African Journal of Agricultural Research

Volume 10 Number 38 17 September 2015

ISSN 1991-637X

Academic Journals

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African Journal of Agricultural Research

Table of Contents: Volume 10 Number 38 1 7 September, 2015

ARTICLES

academicJournals

Vol. 10(38), pp. 3678-3685, 17 September, 2015
DOI: 10.5897/AJAR2015.10094
Article Number: 5F5178E55548
ISSN 1991-637X

http://www.academicjournals.org/AJAR

AfricanJournalof Agricultural Research

Full Length Research Paper

Effect of temperature on life history parameters of brown planthopper(*Nilaparvata lugens* Stal)

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Received 1 July, 2015; Accepted 10 September, 2015

Climate change, especially temperature increase, would affect insect physiology, behavior, and development as well as species distribution and abundance, evidenced by changes in the number of generations a year, increasing survival rates in winter, and the earlier appearance of some insects. Hence, an investigation was undertaken to understand effect of elevated temperature on population dynamics of Brown Planthopper (BPH). Experiments were carried out in Temperature control chamber (TCC) with five different constant temperatures (28.0, 30.0, 32.0, 34.0 and 36.0°C). Age specific life table was constructed for *Nilaparvata lugens* at various temperature regimes and it revealed that BPH took as long as 44 days to complete the generation at 28.0°C and as short as 32 days at 36.0°C. The 50% mortality occurred on 20.1 days after incubation at 28.0°C, whereas it was observed as early as on 6.3 days at 36.0°C. Pre-oviposition period decreased considerably with increasing temperatures. Total number of eggs recorded was more (233) at 30.0°C and less (116) at 36.0°C. It was also noted that the 50% fecundity in BPH was recorded on 36th day after incubation at 28.0°C, whereas it was observed on 24.3 days itself when the BPH was reared at 36.0°C. The net reproductive rate of BPH was observed to be higher at lower temperature regimes. All the growth parameters were observed to decrease at 36°C, which reveals that the temperature increase above 34 °C is detrimental to the development of BPH.

Key words: Global warming, temperature, life table, population growth, population dynamics.

INTRODUCTION

Rice is the most important food crop with more than 90% of global production occurring in tropical and semi-tropical Asia. In several Asian countries, rice provides between 50 and 70% of the energy and protein dietary requirements. The rapid acceleration of rice production over the last three decades has been a primary contributor to improvements in world food security (FAO, 2012). However, there are still 800 million people suffering from food deficits, which are further increased by the insect pest problems. Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to temperature increase up to certain limit.

Insects flourish in all climates. It is reported that among

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all the climatic factors, temperature has probably the greatest effect on insect development (Bale et al., 2002). Climate change, especially temperature increase, will affect insect physiology, behavior, and development as well as species distribution and abundance, evidenced by changes in the number of generations a year, increasing survival rates in winter, and the earlier appearance of some insects (Huang et al., 2010). The duration of the immature stages and the time required to complete the cycle from egg to adult of Diamondback moth (*Plutella xylostella*) were significantly affected by temperature (Marchioro and Foerster, 2011). With temperatures within their viable range, insects respond to higher temperature with increased rates of development, more number of generations with less time between generations. Very high temperatures reduce insect longevity (Das et al., 2011). The population dynamics of the insect pests is expected to change with elevated air temperature influenced by global warming (Kwon et al., 2012). Hence, an investigation was undertaken to understand effects of increasing temperature on population dynamics of Brown Planthopper (BPH), *Nilaparvatalugens* (Stal) which is one of the major pests and has in recent years caused extensive damage to the rice crop in Asia.

MATERIALS AND METHODS

Study area

The study was conducted at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore from 2010 to 2013. It is situated in the western zone of Tamil Nadu state at 11° N latitude and 77° E longitude and at an elevation of 427 m above the mean sea level. It is generally a dry district with an average rainfall of 720.8 mm distributed in 47 rainy days. The mean annual maximum and minimum temperatures are 31.9 and 21.4°C, respectively.

