover, recoverable total sugar (RTS) is the most important variable for both industry and producers, as industrial units determine the price to be paid to the producers based on RTS, following a methodology described by CONSECANA (2006). Thus, the results of larger RTS values imply in greater crop economic profitability.

The ethanol amounts found in this study were similar to those reported by Oliveira et al. (2012), with values of 90.2 and 115.09 l (maximum and minimum). Neto et al. (2006), studying different irrigation depths and fertilizer levels, had gross yield of alcohol with an average of 6.25 m^{3} ha^{-1} at the minimum fertilization of 86 kg ha^{-1} of N, and 8.91 m^{3} ha^{-1} at maximum N fertilization of 305 kg ha^{-1}. Increasing alcohol productivity due to nitrogen application was also observed by Carvalho et al. (2009), who found that the application of 112 kg ha^{-1} of nitrogen provided the greatest yield (9.8 m^{3} ha^{-1} of alcohol).

Results found in this research, regarding irrigated and rainfed sugarcane, are similar to those reported by Moura et al. (2005), Farias et al. (2009), Deon et al. (2010), Oliveira et al. (2012), Oliveira et al. (2014a, 2014b), Silva et al. (2014), and Simões et al. (2015), observing significant positive correlation among irrigation depth and the variables that define the quality of the sugarcane raw material. Dalri et al. (2008) reported that the irrigation factor did not presented significant effect for all traits studied in plant cane. Dalri and Cruz (2008) researched ratoon cane and second ratoon cane and they found that there were no statistical differences between the irrigated treatment and the control treatment. In fact, these authors observed that there were no treatment effects on the sugarcane technological quality in both cycles. Farias et al. (2009) found that only the fiber was negative. Deon et al. (2010) investigated the second ratoon cane and observed that technological variables were not altered by irrigation. According to Oliveira et al. (2011a, b), there was difference only for °Brix, Pol%$_{\text{sugarcane juice}}$, and fiber, with reduction only in the fiber content among the hydric regimes. Correia et al. (2014) observed that for the irrigation factor, there was significant difference in Pol%$_{\text{sugarcane juice}}$ and purity.

Conclusion

The sugarcane grown in rainfed and irrigated with 60% ET_c had economic viability with financial return in the year of implementation and 4 years and 4 months, respectively. The difference in the cost of production and the net profit of sugarcane grown in rainfed and 60% ET_c, was 53.94 and 52.20%, respectively.

In the crop cycles, the irrigation promoted an increase in technological parameters for the production of ethanol compared to rainfed sugarcane. RTS received the largest increase in treatment 90% of ET_c with a difference of 4.25 and 1.52% for the plant and ratoon cane, respectively. The smallest increases were observed for purity and Pol$_{\%\text{sugarcane}}$, in treatment 60% of ET_c, with 0.52 and 0.78% in the plant and ratoon sugarcane, respectively.

Regarding irrigation, in plant cane, the only variable that showed no statistically significant difference was the fiber and, in ratoon cane, the technological parameters showed no statistically significant difference.

Conflict of Interests

The authors have not declared any conflict of interests.

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The effects of sewage sludge, mineral and organic fertilizers on initial growth of *Urochloa brizantha* cv Marandu (Hochst. ex A. Rich.) R.D Webster

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The application of biosolids on agricultural soils is a procedure used by municipalities and private companies to dispose, purposefully or inadvertently, of residue. This study evaluated the effects of limed sewage sludge and inorganic or organomineral fertilizers on the chemical properties of red latosol and the contents of chlorophyll A and B in the fresh and dry matter of *Urochloa brizantha* cv Marandu. The experimental design was composed of randomized blocks due to a lighting gradient in the greenhouse, with 10 treatments and four replications. Treatments included: mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5); limed sludge (60 kg ha^{-1} N); limed sludge (48 kg ha^{-1} N) + mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5); limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S); limed sludge (60 kg ha^{-1} N) + magnesite (30 kg ha^{-1} Mg); limed sludge (60 kg ha^{-1} N) + single superphosphate (120 kg ha^{-1} P_2O_5); limed sludge (60 kg ha^{-1} N) + verdete (60 kg ha^{-1} K_2O); limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S) + magnesite (30 kg ha^{-1} Mg) + single superphosphate (120 kg ha^{-1} P_2O_5) + verdete (60 kg ha^{-1} K_2O); organomineral fertilizer 05-24-08 (120 kg ha^{-1} P_2O_5) and control with no addition of nutrient sources. Soil properties, pH, V (base saturation), m (aluminum saturation), OM (Organic Matter), P (Phosphorus), K (Potassium), S (Sulfur), Ca (Calcium), Mg (Magnesium), B (Boron), Cu (Copper), Fe (Iron), Mn (Manganese) and Zn (Zinc), as well as the chlorophyll A and B of fresh and dry matter of *U. brizantha* cv. Marandu were evaluated 30 days after germination. Limed sludge combined, or not, with mineral fertilizers, behaved as a soil corrective, increased the Ca and Mg content of the soil and reduced the Fe and Mn content. The fertilizer sources evaluated did not affect the contents of OM, organic carbon, Cu or B. Single superphosphate mixed with limed sludge and the mixture of gypsum, magnesite, single superphosphate or verdete with limed sludge resulted in greater P and S. content in the soil. Verdete mixed with limed sludge did not increase soil K or chlorophyll B contents. However, Zn contents were increased with the Verdete mixture. The highest level of fresh matter production was obtained with mineral fertilizer, organomineral fertilizer and sludge plus mineral fertilizer. Dry matter production, on the other hand, was increased only by the application of mineral fertilizer.

Key words: Biosolid, forage, mineral nutrition, organic fertilizers.

INTRODUCTION

The disposal of sewage sludge in sanitary landfills, presently accepted by environmental agencies of the Sistema Nacional de Meio Ambiente (SISNAMA) in Brazil, does not cause it to dissipate or eliminate its potential to produce pathologies and environment contamination. It simply delays the problem, to be dealt with in the near future.

According to Smith et al. (2015) the term biosolid describes sewage sludge that has been treated to reduce the level of pathogenic agents. Andrade et al. (2006) and Ceolato et al. (2011) believed that the agricultural use of biosolids is an alternative for the ultimate disposal of this residue as well as to prevent possible adverse effects on the environment and conserve natural resources while simultaneously obtaining agricultural benefits.

Ceolato et al. (2011) used liquid sewage sludge sanitized with hydrated lime for the production of *Urochloa decumbens*. They observed that the sludge functioned as a soil corrective, increasing macro and micro nutrient levels. Backes et al. (2009) evaluated the use of sewage sludge on forage grass formation and determined that the sludge presented similar results to mineral fertilizer. Araujo et al. (2009) used sewage sludge in Ultisol for the development of *U. decumbens* and observed increased dry biomass production and leaf nitrogen content. Chueiri et al. (2007) combined doses of sewage sludge with mineral fertilizer for application on wheat and found higher levels of K, N, Mg, Cu and Zn in the leaves.

From an agriculture perspective, sewage sludge could be used as a biosolid for the recuperation of degraded pasture land and to provide adequate disposal of the residue. *Urochloa Brizantha* cv Marandu is the most planted forage grass in Brazil (Gaspar-Oliveira et al., 2008). According to Mtshali et al. (2014) and Tontti et al. (2016), however, sewage sludge may not contain all of the essential nutrients in adequate quantities for plant development. If this is the case, the sewage sludge would require the supplementation of inorganic fertilizers. Berton and Nogueira (2010) reported that the benefits of sludge are disproportionate to crop needs, especially in relation to potassium and boron, thus requiring adjustments according to the crop.

Silva et al. (2010) stated that alkaline sewage sludge could be used with single superphosphate as a source of mineral nutrients when a level of 0.436% P is taken into account. Specific low cost and easily accessible mineral nutrient sources such as verdete, agricultural gypsum, magnesite, formulated fertilizers and single superphosphate can be used for balancing nutrients according to forage demands.

Verdete is a green colored rock, composed of 13% quartz, 29% potassium feldspar, 57% mica and less than 1% of other minerals (Kahn et al., 2011). According to Piza et al. (2009) the concentration of K_2O in verdete varies from 7 to 14%. Single superphosphate supplies three macronutrients (phosphorus, calcium and sulfur), the first two of which come from the mineral apatite, while sulfur in the form of sulfuric acid, is used for dissolving the rock, making it the most common source of phosphorus for forage plants (Monteiro, 2008).

Magnesite is the main source of natural magnesium and can be enriched by calcination. It is used as a source of magnesium for agricultural crops (Correia, 2001). Bernardi et al. (2009) have stated that supplying calcinated magnesite is an effective way to provide magnesium for *Panicum maximum* cv. Tanzânia. Agricultural gypsum is a residue of the production of phosphoric acid and despite not changing soil pH, it acts in the subsurface reducing the toxicity of exchangeable Al in plants. It also reduces the toxicity of Al in soil solutions and supplies Ca and S in the 0 to 20 cm layer of latosol (oxisol) (Kaneko et al., 2015).

U. Brizantha cv. Marandu has good adaptation in medium to high levels of soil fertility. However, in order to reach production potential, fertilization is one of the most important factors since it supplies nutrients for metabolic needs and more adequate development (Costa et al., 2009). Brazilian pasture lands, in general, present low animal support capacity, especially due to the sparse use of fertilizers. This reflects directly on meat and milk production.

This study evaluated the chemical properties and chlorophyll A and B contents of Brazilian red latosol, as well as the fresh and dry matter weights of *U. brizantha* cv Marandu fertilized with limed sewage sludge and organic and inorganic fertilizers.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Instituto de Ciências Agrárias of the Universidade Federal de Uberlândia UFU), in Uberlândia, State of Minas Gerais, Brazil, located at 18° 53' 05" S and 48° 15' 37" W, from March to May, 2014. The soil used in the experiment was classified as red latosol (oxisol) of medium texture, collected from the 0 to 20 cm depth layer, in an area of degraded pasture at the experimental farm (UFU). According to the classification of Köppen (1918), the climate of the region has dry winters and rainy summers. The average rainfall in the driest month is approximately 60 mm compared to 250 mm in the wettest month of the summer. The total average rainfall is between 1,500 and 1,600 mm (Mendes, 2001). Rainfall distribution and maximum and minimum temperatures during the time of the experiment are shown in Table 1.

The soil was air dried and passed through a sieve. A sample taken to determine chemical characterization produced the following results: pH_{H2O}= 4.9, P meh^{-1}= .3 mg dm^{-3}, K^{+} =21 mg dm^{-3}, S-SO_4^{2-}= 3 mg dm^{-3}, Ca^{2+}=0.2 $cmol_c$ dm^{-3}, Mg^{2+}=0.1 $cmol_c$ dm^{-3}, Al^{3+}=0.4 $cmol_c$ dm^{-3}, organic matter (OM)=2.7 dag kg^{-1}, organic carbon (OC)=1.6 dag kg^{-1}, SB = 0.35 $cmol_c$ dm^{-3}, t=0.75 $cmol_c$ dm^{-3}, T=4.15 $cmol_c$ dm^{-3}, V=8 dag kg^{-1}, m=53 dag kg^{-1}, B= 0.04 mg dm^{-3}, Cu=0.7 mg dm^{-3}, Fe= 41 mg dm^{-3}, Mn=1.2 mg dm^{-3}, and Zn=0.4 mg dm-3.

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Table 1. Rainfall and temperature data of the area of the experiment, Uberlândia, Minas Gerais, Brazil, 2014.

Months	Precipitation (mm)	Maximum temperature (°C)	Minimum temperature (°C)
March	149.10	30.58	19.45
April	61.80	30.28	18.31

Source: INMET (2014).

Table 2. Chemical attributes of limed sewage sludge, Uberlândia, Minas Gerais, Brazil, 2014.

Attribute	Unit	Value	Methodology
pH in $CaCl_2$	-	12.65	Embrapa (2009)[1]
Organic Matter – OM	g kg^{-1}	368.60	Embrapa (2009)
Carbon – C	g kg^{-1}	213.80	Embrapa (2009)
Nitrogen – N	g kg^{-1}	20.88	Embrapa (2009)
Sodium – Na	g kg^{-1}	0.61	Embrapa (2009)
Aluminum – Al	g kg^{-1}	20.10	Embrapa (2009)
Calcium – Ca	g kg^{-1}	302.0	Embrapa (2009)
Magnesium – Mg	g kg^{-1}	4.2	Embrapa (2009)
Phosphorus – P	g kg^{-1}	1.6	Embrapa (2009)
Potassium – K	g kg^{-1}	0.6	Embrapa (2009)
Sulfur – S	g kg^{-1}	12.4	Embrapa (2009)
Iron – Fe	mg kg	12,753.25	Embrapa (2009)
Zinc – Zn	mg kg^{-1}	1180.00	Embrapa (2009)
Cooper – Cu	mg kg^{-1}	157.91	Embrapa (2009)
Cadmium – Cd	mg kg^{-1}	0.45	Embrapa (2009)
Chromium – Cr	mg kg^{-1}	85.34	Embrapa (2009)
Nickel – Ni	mg kg^{-1}	19.86	Embrapa (2009)
Lead – Pb	mg kg^{-1}	ND[2]	Embrapa (2009)

[1/]Embrapa (Brazilian Agricultural Research Corporation). [2/]ND: Not detected.

The sewage sludge used in the experiment was obtained by anaerobic process. After a dewatering step obtained by the addition of iron chlorite and centrifugation at the sewage treatment unit in Uberlândia, MG, the sludge was sanitized with hydrated lime in the proportion of 30% of the sludge dry matter. The sludge originated from households. Its chemical properties are shown in Table 2. This material was dried, crushed and subjected to sulfuric digestion for the determination of N. Nitric-perchloric digestion was used for identification of P, K, Ca, Mg, S, Cu, Fe, Mn, Zn, Na, Ni, Cd, Pb, Al, Mg and Fe levels and calcination in a muffle kiln determined organic matter contents. The pH was determined in $CaCl_2$ solution at .010 ml L^{-1}, according to the methodology proposed by EMBRAPA (2009).

The experimental design was composed of randomized blocks due to a lighting gradient in the greenhouse, with 10 treatments and four replications.

Treatments included: mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5), limed sludge (60 kg ha^{-1} N), limed sludge (48 kg ha^{-1} N) + mineral fertilizer 3-30-10 (120 kg ha^{-1} P_2O_5), limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S), limed sludge (60 kg ha^{-1} N) + magnesite (30 kg ha^{-1} Mg), limed sludge (60 kg ha^{-1} N) + single superphosphate (120 kg ha^{-1} P_2O_5), limed sludge (60 kg ha^{-1} N) + verdete (60 kg ha^{-1} K_2O), limed sludge (60 kg ha^{-1} N) + agricultural gypsum (40 kg ha^{-1} S) + magnesite (30 kg ha^{-1} Mg) + single superphosphate (120 kg ha^{-1} P_2O_5) + verdete (60 kg ha^{-1} K_2O), organomineral fertilizer 05-24-08 (120 kg ha^{-1} P_2O_5), and a control (no nutrient sources), as reported in Table 3.

Nutrient application doses were based on the recommendations of Cantarutti et al. (1999) for the establishment of forage grasses. Primary and secondary macronutrient contents of the mineral fertilizers used in the experiment are presented in Table 4.

Each experimental unit consisted of two 5-dm^3 pots. Fifteen seeds of *U. brizantha* cv Marandu were sown in each pot and, 25 days later, thinned to four seedlings per pot (Figure 1).

Watering was provided as needed to maintain soil moisture at 60% of field capacity. Chlorophyll A and B were evaluated 30 days after sowing using a chlorophyll log. Plants were harvested, weighed, dried in an oven until constant weight, and weighed again. Soil samples were air dried, sieved through a 2 mm mesh sieve, and taken to the laboratory for the analysis of pH, V (base saturation), m (aluminum saturation), OM, OC and P, K, S, Ca, Mg, B, Cu, Fe, Mn and Zn contents according to the methodology of EMBRAPA (2009).

Data were submitted to tests of homogeneity of variance, normality of residues and block non additivity using SPSS Statistical Package 17.0. An analysis of variance was conducted with SISVAR (FERREIRA, 2008) and the averages compared by the Scott-Knott test at 0.05 significance. Also, the averages were compared with the control treatment by the Dunnet test at 0.05 significance.

Table 3. Fertilizer sources and application doses of the experiment, Uberlândia, Minas Gerais, Brazil, 2014.

Fertilizer source	Application dose
Mineral fertilizer (MF)	400 kg ha^{-1}
Limed sludge (L)	2.608.70 kg ha^{-1}
Limed sludge (L)+ Mineral fertilizer (MF)	2,608.70 kg ha^{-1}(L) + 400 kg ha^{-1} (MF)
Limed sludge (L) + Gypsum (G)	2.608.70 kg ha^{-1}(L) + 312 kg ha^{-1} (G)
Limed sludge (L) + Magnesite (M)	2.608.70 kg ha^{-1}(L) + 52 kg ha^{-1}
Limed sludge (L) + Single superphosphate (SS)	2.608.70 kg ha^{-1}(L) + 668 k ha^{-1}
Limed sludge (L) + Verdete (V)	2.608.70 kg ha^{-1}(L) + 560 kg ha^{-1}
Limed sludge (L) + G + M + SS + V	2.608.70 kg ha^{-1}(L), 312 kg ha^{-1} (G), 52 kg ha^{-1} (M), 668 kg ha^{-1} (SS), 560 kg ha^{-1} (V)
Organomineral (O)	500 kg ha^{-1}

Table 4. Nutrient contents of each source used in the experiment, Uberlândia, Minas Gerais, Brazil, 2014.

Fertilizer source	N	P_2O_5	K_2O	S	CaO	MgO
	dag kg^{-1}					
Mineral fertilizer	3	30	10	-	-	-
Agricultural gypsum	-	-	-	15	20.3	-
Magnesite	-	-	-	-	-	56
Single superphosphate	-	18	-	12	20	-
Verdete	-	-	11	-	-	-
Organomineral	5	24	8	-	-	-

Figure 1. The experimental site with the pots of *Urocholoa brizantha* cv Marandu.

Table 5. Properties of the soil cultivated with *Urochloa brizantha* cv Marandu, following the application of limed sludge, organomineral fertilizer and mineral fertilizers.

Fertilizer source	**pH H_2O**	**V**	**m**	**O.M**	**O.C**
		dag kg^{-1}	**dag kg^{-1}**	**g kg^{-1}**	**g kg^{-1}**
Mineral fertilizer	4.75^{b}	20^{b}	44^{b}	1.90^{ns}	1.10^{ns}
Limed sludge	6.18^{*a}	53^{*a}	0^{*a}	1.75^{ns}	1.02^{ns}
Limed sludge + Mineral fertilizer	6.00^{*a}	47^{*a}	0^{*a}	1.93^{ns}	1.12^{ns}
Limed sludge + Gypsum (G)	6.30^{*a}	56^{*a}	0^{*a}	2.00^{ns}	1.16^{ns}
Limed sludge + Magnesite (M)	6.35^{*a}	53^{*a}	0^{*a}	1.90^{ns}	1.10^{ns}
Limed sludge + Single superphosphate (SS)	6.35^{*a}	56^{*a}	0^{*a}	1.98^{ns}	1.15^{ns}
Limed sludge + Verdete (V)	6.63^{*a}	60^{*a}	0^{*a}	1.98^{ns}	1.15^{ns}
Limed sludge + G+ M+SS+V	6.33^{*a}	57^{*a}	0^{*a}	1.78^{ns}	1.03^{ns}
Organomineral	5.00^{b}	20^{b}	39^{*b}	1.90^{ns}	1.10^{ns}
Control	4.50^{b}	17^{b}	50^{c}	1.83^{ns}	1.06^{ns}
Coefficients of Variation (CV)	5.38%	14.30%	31.51%	11.46	11.53%

ns: Non significant by F test. Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance. V: Base saturation; m: aluminum saturation; OM: organic matter; OC: organic carbon (EMBRAPA, 2009).

RESULTS AND DISCUSSION

The values of soil pH, base saturation (V) and aluminum saturation (m) were affected by the treatments evaluated ($P<0.05$); however, no differences were observed for OM and OC, $P>0.05$ (Table 5).

The values of soil pH (4.50) and base saturation (17 dag kg^{-1}) (Table 4), determined before addition of the treatments, were classified as low and very low, respectively (Alvarez et al., 1999). The use of limed sludge alone, limed sludge plus mineral fertilizer, limed sludge plus gypsum, limed sludge plus magnesite, limed sludge plus single superphosphate, limed sludge plus verdete, limed sludge plus gypsum, magnesite, single superphosphate and verdete all increased soil pH (6.0 to 6.35) and base saturation (47 to 60%), bringing it to average and high values (Alvarez et al., 1999). As expected, increased pH was due to the alkalinity of the sludge used (pH 12.65) since hydrate lime ($Ca(OH)_2$) was used to eliminate pathogens and to stabilize the residue. Similar results have been reported by Nascimento et al. (2014), who stated that limed sludge increased soil pH from 5.85 to 7.85 in the 0 to 20 cm layer at a dosage of 50.42 t ha^{-1}. Also, Berton and Nogueira (2010) mentioned that fertilization with sludge stabilized with hydrated lime tended to increase soil pH and to reduce potential acidity, mostly by precipitating aluminum. Mineral fertilizer with NPK and the organomineral fertilizer did not increase values (pH and base saturation – V) in relation to the control 30 days after sowing *U. brizantha* cv. Marandu.