Temperature control chamber

Experiments were carried out in temperature control chamber (TCC), where temperature was controlled using fogger and a mist fan. The TCC has a total area of 25 m^2 (5 m × 5 m) with a column height of 4m and fabricated using galvanized steel pipes. The roofing and outer walls are constructed with polycarbonate material. Weather sensors for recording air temperature at any required interval are placed inside the chamber. Required levels of temperature can be maintained by giving commands through the control panel. Temperature was recorded at hourly interval by the sensor and the sensor was connected to a data logger. All these data will automatically be stored in the data logger storage module. The data logger is connected to the computer and the data recorded is downloaded to the computer by Emcon GH 485/2 software program at regular intervals. For this investigation, five different constant temperatures (28.0, 30.0, 32.0, 34.0 and 36.0°C) with three replications were considered.

Brown planthopper (BPH)

BPH was mass reared separately on the susceptible rice variety ADT 43 as outlined by Heinrichs et al. (1985). Initial population was collected from the rice fields at Paddy Breeding Station, TNAU, Coimbatore. Adults were confined on 30 day old potted plants of ADT 43 placed in wooden wire netted and glass topped oviposition cages. The insects were removed three days after oviposition and the potted plants with eggs were collected and placed in separate cages to allow the eggs for nymphal emergence. The emerged nymphs were transferred to 15 day old ADT 43 rice seedlings raised in germination trays and these in turn were placed in galvanized iron (GI) trays (62 × 47 × 15 cm) containing 5 cm depth of water. ADT 43 seedlings in trays were changed periodically and thus continuous pure cultures of planthoppers were maintained. The nymphs hatched were used for the studies.

Observations

Data on vital schedules of survival, mortality and fecundity were collected for BPH at each temperature regime. The observations on fecundity and total number of females emerged were recorded from the experiment. By using the above said observations life and fecundity tables were constructed for BPH at different temperature regimes. The methodology followed in the present investigation was adopted from Iranipour et al. (2010).

Experimental procedure for different observations

This study was carried out first by collecting the female nymphs from mass culture and these nymphs were kept separately in each insect cage (Height-0.84 m, Width - 0.77 m, Length - 0.77 m, Netted in three sides) under different temperature regimes with a month duration of paddy crop for egg laying. Date of egg laying and hatching was recorded. Egg masses with leaf sheath were kept in Petri dishes in incubator to maintain temperatures. To prevent drying, the one end of which was covered with moist cotton. Observations of these eggs were made till they hatched.

On hatching, nymphs of first stage were detected from the egg mass and collected with the help of camel hair brush and kept separately with rice stem, covered with moist cotton at one end to prevent drying. The rice stem with nymph were kept separately in test tubes of 5 × 1 cm size, plugged with cotton and all the tubes were placed under different temperature regimes. The nymphs were monitored daily and provided with fresh plant materials for their development. Mortality was recorded daily until their death.

For fecundity of female adults, freshly emerged male and female adults were kept together in an insect cage with rice seedlings for mating. The pre oviposition period was calculated by observing the first laying of eggs by female adults after the completion of nymphal stages.

Age specific life table construction

Temperature-dependent complete life tables for BPH is built by partitioning its life-cycle into distinct development stages (e.g., eggs, nymphs and adults), and by evaluating the development time and survival or mortality for each individual stage.

Survivorship (l_x)

The proportion of live births that survive to the beginning of any age interval is defined as age specific survivorship (l_x). Proportion surviving to each life stage (l_x) can be found by dividing the number of individuals living at the beginning of each age (a_x) by the initial number of eggs (a_0). The first survivorship value entered in any life table (l_0) is always 1.0; one hundred percent of the individuals are

observed at the first stage (Priyanga and Romina, 2012). Subsequent values for l_x are calculated by dividing the number of individuals observed at a given stage by the original number of individuals (a_x/a_0). Survivorship (l_x) is presented in the form of graph which can provide a visual representation of how survivorship in a population changes with age and can be used to make quick assessments of differences between populations.

Fixation of survivorship curves

The probabilities of survival in function of age of insect pest follow logistic pattern (Type III curve). Hence fixation by Doesn't Use Derivative (DUD) method (Raltson and Jenrich, 1978), using the following equation.

$$\text{Probability of Survival (y)} = \frac{1}{1 + \exp\left[\frac{x - a}{b}\right]}$$

Where, a isday in which 50% mortality recorded; b isintercept; x isage (days).