No significant differences were observed between limed sludge alone and limed sludge supplemented with various fertilizers (mineral fertilizer, gypsum (G), magnesite (M), single superphosphate (SS), verdete (V) or the mixture of gypsum, magnesite, single superphosphate and verdete) in relation to pH, base saturation (V) and aluminum saturation (m) (Table 5). A maximum value of Al^{+3} saturation tolerated by *U. brizantha* cv. Marandu was found to be 25 dag kg^{-1} and the target base saturation with liming was 45 dag kg^{-1} (Alvarez et al., 1999).

The use of limed sewage sludge alone or combined with some source of mineral fertilizer presented lower values of aluminum saturation (m) than was found with organomineral fertilizer, mineral NPK fertilizer or the control treatment. According to Kiehl (2008) organomineral fertilizers vary according to the constitution of the organic and mineral sources that are used; however, it is expected that such fertilizer will correct soil acidity with lower reactive chemical potential. Carvalho et al. (2015) observed improvement in base sum and in effective and total CEC in soil cultivated with olive trees (*Olea europaea*) eight months after application of the organomineral fertilizer, in comparison with the use of mineral fertilizer. Aluminum saturation (m) in soil fertilized organomineral fertilizer and mineral fertilizer presented values of 39 and 44 dag kg^{-1}, respectively, which were lower than the control (50 dag kg^{-1}); however, far too high for the establishment and production of *U. brizantha* cv Marandu. According to Vitorello et al. (2005), the excess of aluminum in tropical soils promotes toxicity to plants and is the main limiting factor for food and biomass production in the world.

Consequences of increased soil pH after the addition of hydrated lime in the sludge liming process include aluminum precipitation and neutralization of H+, resulting in greater amounts of negative electric charges in the soil. Increased soil base saturation was observed in treatments receiving limed sludge, and aluminum

Table 6. Primary (P and K) and secondary (S, Ca, Mg) macronutrients in soil cultivated with *Urochloa brizantha* cv. Marandu after application of limed sludge, organomineral fertilizer and mineral fertilizers.

Fertilizer source	**P**	**K**	**S**	**Ca**	**Mg**
	mg dm^{-3}			**Cmol$_{c}$ dm^{-3}**	
Mineral fertilizer	7.25^{c}	16.00^{*b}	7.00^{b}	0.50^{b}	0.10^{b}
Limed sludge	1.40^{c}	17.50^{a}	19.25^{b}	1.43^{*a}	0.20^{*a}
Limed sludge + Mineral fertilizer	11.85^{*b}	19.00^{a}	14.75^{b}	1.30^{*a}	0.14^{a}
Limed sludge + Gypsum (G)	3.53^{c}	15.00^{*b}	28.00^{*b}	1.58^{*a}	0.15^{*a}
Limed sludge + Magnesite (M)	9.08^{b}	16.00^{*b}	16.25^{b}	1.38^{*a}	0.20^{*a}
Limed sludge + Single superphosphate (SS)	18.75^{*a}	15.00^{*b}	51.50^{*a}	1.68^{*a}	0.18^{*a}
Limed sludge + Verdete (V)	3.85^{c}	18.25^{a}	16.75^{b}	1.68^{*a}	0.18^{*a}
Limed sludge + G + M+ SS+V	16.05^{*a}	14.00^{*b}	45.00^{*a}	1.58^{*a}	0.20^{*a}
Organomineral (5-24-08)	10.45^{b}	16.75^{*b}	3.00^{b}	0.48^{b}	0.10^{b}
Control	1.28^{c}	21.50^{a}	6.00^{b}	0.40^{b}	0.08^{b}
Coefficient of variation (CV)	57.79%	13.30%	50.54%	17.25%	25.01%

Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance.

saturation was reduced to zero, indicating that limed sludge, by itself or combined with different mineral fertilizer sources, acts as a soil corrective under the conditions evaluated. Exchangeable aluminum was thus reduced, while increasing soil pH and base saturation (Table 1). Fia et al. (2005) have stated, however, that the doses of limed sludge were considered adequate for plant mineral nutrition result in undesirable increases in soil pH. They recommend its use only as a soil acidity corrective, not as organic fertilizer. According to Ceolato et al. (2011), sewage sludge sanitized with hydrated lime acts as a soil corrective due to its high pH. They report that sludge also supplies calcium and magnesium to forage plants. Under these conditions, the application of sludge residue on agricultural crops has productive as well as social advantages, with less impact on public health and the environment.

Although sewage sludge is rich in organic matter, its application alone or with mineral sources (mineral fertilizer, gypsum (G), magnesite (M), single superphosphate (SS), verdete (V) and its mixture with gypsum, magnesite, single superphosphate and verdete) all did not affect soil carbon or organic matter contents (Table 1). Similarly, Nascimento et al. (2014) did not find increased organic matter content after a single application of limed sludge at 50.42 t ha^{-1} in safflower production. Bueno et al. (2011) reported increases in soil organic matter after several applications of sewage sludge.

Available soil phosphorus (P) levels in the control treatment were below the agricultural acceptable threshold of 1.28 mg dm^{-3} (Table 6). According to Alvarez et al. (1999), adequate soil phosphorus content for the establishment and growth of *U. brizantha* cv Marandu is above 20.1 mg dm^{-3}. Ourives et al. (2010) reported that physical-chemical characteristics of latosols, such as low phosphorus availability, restrict high yield in forage grasses, including Marandu grass. Phosphorus plays important roles in *U. brizantha* cv. Marandu during the establishment stage, improving tillering, root system development and also within the cell energy transfer metabolism, respiration and photosynthesis. All of this is in addition to the structural role of phosphorus in genes and chromosomes, as well as coenzymes, phosphoproteins and phospholipids (Rezende et al., 2011).

The highest phosphorus (P) averages in soil solution were obtained with limed sludge plus single superphosphate (18.75 mg dm^{-3}) and limed sludge mixed with gypsum, magnesite, single superphosphate and verdete (16.05 mg dm^{-3}). These averages were different from the control (1.28 mg dm^{-3}) and from all other treatments evaluated. Higher soil phosphorus contents were due to the mineral fertilizer: single superphosphate. Soil pH conditions following treatments with limed sludge plus single superphosphate, and limed sludge plus gypsum plus magnesite plus single superphosphate plus verdete resulted in greater availability of P in the single superphosphate. According to Silva et al. (2010) limed sewage sludge supplemented with single superphosphate at 0.436 dag kg^{-1} P increases soil extractable P and the accumulation of P in plants.

Phosphorus (P) contents in limed sludge, in mineral fertilizer with NPK, in limed sludge plus agricultural gypsum, in limed sludge plus verdete and in the treatment with no fertilization were not different from each other by the Scott-Knott test. They each presented values lower than the treatments with limed sludge plus magnesite, organomineral fertilizer and limed sludge plus mineral fertilizer with NPK.

Potassium (K) levels in the treatment with limed sludge, limed sludge plus mineral fertilizer, and limed sludge plus verdete, were not statistically different from the control treatment, indicating that their use did not change exchangeable soil K contents. However, a decrease in exchangeable soil K contents was observed in treatments with limed sludge plus gypsum, mineral fertilizer with NPK, limed sludge plus magnesite, limed sludge plus single superphosphate, and limed sludge plus gypsum plus magnesite plus single superphosphate plus verdete, all of which were lower than the control and the other treatments. This finding could be explained by the low dosage of limed sludge (2.6 t ha^{-1}) used in the experiment and low K content of sewage sludge. Bremm et al. (2012) used limed sludge at 15 t ha^{-1} in a clay latosol for maize production and observed that potassium content was not affected by the addition of limed material to the soil; presenting values lower than the non modified soil. Potassium is a macronutrient present in low concentrations in sewage sludge. Usually, complementation is required for agricultural use (Garcia et al., 2009). Although verdete contains 11 dag kg^{-1} K_2O, its use with hydrated lime was not sufficient to increase soil exchangeable K^+ contents in comparison with the control treatment.

Soil sulfur (S) content in the control treatment was 6.0 mg dm^{-3}. According to Fancelli et al. (2007), soils with S contents below 10 to 12 mg dm^{-3} are considered lacking in this element and limiting for plant growth. Fertilization with NPK, limed sludge, limed sludge plus fertilization with NPK, limed sludge plus magnesite, limed sludge plus verdete and fertilization with organomineral fertilizer did not differ among themselves or with the control treatment. Treatment with limed sludge plus agricultural gypsum presented S contents of 28.0 mg dm^{-3}, which was greater than observed in the control (6.0 mg dm^{-3}) but less than the treatment with limed sludge plus single superphosphate (51.5 mg dm^{-3}) and limed sludge mixed with agricultural gypsum, magnesite, single superphosphate or verdete (45.0 mg dm^{-3}). Single superphosphate was the mineral fertilizer source that contributed most to soil S contents, followed by calcium sulfate (agricultural gypsum). Limed sludge did not increase soil S content, thus requiring supplementation with a mineral source.

Exchangeable Ca and Mg contents in the control treatment were 0.40 and 0.08 Cmol$_c$ dm^{-3}, respectively, considered very low for plant establishment and production (Table 2) (Alvarez et al., 1999). The Ca and Mg contents of the soil after addition of NPK fertilizer or organomineral were similar to the control treatment. The fact that Ca and Mg contents did not increase after the addition of mineral or organomineral fertilizers was understood to be because these elements were not present in the formulation of either one. Treatments receiving limed sludge presented higher averages of Ca and Mg than the control, NPK and organomineral fertilizers. Increased Ca and Mg contents in treatments with limed sludge were due to the presence of Ca and Mg in the hydrated lime used for the sanitation of the sludge. Initially, limed sludge presented Ca contents of 302 g kg^{-1} and Mg of 42 g kg^{-1}, respectively. Similar results were reported by Ceolato et al. (2011), who stated that soil Ca and Mg contents increased following the addition of limed sludge for the cultivation of *U. decumbens*. Also, Fia et al. (2005) observed increased Ca and Mg contents in substrates treated with limed sewage sludge.