Fecundity (m_x)

Fecundity derived from the word fecund, generally refers to the ability to reproduce. In demography, fecundity is the potential reproductive capacity of an individual or population. In biology, the definition is more equivalent to fertility, or the actual reproductive rate of an organism or population, measured by the number of eggs (Fox, 1993). The eggs produced per surviving individual at each age (m_x) or individual fecundity, were measured as F_x (Total number of eggs) divided by a_x (Total number of female). The number of eggs produced per original individual at each age (l_xm_x) is an important value to consider in population studies.

Net reproductive rate

The average number of offspring that a female produces during her lifetime is called as net reproductive rate (R_o). If all females survived to the oldest possible age for that population, the net reproductive rate would simply be the sum of the average number of offspring produced by females at each age. In real populations, however, some females die at every age. The net reproductive rate for a set cohort is obtained by multiplying the proportion of females surviving to each age (l_x) by the average number of offspring produced at each age (m_x) and then adding the products from all the age groups:

$R_0 = \Sigma\, l_x m_x$

Where, Ro is Net reproductive rate, and l_xm_x is equivalent to the number of offspring (normally females) per original females produced at the age interval '*x'* starting '*i*' to '∞'

A net reproductive rate of 1.0 indicates that a population is neither increasing nor decreasing but replacing its numbers exactly. This rate indicates population stability. Any number below 1.0 indicates a decrease in population, while any number above indicates an increase.

Intrinsic rate of natural increase

The intrinsic rate of natural increase (r_m) is the actual rate of natural increase of a specific population under stable age distribution, multiplying in specific constant environmental condition where space and food are *ad libitum*. It is also known as Malthusian parameter (Birch, 1948; Carey, 1993). Very simply, this rate can be understood as the number of births minus the number of deaths per generation time. To derive this value using a life table, the natural logarithm of the net reproductive rate is divided by the mean generation time:

$$\text{Intrinsic rate of natural increase } (r_m) = \frac{\text{Net reproductive rate } (R_0)}{\text{Generation time (T)}}$$

Values above zero indicate that the population is increasing; the higher the value, the faster the growth rate. If a population has an intrinsic rate of natural increase of zero, then it is said to have stable age distribution and is neither growing nor declining in numbers.

Finite rate of increase (λ)

The finite rate of increase is the antilog of the intrinsic rate (infinitesimal) increase.

$\lambda = e^{r_m}$

It is useful to calculate the finite rate of increase as in indicates the number of times the population multiplies in a unit of time.

Mean generation time (T)

The other value needed to calculate the rate at which the population can grow is the mean generation time (*T*). Generation time is the average interval between the birth of an individual and the birth of its offspring. To determine the mean generation time of a population, the age of the individuals (*x*) is multiplied by the proportion of females surviving to that age (l_x) and the average number of offspring left by females at that age (m_x). This calculation is performed for each age group, and the values are added together and divided by the net reproductive rate (R_o) to yield the result.

$$T = \sum \left(\frac{l_x m_x}{R_o}\right)$$

Where, $R_o$isnet reproductive rate, and l_xm_x is equivalent to the number of offspring (normally females) per original females produced at the age interval '*x'* starting '*i*' to '∞'.

Doubling time of population (t)

It is the effective time necessary for doubling of population and is arrived at by the following formula

$$t = \frac{\ln 2}{r_m}$$

r_m is intrinsic rate of natural increase.

RESULTS

Development time

Age specific life table was constructed for *N. lugens*at

Table 1. Life table parameters of BPH at different temperature regimes.

Parameter	28.0°C	30.0°C	32.0°C	34.0°C	36.0°C	SED	CD (0.05)
Actual generation time (days)	44.0	44.0	40.0	33.0	31.0	1.077	2.48
Life expectancy (e_x) (days)	19.14	20.60	18.48	12.30	10.51	0.477	1.099
Pre-oviposition period	5	4	4	3	2	0.107	0.248
Age of first oviposition (day)	32	31	29	23	21	0.768	1.772
Age of 50% oviposition (day)	36	35.4	32.5	26.3	24.3	0.871	2.008
Age of last oviposition (day)	43	42	39	33	31	1.047	2.414
Age of maximum oviposition (day)	35	35	31	24	22	0.843	1.944
Length oviposition (days)	12	12	11	11	11	0.306	0.706
Net Reproductive rate (R_o) (females/female)	36.02	39.95	32.03	16.33	8.84	0.877	2.021
Intrinsic rate of natural increase (r_m) (day^{-1})	0.1011	0.1062	0.1083	0.1091	0.0935	0.002	0.006
Finite rate of increase (λ) (day^{-1})	1.1064	1.1121	1.1144	1.1153	1.0980	0.029	0.067
Mean generation time (T) (days)	35.46	34.72	32.00	25.59	23.30	0.854	1.970
Doubling time (t) (days)	6.86	6.53	6.40	6.35	7.41	0.177	0.409

Results are the means of three replications; CD, Critical difference; SED, standard deviation.

various temperature regimes and it revealed that BPH took as long as 44 days to complete the generation at 28.0°C and as short as 31 days at 36.0°C. The time taken for the development was inversely proportional to increasing temperatures (Table 1).

Survivorship (l_x)

The graph constructed by using the age specific survival of BPH indicated that it belongs to type III survivorship curve (Figure 1). The data revealed that the number of survivors decreased with the progress of time. During the early stage of the insects the curve was observed to dip steeply at higher temperature regimes as the mortality during early stage of the insect was higher at higher temperature regimes. The 50% mortality occurred on 20.1 days after incubation at 28.0°C, whereas it was observed as early as on 6.3 days at 36.0°C (Figure 1). This revealed that, BPH died earlier and faster at higher temperature regimes. Using the Doesn't Use Derivative (DUD) method, survivorship curves of different temperature were smoothened. Parameters (a and b) of the smoothened curves of different temperature regimes are given in Table 2.

Fecundity

Pre-oviposition period decreased considerably with increasing temperatures. It was observed to be five days at 28.0°C, but only 2 days at 36.0°C. There was a decrease in the oviposition period when the temperature increased. The oviposition period was 12 days at 28.0 and 30.0°C and 11 days at the remaining temperature regimes (Table 1). It indicated that the adults at higher temperature started laying their eggs earlier and completed the egg laying earlier, than the insects reared at lower temperature regimes. Age of first and last oviposition was observed to be 32^{nd} and 43^{rd} day respectively, at 28.0°C. At 36.0°C, they were recorded on 21^{st} and 31^{st} day, respectively (Table 1). The gross reproductive rate decreased at the higher temperature regimes. Total number of eggs recorded was more (233) at 30.0°C and less (116) at 36.0°C (Figure 2). It was also noted that the 50% fecundity in BPH was recorded on 36^{th} day after incubation at 28.0°C, whereas it was observed on 24.3 days itself when the BPH was reared at 36.0°C (Figure 3).

Net reproductive rate (R_o)

The net reproductive rate of BPH was observed to be higher at lower temperature regimes (28.0 and 30.0°C) of the experiment and lesser at higher temperature regimes. The highest R_o of 39.95 females/female was recorded at 30.0°C followed by 36.02 females/female at 28.0°C and the lowest R_o of 8.84 female/female was recorded at 36.0°C followed by 16.33 females/female at 34.0°C (Table 1).

Population growth parameters

Intrinsic rate of natural increase (r_m)

The intrinsic rate of natural increase (r_m) increased with increasing temperatures. It was 0.1091/day at 34.0°C, whereas it was 0.1011/day at 28.0°C. However, the increase in r_m has a turnaround after 34.0°C and hence at 36.0°C, r_m has been reduced to 0.09353/day (Table 1).