Soil contents of B and Cu were not affected by the fertilizer sources evaluated (P>0.05) (Table 7). Similar results were reported for Cu in studies by Nascimento et al. (2014), who observed that limed sludge did not affect soil Cu contents at the depth of 0 to 20 cm cultivated with safflower. Boron contents in the treatments evaluated varied from .09 mg dm^{-3} in the control to 0.17 mg dm^{-3} in the organomineral treatment (Table 3). According to Galrão (2004), such levels are considered low (<0.2 mg dm^{-3}) and the use of boron at 2.0 kg ha^{-1} is recommended for the establishment of *Urochloa brizantha* cv Marandu in savannah soil for intensive management systems. Copper contents varied from 0.83 to 0.95 mg dm^{-3} in the treatments, which was considered high (> 0.8 mg dm^{-3}), according to Galrão (2004), for the establishment of *U. brizantha* cv Marandu.

The application of limed sewage sludge alone, or in mixture with inorganic fertilizers, affected soil contents of Zn, Mn and Fe, in soils with higher levels of Zn and lower levels of Mn and Fe in relation to those observed in the control, with organomineral and mineral fertilizer or with NPK (Table 6). Contrasting results were found by Pigozzo et al. (2008), who found higher levels of available Fe and Mn, in soils treated with sewage sludge and cultivated with maize. According to Dechen and Nachtigall (2006), Mn has great affinity with soil organic matter, becoming unavailable to plants. In the present study, limed sewage sludge had a high organic matter content, which may have contributed to complexing the Mn with soil particles. Initially, limed sludge presented high pH (12.65), which could have precipitated the Mn and Fe in the residue, decreasing their availability to plants following soil treatment. Usman et al. (2012) reported that sewage sludge, under alkaline conditions, precipitates heavy metals present in lower availability, when applied to the soil. Lana et al. (2014) stated that there are complex inter-relations affecting Fe availability in residues applied to the soil. The observed Fe content found in the control was 43.25 mg kg^{-1}, which was considered good (> 31 mg dm^{-3}) by Alvarez et al. (1999).

Manganese contents in the control, mineral fertilizer with NPK, and in organomineral treatments were 2.18, 2.08 and 1.95 mg dm^{-3}, respectively. According to Galdrão (2004), the observed values were considered average for savannah soils. Treatments receiving limed sludge alone or in mixture with inorganic fertilizers presented soil Mn contents varying from 1.28 mg dm^{-3}, in limed sludge plus gypsum, magnesite, single superphosphate and verdete, to 1.63 mg dm^{-3}, in limed sludge plus single superphosphate, considered low for the establishment of *U. brizantha* cv Marandu under intensive management in

Table 7. Micronutrients in soil cultivated with *Urochloa brizantha* cv. Marandu, following the application of limed sludge, organomineral fertilizer and mineral fertilizers.

Fertilizer source	B	Cu	Fe	Mn	Zn
			-mg dm^{-3}		
Mineral fertilizer	0.10^{ns}	0.95^{ns}	37.50^{a}	2.08^{a}	0.43^{c}
Limed sludge	0.12^{ns}	0.95^{ns}	$27.50*^{b}$	$1.32*^{b}$	$1.10*^{b}$
Limed sludge + Mineral fertilizer	0.10^{ns}	0.85^{ns}	$26.75*^{b}$	$1.43*^{b}$	$1.15*^{b}$
Limed sludge + Gypsum (G)	0.12^{ns}	0.95^{ns}	$24.50*^{b}$	$1.35*^{b}$	$1.15*^{b}$
Limed sludge + Magnesite (M)	0.10^{ns}	0.90^{ns}	$24.25*^{b}$	$1.38*^{b}$	$1.28*^{b}$
Limed sludge + Single superphosphate (SS)	0.12^{ns}	0.88^{ns}	$28.50*^{b}$	1.63^{b}	$1.28*^{b}$
Limed sludge + Verdete (V)	0.10^{ns}	0.95^{ns}	$22.75*^{b}$	$1.33*^{b}$	$1.73*^{a}$
Limed sludge + G + M+ SS+V	0.14^{ns}	0.83^{ns}	$21.75*^{b}$	$1.28*^{b}$	$1.23*^{b}$
Organomineral	0.17^{ns}	0.95^{ns}	37.00^{a}	1.95^{a}	0.40^{c}
Control	0.09^{ns}	0.93^{ns}	43.25^{a}	2.18^{a}	0.23^{c}
Coefficient of variation (CV)	45.79%	35.14%	14.79%	17.63%	20.53%

Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance. ns: Not significant by the F test.

savannah soils (Galdrão, 2004). Soils presenting low Mn contents should receive a dose 6.0 kg ha^{-1}, which can be splitted into three applications (Galdrão, 2004).

The highest Zn soil content was observed with limed sludge plus verdete, an average value of 1.73 mg dm^{-3}. Nascimento et al. (2014) observed higher soil Zn content in the 0 to 20 cm layer after treatment with sewage sludge in contrast with the chemical fertilization recommended for safflower. Increased Zn content after fertilization with sewage sludge was also observed in studies by Zuba Júnior et al. (2011), Nogueira et al. (2013) and Cavalcanti et al. (2015). According to Haynes et al. (2009), domestic sewage sludge is usually rich in Zn because this element is present in various healthcare products, such as hand lotion, skin cream, makeup, deodorant, and shampoo, among others. Similarly, Ferraz et al. (2014) stated that increased Zn following fertilization with sludge can be attributed to the disposal of residues rich in trace elements in the sewage system.

Soil Zn content in treatments receiving limed sludge alone (1.10 mg dm^{-3}), limed sludge plus mineral fertilizer (1.15 mg dm^{-3}), limed sludge plus agricultural gypsum (1.15 mg dm^{-3}), limed sludge plus magnesite (1.28 mg dm^{-3}), limed sludge plus single superphosphate (1.28 mg dm^{-3}) and the mixture of limed sludge with gypsum, magnesite, single superphosphate and verdete (1.23 mg dm^{-3}) are all classified, according to Galdrão (2004), with averages in the range of 1.1 to 1.6 mg dm^{-3} (Table 3). The zinc content observed in limed sludge plus verdete (1.73 mg dm^{-3}) is considered high, according to Galdrão (2004). The control treatment, mineral fertilizer with NPK and the organomineral fertilizer presented low Zn contents (0.23, 0.43 and 0.40 mg dm^{-3}, respectively). Savannah soils with low Zn availability should be treated with this fertilizer at a dose of 2.0 kg ha^{-1} for the establishment of *U. brizantha* cv Marandu for intensive management foraging (Galdrão, 2004).

Copper and zinc are considered trace elements and should be monitored in agricultural soils receiving sewage sludge or other by-products, as required by the CONAMA Resolution 375/2006 (Brasil, 2006). In terms of results, adding Cu and Zn to soils with the application of limed sludge, limed sludge plus mineral fertilizer, limed sludge plus agricultural gypsum, limed sludge plus magnesite, limed sludge plus single superphosphate, limed sludge plus verdete, limed sludge plus gypsum, magnesite, single superphosphate and verdete, resulted in Zn contents of 1.9, 1.7, 1.9, 1.8, 1.76 1.9 and 1.66 kg ha^{-1}, respectively. The Cu contents of the same treatments were: 2.06, 2.30, 2.30, 2.56, 2.56, 3.56 and 2.46 kg ha^{-1}, respectively. It is important to note that such values are well below the theoretically accumulated loads for Zn (445 kg ha^{-1}) and for Cu (137 kg ha^{-1}) permitted for inorganic substances by the application of sewage sludge or by-products in agricultural soils, as determined by the CONAMA Resolution 375/2006 (Brasil, 2006).

The fertilizer sources did not affect chlorophyll A contents of *U. brizantha* cv Marandu (P>0.05) (Table 8). This lack of variation in chlorophyll A was also observed by Fassio et al. (2008) for *U. brizantha* cv Marandu, with mineral and organic fertilizers containing 320 kg ha^{-1} N, 90 kg ha^{-1} P_2O_5 and 120 kg ha^{-1} K_2O, associated with arbuscular mycorrhizal fungi. According to Abreu and Monteiro (1999), chlorophyll contents in recently expanded leaf blades of Marandu grass at 14, 28 and 42 days of plant growth were 31, 18 and 14 units, respectively, when nitrogen fertilization was inadequate. In the present study, chlorophyll A content in the control treatment was 24.45 units 30 days after sowing. Chlorophyll A content corresponds, approximately, to three or four times the chlorophyll B content (Table 8). Monteith (1978) states that this is a characteristic of

Table 8. Chlorophyll A and B contents of fresh and dry matter of *Urochloa brizantha* cv Marandu fertilized with limed sewage sludge, and inorganic and organic fertilizers.

Fertilizer source	Chlorophyll A	Chlorophyll B	Fresh matter (g)	Dry matter (g)
Mineral fertilizer	33.95^{ns}	10.05^{*a}	35.66^{*a}	7.09^{*a}
Limed sludge	32.10^{ns}	5.90^{b}	11.45^{*c}	2.47^{d}
Limed sludge + mineral fertilizer	32.48^{ns}	8.58^{*a}	32.79^{*a}	5.82^{*b}
Limed sludge + Gypsum (G)	33.38^{ns}	7.63^{*a}	13.37^{*c}	2.79^{d}
Limed sludge + Magnesite (M)	29.40^{ns}	7.50^{*a}	13.23^{*c}	2.55^{d}
Limed sludge + Single superphosphate (SS)	33.75^{ns}	9.80^{*a}	21.93^{*b}	4.79^{*c}
Limed sludge + Verdete (V)	30.55^{ns}	6.10^{b}	9.43^{c}	1.79^{d}
Limed sludge + G+M+SS+V	34.35^{ns}	9.18^{*a}	24.82^{*b}	4.69^{*c}
Organomineral	31.13^{ns}	7.95^{*a}	32.01^{*a}	5.98^{*b}
Control	24.45^{ns}	4.15^{b}	2.678^{d}	0.63^{e}

Averages followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability. *Significantly different in relation to the control, by the Dunnet test at 0.05 significance. ns: Not significant by the F test.

photosynthesis in C4 plants such as *U. brizantha* cv Marandu.

Chlorophyll B contents in the fresh and dry matter of *U. brizantha* cv Marandu were affected by the fertilizer sources evaluated ($P<0.05$) (Table 8). Mineral fertilizer with NPK, limed sludge plus mineral fertilizer, limed sludge plus gypsum, limed sludge plus magnesite, limed sludge plus single superphosphate, the mixture of limed sludge with gypsum, magnesite, single superphosphate and verdete and the organomineral fertilizer all improved the nutritional state of the plants by supplying mineral nutrients. This resulted in plants with higher chlorophyll B contents than the control. Chlorophyll B contents in limed sludge and in limed sludge plus verdete were not different from the control. According to Martins and Pitelli (2000) liming soil reduces acidity and favors mineral nutrient absorption, increasing chlorophyll A and B contents in *Urocholoa plantaginea*. Costa et al. (2008) reported that there is a direct relation between chlorophyll contents and leaf N concentration in recently expanded leaves of Marandu grass. Increased chlorophyll B content in the present study was a result of the nutrient sources evaluated (mineral fertilizer, agricultural gypsum, magnesite, single superphosphate, organomineral, and the mixture of gypsum, magnesite, single superphosphate and verdete). Limed sludge by itself did not increase chlorophyll B contents at the dosage evaluated (2.6 t ha^{-1}) since it does not supply the mineral nutrients in adequate amounts for forage plants.