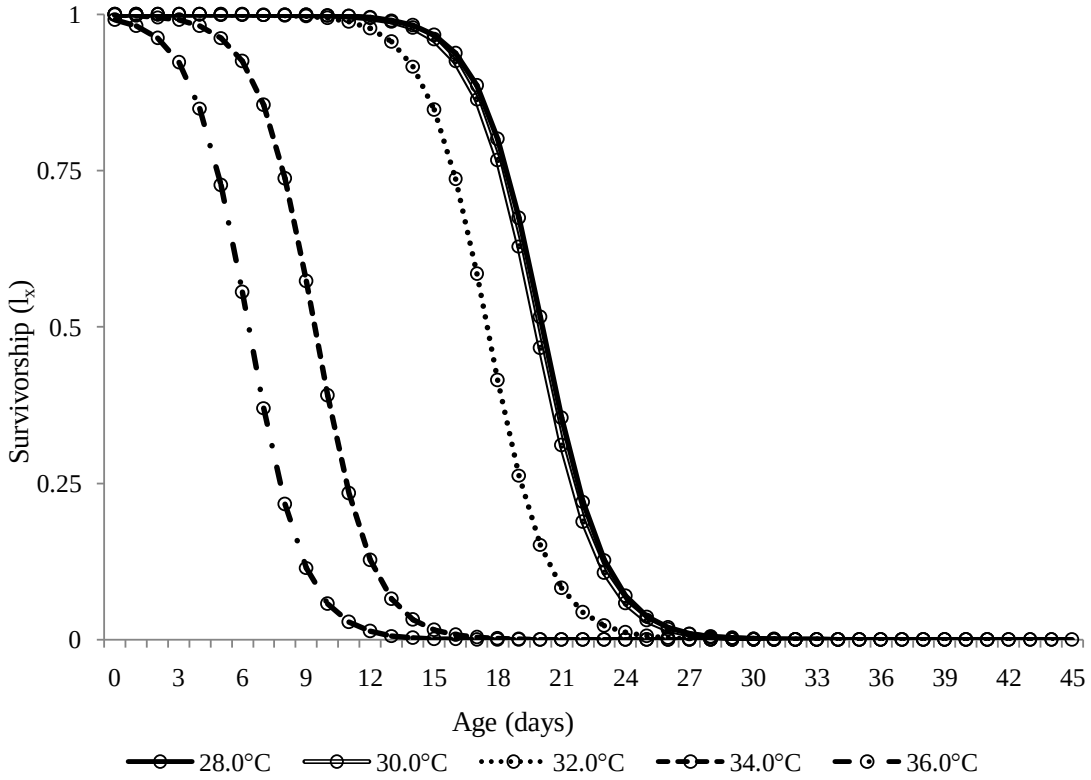

Figure 1. Age specific survivorship of BPH at different temperature regimes.

Table 2. Response of survival of BPH at different temperature regimes.

Temperature regimes	'a' (50% mortality)	'b' (Intercept)	r^2 Value
28.0°C	20.1	1.510	0.831
30.0°C	19.8	1.510	0.829
32.0°C	17.5	1.456	0.866
34.0°C	9.4	1.351	0.907
36.0°C	6.3	1.325	0.893
SED	0.4622		
CD (0.05)	1.0659		

Results are the mean of three replications. r^2, Regression coefficient.

Finite rate of increase (λ)

The finite rate of increase (λ) increased with increasing temperatures. It was 1.1153/day at 34.0°C, whereas it was 1.1064/day at 28.0°C. Even though, the **λ** was increased with increasing temperature, a turnaround was noticed in **λ** after 34.0°C and hence at 36.0°C **λ** has been reduced to 1.09804/day (Table 1).

Doubling time (t)

The doublingtime required by BPH to double its population decreased with increasing temperatures. BPH took as long as 6.86 days for doubling the population at 28.0°C, whereas it took only 6.35 days at 34.0°C. However, the decrease in doubling time has a shift after 34.0°C and hence it has been increased to 7.41 days at 36.0°C (Table 1).

Mean generation time (T)

The mean generation time was observed to be decreased with increasing temperatures. The BPH took 35.46 daysto complete the generation at 28.0°C,

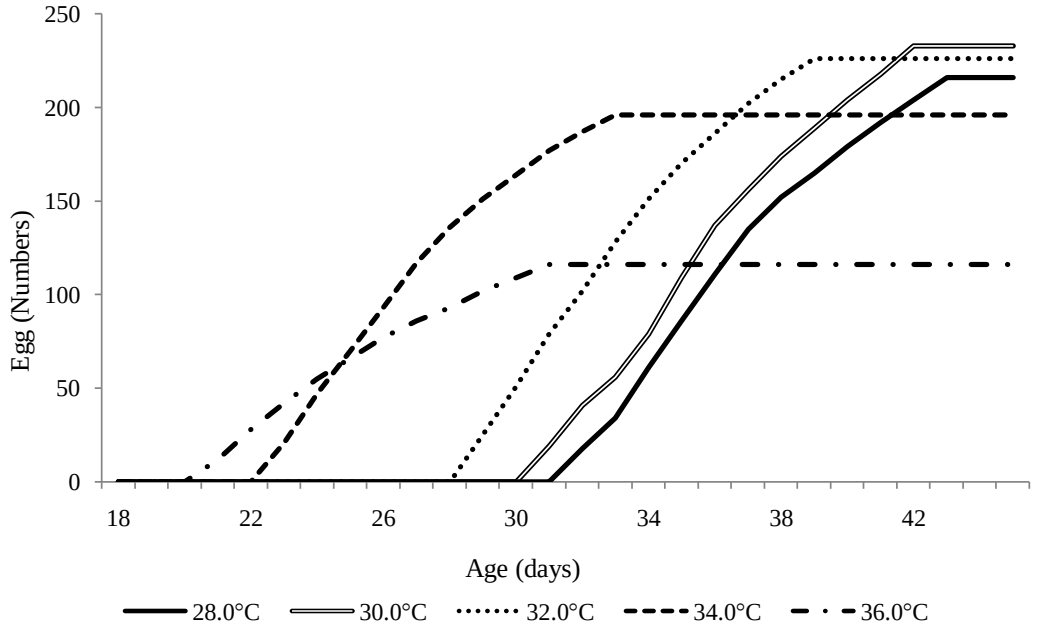

Figure 2. Cumulative fecundity of BPH at different temperature regimes.

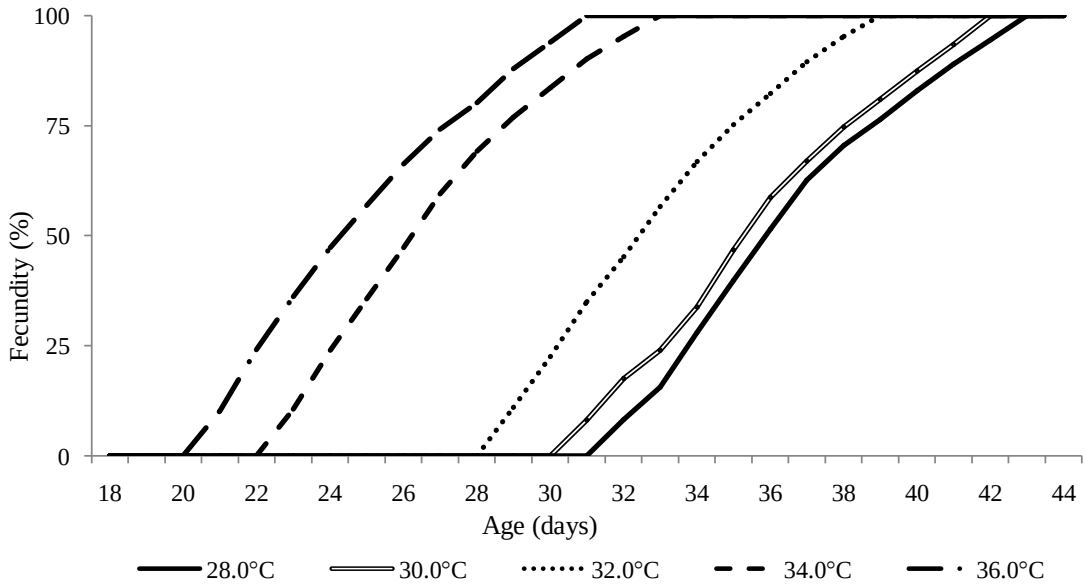

Figure 3. Percent cumulative fecundity of BPH at different temperature regimes.

whereas it took only 23.30 days at 36.0°C (Table 1).

DISCUSSION

Generation time

The mean generation time of BPH was longer at lower temperature regimes and was shorter at higher temperature regimes. Temperature is an important factor, which exerts a profound influence on the development of insects. Development time is mostly dependant on the metabolic rate of the insects. The metabolic rate of insects depends on their body temperature. The temperature inside the insect's body achieves equal or close values to the ambient temperature. Hence, the metabolic rate of insects increases linearly with ambient temperature and results in faster development at higher

temperature (Grodzicki and Walentynowicz, 2011).