Mineral fertilizer with NPK, limed sludge plus mineral fertilizer and organomineral fertilization resulted in increased fresh matter production (Table 4). Dry matter increased only in the treatment with mineral fertilizer plus NPK. However, all treatments evaluated presented fresh and dry matter weights greater than the control. Several studies have demonstrated increased fresh and dry matter of *U. brizantha* cv Marandu following the use of mineral or organic fertilizers (Costa et al., 2008; Lara et al., 2015; Dias et al., 2015).

Conclusions

Limed sludge, applied at 2.6 t ha^{-1}, combined or not with mineral fertilizers increased soil, V (base saturation), pH, reduced aluminum saturations to adequate levels for *U. brizantha* cv. Marandu development, and increased soil Ca and Mg contents, together with lower Fe and Mn soil contents.

Soil organic matter, organic carbon, Cu and B contents were not affected by limed sludge and the fertilizer sources evaluated.

Higher levels of P and S were observed after fertilization with limed sludge combined with single superphosphate and the mixture with gypsum, magnesite, single superphosphate and verdete. Neither verdete nor any of the other fertilizer sources evaluated increased K content. Limed sludge plus verdete resulted in the higher Zn content.

Limed sludge and limed sludge plus verdete did not increase chlorophyll B content of *U. brizantha* cv. Marandu. Limed sludge plus mineral fertilizer and limed sludge plus organomineral fertilizer increased fresh matter of the forage grass evaluated. However, only the mineral fertilizer increased dry matter.

It was concluded that the limed sewage sludge provides agronomic benefits. Additionally, its application on agricultural land, as required by environmental regulations, can produce social and environmental benefits with less impact on public health and the environment.

Conflict of interests

The authors have not declared any conflict of interests.

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Properties, classification, genesis and agricultural suitability of soils in a semiarid pediplain of North Cameroon

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The aim of the study was to determine the morphological and physicochemical characteristics, classification, genesis and suitability of soils developed on pediplain around granitic hills in Minawao in the Far North region of Cameroon. The studied soil profile had 450 cm thick. It is composed of two subsections formed by erosion and cumulization. The upper subsection classified as typic ustifluvents clayey isohyperthermic is characterized by the high content of coarse elements showing stratifications in some part of the horizons. It recovers the below subsection classified as thapto typic haplustalfs clayey isohyperthermic. They are clayey, with clay contents ranging from 45 to 49%, and slightly acidic. Total nitrogen and organic carbon contents are very low ranging respectively from 0.05 to 0.11 and 0.25 to 0.63. Available phosphorous contents are below critical level. Calcium and Magnesium dominate the exchange complex of these soils. Their values range respectively from 12.96 to 15.04 cmol (+)/kg and 3.52 to 6.56 cmol (+)/kg. The CEC values are high, ranging from 44.64 to 57.84 cmol(+)/kg of soil. The CEC clay range from 89.92 to 117.02 cmol(+)/kg of clay. Base saturation percentage values are low, ranging from 37.05 to 42%, corresponding to a mean value of 39.74%. The studied soils are globally subjected to problems of low organic matter content, high coarse material content and low pH for the cultivation of *Sorghum*, *Cotton*, *Soya*, *Groundnut, Maize* and *Cowpea*. These problems could be solved through introduction of DMC systems, addition of available organic substrates, restoration of the cation balance and liming.

Key words: Soils, properties, genesis, suitability, North Cameroon.

INTRODUCTION

Arid and semiarid zones cover approximately 40% of the land surface, with a continuous increase in the area by desertification processes, induced mainly by human activities and/or climatic change (Moshki and Lamersdorf,

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2011; Vásquez-Méndez et al., 2011). The detachment of particles of soil, surficial sediments and rocks, is caused by raindrops and runoff, hydrological processes of sheet erosion, rill and gully erosion, and through mass wasting and wind action (Kim and Gilley, 2008; Vásquez-Méndez et al., 2011). In arid and semiarid areas, soils with little or no vegetation cover are exposed to torrential precipitation events, characterized by short durations and high intensities, and are prompt to the occurrence of physical and chemical processes that change the surface layer conditions (Vásquez-Méndez et al., 2011). Surface cover associated with vegetation and rocks is known to have an important influence on the generation of sediment in semiarid landscapes (Nearing et al., 2005; Bautista et al., 2007). It is well documented that soils of arid and semiarid zones are very susceptible to water erosion (Cornelis, 2006) mostly due to a scanty vegetation cover, low organic matter content and the little resistance to the erosion forces (Nearing et al., 2005; Vásquez-Méndez et al., 2011). Slope gradient is generally considered to be a factor that influences soil erosion in most environments (Wischmeier and Smith, 1978) along with wind speed, soil cover, and rainfall force. Erosion and salinity continues to be a primary cause of soil degradation throughout the world, and has become an issue of significant and severe societal and environmental concern (Wei et al., 2007; Vásquez-Méndez et al., 2011). About 80% of the world´s agricultural land suffers moderate to severe erosion, and 10% suffers slight to moderate erosion (Pimentel et al., 1995). Erosion by water and wind adversely affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, infiltration rates, organic matter, soil biota and soil depth (Vásquez-Méndez et al., 2011; Li et al., 2014; Padidar et al., 2016). Cameroon is also experiencing significant problems with land degradation and declining soil fertility due to soil erosion (Boli, 1996). Farmers have responded to pressures of feeding a growing population by clearing new land (Markham and Fonjong, 2015). They have also reacted to the diminished availability of new land by abandoning traditional practices of crop rotation and leaving fields fallow (Tsozué et al., 2015). There are also problems with soil erosion and droping water tables resulting from overgrazing and poor agricultural practices (Boli, 1996; Markham and Fonjong, 2015). In the Far North region of Cameroon, high population pressure, poor soil management practices, tree cutting for firewood, and overgrazing, combined with climate change factors and recurrent and more extended droughts, are resulting in desertification (Tsozué et al., 2015; Markham and Fonjong, 2015). Facing problem of land degradation, all land formerly devoted to cattle rearing are now cultivated, even soils developed on pediplain or sheet-flood glacis (Tricart and Cailleux, 1969) around granitic hills or inselbergs, naturally sandy and infertile. In this work, three questions specifically addressed. Firstly, what are morphological and physicochemical characteristics of soils developed on pediplain around granitic hills in Minawao in the Far North region of Cameroon? Secondly, to which group of soil do they belong? Third, are they really suitable for the growth of *Sorghum*, *Cotton*, *Soya, Maize, Groundnut* and *Cowpea* which are crops generally cultivated in the area since typical soils of arid and semiarid environment are poor in fertility according to Vásquez-Méndez et al. (2011)? According to The United Nations Refugee Agency, Minawao area shelters fifty six thousand, eight hundred and thirty-eight (56838) Nigerian refugees in May 2016 who leave their country due to "Boko Haram" exactions. Their presence and activities greatly affect the behaviour of few habitants of this area and might create food insecurity in the near future.

MATERIALS AND METHODS

The study was carried out in Minawao in the Mayo Tsanaga Division (Far North region of Cameroon) (Figure 1). The studied site was located in a pediplain devoted mainly for *Sorghum*, *Cotton*, *Soya, Maize, Groundnut* and *Cowpea* cultivation (10°35'02.9" N, 13°52'16.3 E, 581 m a.s.l.). The climate is characterized by a total annual rainfall of 1074 mm and a mean annual temperature of 26°C. The aridity index of de Martonne (1926) showed five months of rainy season from May to September (Aridity index > 20) and seven dry months (aridity index < 20) (Table 1). Natural vegetation had disappeared apart from some rare trees recalling the ancient dry forest. The relief was constituted of two geomorphological units, hills/inselbergs and pediplains. The bedrock was deformed granite characterized by an orientation of minerals, composed of quartz, feldspars and abundant biotite.

Field work consisted of direct observations, description of environmental settings and soil survey trough boreholes. Boreholes were made manually along a dense network of 20 to 50 m wide. This helped to define one major group of soil in the pediplain on the basis of some morphological profile characteristics (colour, texture, structure, coarse elements, etc) and to identify the point of implantation of a representative soil pit for detailed study. This was followed by soil description and soil sampling according to Hinsch Mikkelson et al. (2009). The main search characters were colour, thickness of horizons, coarse elements, texture, structure, porosity, consistency and boundaries between horizons. After collection, soil samples were packaged in plastic bags, labelled and sent to the laboratory for soil analyses in the University of Dschang. In the laboratory, bulk soil samples were air-dried at room temperature and then sieved (2 mm) to discard coarse fragments. Analyses were carried out on the fine fraction, and include particle size distribution, pH, exchangeable bases, cation exchange capacity (CEC) at pH 7, organic carbon, total nitrogen and available phosphorus. For soil texture analysis, soil organic matter and carbonates were removed with hydrogen peroxide (30%) and diluted hydrochloric acid (10%), respectively. Then, soil samples were dispersed with sodium hexametaphosphate and particle size distribution was analysed by the Robinson’s pipette method. Soil pH was measured potentiometrically in a 1:2.5 soil: solution ratio. Exchangeable bases and CEC were determined using atomic absorption spectrophotometry in a solution of ammonium acetate at pH 7. Total nitrogen was obtained after heat treatment of each sample in a mixture of concentrated sulfuric acid and salicylic acid. The mineralization was accelerated by a catalyst consisting of iron sulphate, selenium and potassium sulphate. The mineralization was

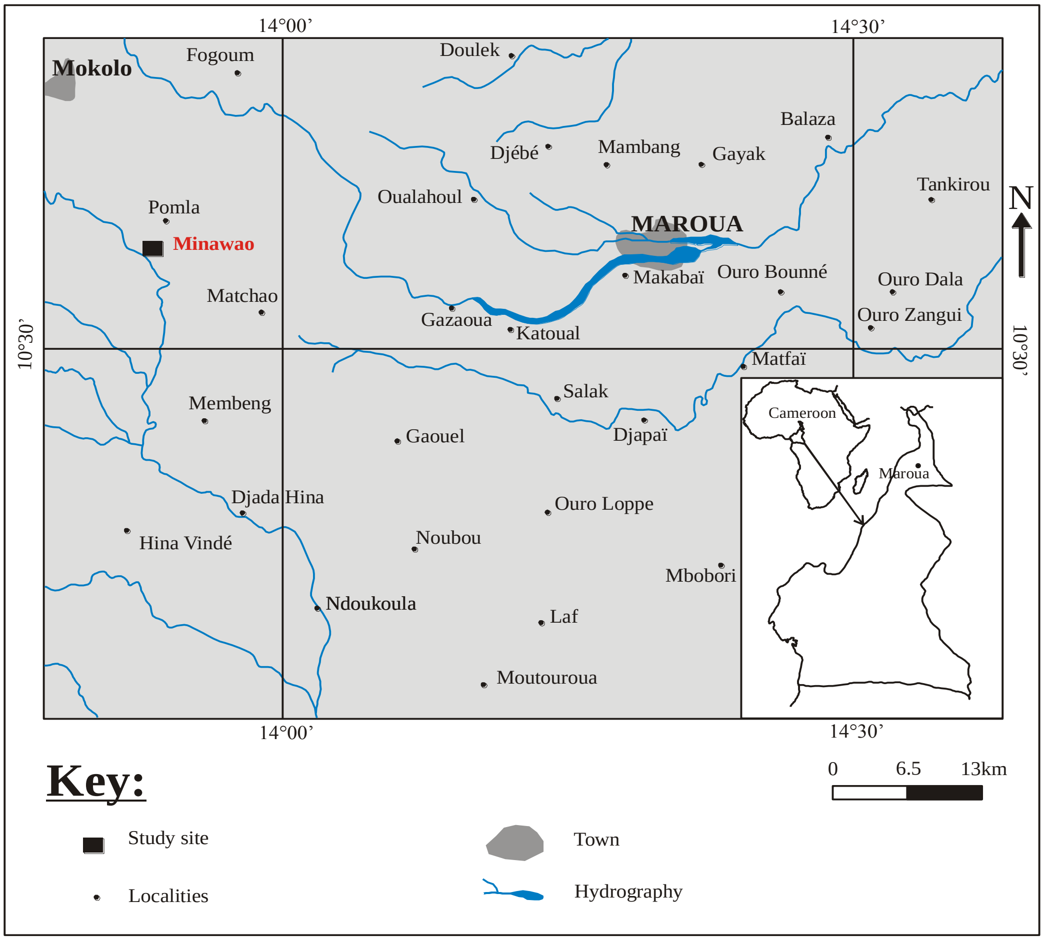

Figure 1. Location of the study site.

Table 1. Total annual rainfall, mean annual air temperature and Aridity index of De Martonne (1926).

Months	J	F	M	A	M	J	J	A	S	O	N	D	Total
Precipitations	0	0	0	28.9	80.8	118.4	259.4	335.1	198.1	51.5	2.6	0	1074.8 mm
Temperatures	22.7	21.8	29.24	31.05	28.64	26.81	24.98	24.25	25.38	26.36	26.71	24.19	/
Aridity index	0	0	0	8.44	25.1	38.6	88.98	117.4	67.2	16.99	0	0	/

followed by distillation via conversion of nitrogen into steam in the form of ammonia (NH_3), after alkalinisation of mineralized extract with NaOH. The distillate was fixed in boric acid (H_3BO_3) and then titrated with sulfuric acid or diluted hydrochloric acid (0.01 N). Organic carbon was determined by the Walkley–Black method (Walkley and Black, 1934). Soil organic matter (OM) content was obtained by multiplying soil organic carbon content by 1.724 (Walkley and Black, 1934). Available phosphorus was determined by Bray 2 method (Bray and Kurtz, 1945). In order to see if the studied soils were really suitable for *Sorghum*, *Cotton*, *Soya, Maize, Groundnut* and *Cowpea*, main crops cultivated in the area, soils were evaluated following the method of Sys et al. (1991a, b, 1993). Soils’ suitability for *Sorghum*, *Cotton*, *Soya, Maize, groundnut* and *Cowpea* were classified as being highly suitable (S1), moderately suitable (S2), marginally suitable (S3), actually not, but potentially suitable (N1) and actually and potentially not suitable (N2), using simple limitation and parametric methods. The mean annual soil temperature (MAST) was calculated according to the following equation: MAST= 6.84 + (0.925*MAAT) - (0.0031*Precipitations) (Bai, 2009). In this equation, MAAT is the mean annual air temperature. The studied soils were classified according to Soil Survey Staff (2010). The data collected were analysed using descriptive statistics with XLSTAT 2008.6.03. Pearson correlation analysis was used to determine the relationship between soil parameters.

RESULTS

Morphology of soils

The studied soil profile was 450 cm thick (Figure 2). From the surface to the bottom of the profile, four horizons

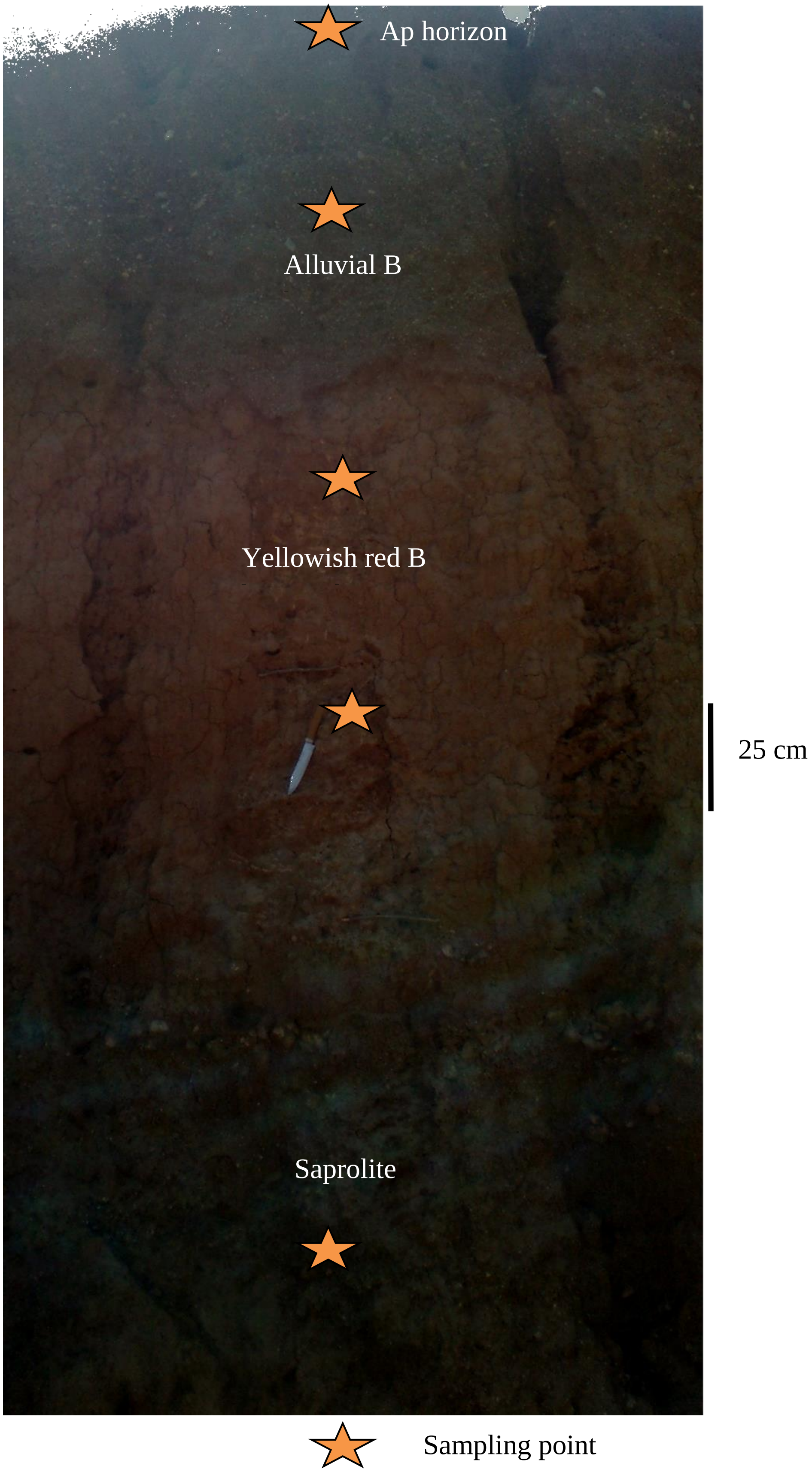

Figure 2. Typical profile of the semi-arid pediplain of Northern Cameroon.

Table 2. Physicochemical characteristics of soils.

Horizons	Depth	Sand	Silt	Clay	Textural	pH_{H2O}	pH_{KCl}	N	OC	OM	C/N	Avail. P	Ca^{2+}	Mg^{2+}	K^+	Na^+	S	CEC	CEC Clay	S/CEC
	(cm)	(%)	(%)	(%)	class			(%)	(%)	(%)		(mg/kg)	cmol(+)/kg							(%)
Humiferous surface horizon	0-30	39	14	47	Clay	5.8	5.4	0.11	0.36	0.63	3.35	4.24	12.96	4.16	0.42	0.65	18.19	48.88	102.47	37.21
Alluvial B horizon	30-160	37	18	45	Clay	5.8	5.1	0.08	0.22	0.38	2.83	4.64	15.04	6.56	1.14	0.65	23.39	55.68	122.76	42.01
Yellowish red B horizon	160-240	19	32	49	Clay	5.7	4.8	0.07	0.15	0.25	2.21	2.40	12.96	6.24	0.78	0.65	20.63	49.28	99.96	41.86
	240-300	19	32	49	Clay	6.1	4.9	0.09	0.25	0.44	2.69	4.92	14.56	5.44	0.78	0.65	21.43	57.84	117.02	37.05
Saprolite	300-450	29	22	49	Clay	6.4	5.1	0.05	0.29	0.50	5.54	5.15	13.76	3.52	0.42	0.43	18.13	44.64	89.92	40.61

were distinguished and presented as follow:

Humiferous surface (Ap) horizon (0-30 cm): The colour was dark olive brown (2.5Y3/3) when dry. The horizon was characterized by a clayey texture (fine earth), poorly developed lumpy structure; the consistence is slightly hard when dry and non sticky and non plastic when wet; coarse elements are abundant (50%), irregularly shape with various sizes and composed mainly of quartz and feldspars particles; rootlets are rare; the boundary is irregular and gradual;

Alluvial (B) horizon (30-160 cm): The colour was dark brown (10YR3/3) when dry. The horizon was characterized by a clayey texture (fine earth), a particulate structure; the consistency was slightly hard when dry, non sticky and non plastic when wet; coarse elements were dominant (>80 %), irregularly shape, with various sizes and composed mainly of quartz and feldspars, showing stratification in some part of the horizon; there were very few rootlets; the boundary was regular and abrupt;

Yellowish red (B) horizon (160-300 cm): The colour was brownish yellow (10YR6/6) when dry. The horizon was characterized by a clayey texture, a very fine blocky structure; the consistency was hard when dry, and sticky and plastic when wet; coarse elements were very few to few, irregularly shape, with various sizes; dark brown typic coatings were observed on the walls of some voids; the boundary was regular and gradual;

Saprolite (300-450 cm): It was light olive brown (2.5Y5/4) when dry, with a clayey texture (fine earth) and a granular structure; the consistency was hard when dry, slightly sticky and slightly plastic when wet; coarse elements were very few to few, irregularly shape, with various sizes, composed mainly of quartz and feldspars; there was a quartz vein in the upper part of the horizon, containing angular to subangular fragments of quartz of various sizes.

Physicochemical characteristics of soils

Textural classes of the studied soil were clay. Clay contents ranged from 45 to 49% (Table 2). They were very slightly variable along the soil profile (CV= 3.3%), characterized by negative skewness and kurtosis (Table 3). This soil fraction was followed by sand, whose contents ranged from 19 to 39%. Sand contents were moderately variable (CV=29.8%), characterized by negative skewness and kurtosis (Table 3). They are most represented in the upper part of the soil profile (Table 2). Silt contents on contrary, were the lowest. They ranged from 14 to 32%, with a mean value of 23.6% (Tables 2 and 3). They were moderately variable (CV= 31%), characterized by positive skewness and negative kurtosis (Table 3). There was a significant negative correlation between sand and silt (r=-0.99, p<0.05) (Table 4), confirming the opposite evolution of their contents with depth (Figure 3).

Soil pH was slightly acid and very slightly variable (CV=4.3%). It ranged from 5.7 to 6.4, with a mean value of 5.96 (Tables 2 and 3). No significant correlation existed between soil pH and other soil parameters.

Total nitrogen and organic carbon contents were very low ranging respectively from 0.05 to 0.11 and 0.25 to 0.63 (Tables 2 and 3). Their contents were moderately variable along the soil profile (15<CV<35) (Table 3). C/N ratios were low. They ranged from 2.21 to 5.54 and were high variable along the soil profile (CV=35.10%) (Tables 2 and 3). Available phosphorous contents were below critical level. They ranged between 2.40 and 5.15 mg/kg (Tables 2 and 3). No significant correlation was noted, except a significant negative correlation between C/N and Na+ (r=-0.95, p<0.05) (Table 4).

Table 3. Summary statistic of soil properties.

Soil properties	Minimum	Maximum	Mean	CV	SD	Skewness	Kurtosis
Sand (%)	19.000	39.000	28.600	0.298	8.523	-0.017	-1.724
Silt (%)	14.000	32.000	23.600	0.310	7.316	0.062	-1.639
Clay (%)	45.000	49.000	47.800	0.033	1.577	-0.844	-0.922
pH$_{H2O}$	5.700	6.400	5.960	0.043	0.256	0.727	-1.016
N (%)	0.050	0.110	0.080	0.250	0.02	0.000	-0.950
OC (%)	0.150	0.360	0.254	0.276	0.070	0.043	-0.952
C/N	2.210	5.540	3.324	0.351	1.167	1.151	-0.201
Avail. P (mg/kg)	2.400	5.150	4.270	0.230	0.982	-1.165	-0.210
Ca^{2+} (cmol (+)/kg)	12.960	15.040	13.856	0.060	0.831	0.193	-1.581
Mg^{2+} (cmol (+)/kg)	3.520	6.560	5.184	0.226	1.171	0.233	-1.568
K^{+} (cmol (+)/kg)	0.420	1.140	0.708	0.381	0.270	0.344	-1.153
Na^{+} (cmol (+)/kg)	0.430	0.650	0.606	0.145	0.088	-1.500	0.250
S (cmol (+)/kg)	18.130	23.390	20.354	0.098	1.995	0.202	-1.355
CEC (cmol (+)/kg)	44.640	57.840	51.264	0.094	4.819	0.104	-1.437
S/CEC (%)	37.050	42.010	39.748	0.055	2.186	-0.272	-1.779

Table 4. Correlation coefficient of soil properties

Soil properties	Sand	Silt	Clay	pH$_{H2O}$	N	OC	C/N	Avail. P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	S	CEC	S/CEC
Sand	1														
Silt	**-0.991***	1													
Clay	-0.798	0.711	1												
pH$_{H2O}$	-0.153	0.076	0.466	1											
N	0.352	-0.328	-0.375	-0.543	1										
OC	0.626	-0.700	-0.136	0.341	0.443	1									
C/N	0.277	-0.369	0.206	0.833	-0.522	0.533	1								
Avail. P	0.355	-0.374	-0.181	0.719	-0.021	0.604	0.600	1							
Ca^{2+}	0.068	0.017	-0.439	0.225	-0.095	-0.165	-0.055	0.610	1						
Mg^{2+}	-0.247	0.368	-0.368	-0.679	0.095	-0.793	-0.837	-0.474	0.394	1					
K^{+}	-0.075	0.205	-0.535	-0.456	0.000	-0.672	-0.627	-0.131	0.694	**0.925***	1				
Na^{+}	-0.023	0.109	-0.375	-0.854	0.750	-0.257	**-0.950***	-0.448	0.057	0.709	0.535	1			
S	-0.127	0.255	-0.488	-0.402	0.049	-0.635	-0.640	-0.059	0.745	**0.906***	**0.990***	0.555	1		
CEC	-0.168	0.269	-0.334	-0.290	0.441	-0.273	-0.672	0.163	0.713	0.676	0.744	0.687	0.824	1	
S/CEC	-0.015	0.067	-0.226	-0.178	-0.685	-0.682	0.007	-0.374	0.117	0.452	0.480	-0.197	0.370	-0.219	1

* Significant at $p<0.05$

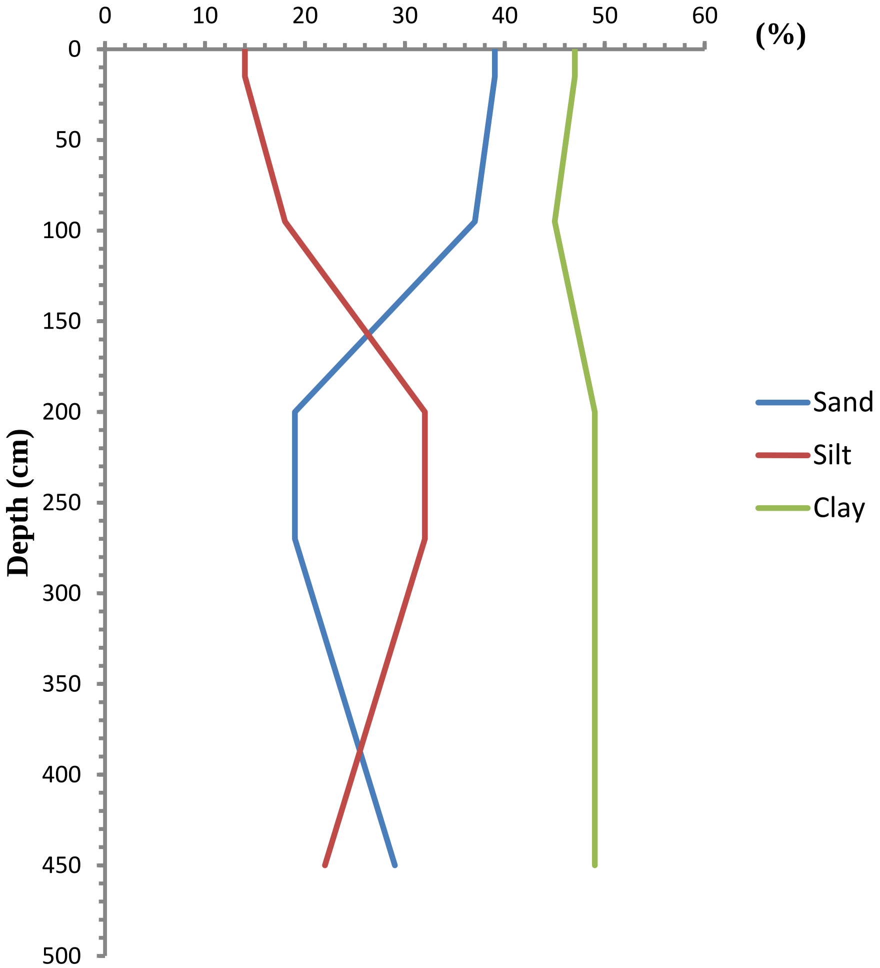

Figure 3. Distribution of soil particle size distribution fractions with depth.

Calcium and Magnesium dominate the exchange complex of these soils. Their values ranged respectively from 12.96 to 15.04 cmol(+)/kg and 3.52 to 6.56 cmol(+)/kg corresponding respectively to mean values of 13.85 cmol(+)/kg and 5.18 cmol(+)/kg (Tables 2 and 3).

The CEC values were high and ranged from 44.64 to 57.84 cmol(+)/kg of soil (Table 2). The CEC clay ranged from 89.92 to 117.02 cmol(+)/kg of clay (Table 2). Base saturation percentage values were low, ranging from 37.05 to 42%, corresponding to a mean value of 39.74% (Table 3). They were very slightly variable and showed a negative skewness and kurtosis (Table 3). Except the significant positive correlation between Mg^{2+} and K^+ (r=0.92, p<0.05) and S (r=0.90, p<0.05) and between K^+ and S (r=0.99, p<0.05), no significant correlation was noted on the exchange complex (Table 4).

Soil classification

The studied soil profile was composed of two subsections (Figure 2). The upper part was characterized by dominance of mineral soil materials (160 cm) and absence of distinct pedogenic horizons. Coarse elements were dominant (50-80 %), irregularly shape, with various sizes and composed mainly of quartz and feldspars, without any structural organization, globally characteristic of alluvial materials. These characteristics observed in the upper part of the soil profile were those of the Entisols order and fluvent suborder (Soil Survey Staff, 2010). These soils remain dry for more than 90 cumulative days but less than 180 days according to the aridity index (Table 1), characteristic of ustic moisture regime. This permitted to classify them in ustifluvents great group and typical ustifluvents subgroup. Although the coarse material was very abundant, the fine earth which composed the soil was clayey and the mean annual soil temperature > 22°C, allowing to classify the studied soil as clayey isohyperthermic family. The upper subsection of the studied soil is thus a typic ustifluvents clayey isohyperthermic.

This upper classified part of the soils overlaid an ancient soil developed on granite, from which it was separated by a regular and abrupt boundary. This ancient soil was constituted of yellowish red B horizon and saprolite. The B horizon showed dark brown typic coatings which represented marks of translocation processes of silicate clays, characteristic of argillic B horizons. There was globally high supply of bases in this part of the soil, with base saturation greater than 35%. This ancient soil composed solely of a saprolite and a B horizon was classified as an Alfisols. These soils experienced drought for more than 90 cumulative days but less than 180 days according to the aridity index (Table 1), characteristic of ustic moisture regime. This permitted to classify this part of the soil profile in ustalfs suborder and haplustalfs great group. The fact that this part of the soil profile was buried permitted to classify it as thapto typic haplustalfs subgroup. The texture was clayey and the mean annual soil temperature was higher than 22°C, leading to the classification of this part of the soil in the clayey isohyperthermic family. The coated soil was thus a thapto typic haplustalfs clayey isohyperthermic.

Suitability of the studied soil for sorghum, cotton, soya, maize, groundnut and cowpea cultivation

Sorghum, Cotton, Soya, Maize, Groundnut and *Cowpea* were main crops widely cultivated in the study area. Their high yields might permit to find solutions against food insecurity created by the installation of Nigerian refugees (56838 refugees) in this area. The studied soil were chemically fertile, but deficient in nitrogen, organic carbon and available phosphorous. Their contents were below the critical levels given by Tabi et al. (2013) and Euroconsult (1989).

On the climate characteristics view point, the mean temperature of the study area was highly suitable (S1) for the development of the six chosen crops. Precipitations were highly suitable (S1) for *Cotton*, *Soya*, *Maize* and *Groundnut*, but moderately suitable (S2) for *Sorghum* and *Cowpea*. Topography and wetness were highly suitable (S1) for the crops growth. On physical soil characteristics view point, texture/structure and soil depth were highly suitable for crop growth. Coarse fragments on contrary constituted a handicap. The studied soils were marginally suitable (S3) for *Sorghum*, *Cotton*, *Soya*, *Maize* and *Cowpea*, but actually and potentially not suitable (N2) for the production of *Groundnut* (Table 5). On soil fertility view point, the studied soils were highly suitable due to apparent CEC and base saturation, except for *Cotton* where soils were moderately suitable for their growth due to base saturation. Soil pH was highly suitable for *Sorghum*, *Soya*, *Maize* and *groundnut*, but moderately suitable for *Cowpea* and marginally suitable for *Cotton*. Organic carbon content might constitute a handicap for the production of all the chosen crops. It was moderately suitable for *Sorghum* and *Cotton* growth but marginally suitable for the four others (Table 5). On the salinity view point, the studied soils were highly suitable (S1) for the selected crops growth.

Globally, the studied soil was moderately suitable for *Sorghum*, *Cotton*, and *Cowpea* due respectively to low organic content, low organic content and base saturation, soil pH and precipitations during crop cycle (Table 5). It was marginally suitable for *Cotton*, *Soya* and *Maize* due to low organic carbon content and high coarse fragments, but marginally suitable for *Sorghum* and *Groundnut* due only for coarse fragments and low organic carbon content respectively. This soil was permanently not suitable for *Groundnut* due to high coarse fragments content (Table 5).

DISCUSSION

Morphological and physicochemical properties

The studied soil was morphologically characterized by two subsections. The first subsection on top showed stratifications which characterize poorly develop soils (Bourgeon, 1989), classified as typic ustifluvents. It overlaid the second subsection of the profile which was classified as thapto typic haplustalfs. This soil morphology is frequently observed in semi-arid pediplains (Bourgeon, 1989). The Ap horizon had high sand content (39%), high quantity of coarse fragments (>50%), average clay content and weak lumpy structure. These properties make the soil very vulnerable to erosion as much as the fragments are easily detached under the impact of rain-drops or running water (Kim and Gilley, 2008; Fasina et al., 2015). The particles tend to lie in close contact due to low contents of bridging materials like organic matter. The land on which most of the soils are situated should not be mechanically cleared as it is done now because this exposes the structurally imbalanced subsoil to erosion, leaching, degradation and compaction (Vásquez-Méndez et al., 2011; Fasina et al., 2015). Soil with higher clay particle content has more stable aggregates against wind erosion (Chen, 1991).

The low organic carbon content of the studied soil might be due to continuous cultivation and frequent burning of farm residues. It might also be due to the effect of high temperature and relative humidity which favour rapid mineralization of organic matter (Fasina et al., 2006; Van Leeuwen et al., 2015). The soils with low organic matter content are prone to wind erosion during the dry and windy fallow period (He et al., 2008). The studied soils have good levels of exchangeable bases, but nitrogen, phosphorous and organic contents are below the critical level. These low contents are due to the absence of vegetation, consequence of competition between farmers and breeders for much (Dongmo et al., 2007). In fact, soils under tree canopies in semiarid

Table 5. Land suitability evaluation of different studied soils for *Sorghum*, *Cotton, Soya, Maize, groundnut* and *Cowpea* using simple limitation and parametric methods.

Land, soil and climate characteristics	Sorghum	Cotton	Soya	Maize	Groundnut	Cowpea
Climate (c)						
Precipitation during crop cycle (mm)	S2	S1-0	S1-1	S1-1	S1-1	S2
Mean temperature during crop cycle (°C)	S1-0	S1-1	S1-1	S1-0	S1-0	S1-0
Topography (t)						
Slope (%)	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1
Wetness (w)						
Flooding	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Drainage	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Physical soil characteristics (s)						
Texture /Structure	S1-0	S1-0	S1-0	S1-0	S1-1	S1-0
Coarse fragment (vol %)	S3	S3	S3	S3	N2	S3
Soil depth (cm)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil fertility characteristics (f)						
Apparent CEC (cmol (+) kg^{-1} clay)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Base saturation (%)	S1-1	S2	S1-1	S1-1	S1-1	S1-1
pH_{H2O}	S1-1	S3	S1-1	S1-1	S-1-1	S2
Organic carbon (%)	S2	S2	S3	S3	S3	S3
Salinity (n)						
ESP (%)	S1-0	S1-0	S1-0	S-0	S1-0	S1-0
Suitability	S2cfS3s	S2fS3sf	S3sf	S3sf	S3fN2s	S2cfS3sf

environments are often more fertile than soils from the surrounding grasslands. Quantities of mineralizable nitrogen, phosphorous, potassium, calcium, organic matter, and the microbial biomass, are significantly higher in soils beneath the canopy than in the open area (Belsky et al., 1989; Vásquez-Méndez et al., 2011).

Soil genesis

Within most landscapes, there is movement of material from one soil to adjacent soils. Movement can take place both on the soil surface and beneath the surface (Buol et al., 2011). The upper subsection of the studied soil is the result of surficial erosion which corresponds to lateral removal of material from the surface of soil by raindrop splash and runoff waters. It also corresponds to transfer of material from hillslope to lower parts of the slope and the accumulation of mineral material by water on the surface of the soil. This accumulation, also called cumulization or accretion, may be considered as geogenic rather than a pedogenic process (Buol et al., 2011). It is well recognized through stratification noted in the upper subsection. Those characteristics, lead to the classification of this upper part of the studied soil in the Entisols order. Erosion and cumulization, commonly recognized as paired processes, are associated in the landscape of the study area. The major factors determining soil genesis, classification, morphological properties, and account of diagnostics horizons in this area appear to be the result of the topography causing erosion rather than climate and the nature of parent material affected by leaching regime and weathering rates (Ozaytekin and Uzun, 2012).

The below subsection classified as thapto typic haplustalfs may be an ancient weathering profile. This soil was formed under more humid climate different from the semi-arid climate which prevailed now in the studied area. This ancient climate leads to the differentiation of a thick soil profile (thickness > 3 m) with a yellowish brown clayey B horizon of 140 cm thick. The absence of an A horizon between the two subsections might be due to the fact that the upper part of the ancient soil profile was removed by erosion process which stops when climatic conditions change into others, favourable to cumulization process. It might also be due to the fact that the slope was eroded until the slope gradient and runoff slowdown, allowing much of the sediment in the runoff from the hillslopes to deposit (Nearing et al., 2005). This leads to peneplanation process which affected all the studied area leading to the formation of the upper part of the studied soils.

Soil suitability

For the cultivation of *Sorghum*, *Cotton*, *Soya*, *Groundnut, Maize* and *Cowpea*, the studied soils are globally subjected to problems of low organic matter content, high coarse material content and low pH for groundnut growth. The low organic matter content has to be substantially increased through effective crop residue management with increased use of leguminous plants as well as judicious use of organic fertilizers (Fasina et al., 2015). It might also been increased trough the introduction of direct-seeding mulch-based cropping (DMC) systems (Brown et al., 2002; Ndah et al., 2015, Tsozué et al., 2015). Soil organic matter was an essential component of soil quality, governing processes like carbon sequestration, nutrient cycling, water retention and soil aggregate turnover (Tsozué et al., 2015; Van Leeuwen et al., 2015). Addition of available organic substrates would promote the growth and activity of indigenous microorganisms (García-Orenes et al., 2010). The accumulation of biomass on the soil surface in the DMC systems, while increasing soil biological activity, intensified the mineralization process of OM, leading thus to rapid mineralization of soil OM, which would therefore improve soil structure (García-Orenes et al., 2009; Costa et al., 2015; Tsozué et al., 2015) and plant nutrition (Chabanne et al., 2001; Séguy et al., 2001). Postharvest incorporation of plant residue into the soil instead of the usual burning of crop residue to stimulate the emergence of new flushes for grazing will stabilize the soil aggregates (Fasina et al., 2015). The problem of acidic pH could be solved by restoration of the cation balance through appropriate use of chemical fertilizers and liming (Verdoodt and Van Ranst, 2003; Asio et al., 2006; Fasina et al., 2015). DMC system is recommended because of the high content of coarse elements in the studied soils. The soil with high coarse elements contents must always be under cover to prevent serious erosion (Fasina et al., 2015).

Conclusion

The studied soils are very thick, characterized by clayey texture. They are slightly acid. The total nitrogen and organic carbon contents are very low and the exchange complex is dominated by calcium and magnesium. These soils are composed of two subsections: the upper subsection, largely dominated by coarse elements is classified as typic ustifluvents clayey isohyperthermic and the below one as thapto typic haplustalfs clayey isohyperthermic. The upper subsection was form by stripping of ancient soil trough erosion and accumulation of coarse elements from hillslopes by cumulization processes. The studied soils are globally subjected to problems of low organic matter content, high coarse material content and low pH for the cultivation of *Sorghum*, *Cotton*, *Soya*, *Groundnut, Maize* and *Cowpea*. These problems could be solved through introduction of DMC systems, addition of available organic substrates, restoration of the cation balance and liming.

Conflict of Interests

The authors have not declared any conflict of interests.

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