Survivorship (l_x)

Survivorship (l_x) decreased with increasing temperature. The time taken for 50% mortality also decreased with increasing temperatures. It indicated that the most of the insects reared under higher temperature regimes died faster and earlier as they were not able to tolerate the higher temperature. When the insects happened to live in higher temperature regimes, respiration increases up to a critical upper limit. After this upper limit, respiration decreases. Hence, higher mortality in insects reared under higher temperature thus explained as the result of decreased respiration when the temperature increased. Yamaguchi et al. (2001) reported that the potential rate of insect population is strongly dependent on temperature, and their survival is impaired at temperature extremes. It was also reported by Kuo et al. (2006) that only 12.5% of nymphs survived when the temperature increased from 10 to 35°C in *T. nigriabdominalis.*

Fecundity

The longer pre-oviposition period at lower temperature may be attributed to the lower metabolic activity at lower temperature regimes (Didonet et al., 1996). Insects need to accumulate more energy to maintain the vital functions. Hence, at lower temperature pre-oviposition period was observed to be more. However, the pre-oviposition period decreased when the insects happened to live at higher temperature regimes as the metabolic rate increased. Similar results were reported by Heong et al. (1995), Son and Lewis (2005) and Ju et al. (2011).

The number of eggs laid by BPH was observed to be lowest at higher temperature regimes. Hence, higher temperature regimes of 34.0 and 36.0°C were not suitable for egg laying and egg growth and development by BPH adults as it reduces fertility and viability of eggs. Xiaoping et al. (1992) also reported that the number of eggs laid by BPH decreased rapidly as the temperature increased.

Net reproductive rate (R_o)

The R_o observed to be decreased at the higher temperature regimes. Similar results were reported by Sataret al. (2008) in cotton aphids. The results revealed that the reproduction rates of the green peach aphid were in general higher at temperatures between 20.0 and 27.5°C (79.29 - 85.33 aphids aphid^{-1}) and decreased with an increase in temperature to 5.00 aphids aphid^{-1} at 30.0°C. The lowest R_o value at higher temperature could be explained due to the heavy mortality of the immature life stages and also adults between emergence and peak oviposition (Amiri et al., 2010).

Population growth parameters

Intrinsic rate of natural increase, finite rate of increase and doubling time are considered as population growth parameters. Population demographic parameters are important in measurement of population growth capacity of an insect under specified conditions. Iranipour et al. (2003) reported that, developmental time decreased as temperature increased. This is the primary reason why the intrinsic rate of natural increase was observed to increase with temperature in the present study. As pointed out by Lewontin (1965) and Dent and Walton (1997), r_m is affected more by age of first reproduction than by fecundity. Delayed development causes a delay in onset of reproduction and a parallel increase in generation time.

Earlier the eggs are produced; more will be their contribution to the value of r_m (Birch, 1948). Thus, the highest r_m value might be attributed to the earlier oviposition at higher temperature regimes for all the pests. However, the experiment results also revealed that the increase in r_m was not continuous as it reduced at 36.0°C. Similar results were also reported by Kuo et al. (2006), De Conti et al. (2010) and Manikandan et al. (2014). The lowest r_m value at 36.0°C could be explained to the heavy mortality at the highest temperature regime.

Conclusion

The results of the experiments revealed that, population growth parameters are increasing with increasing temperature. However, the increase in population growth parameters had a turnaround at 34.0°C and it started decreasing after 34.0°C. All the growth parameters were observed to decrease at 36.0°C, which reveals that the temperature increase above 34.0°C is detrimental to the development of BPH. If the global warming continuous at the present phase, it will influence the BPH negatively and the population growth would be severely affected in the near future.

Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(38), pp. 3686-3695, 17 September, 2015
DOI: 10.5897/AJAR2015.9984
Article Number: 7D2ED6C55553
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effect of fungicide application times in the control management of leaf foliar diseases in maize

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Received 8 June, 2015; Accepted 21 August, 2015

This study aimed to evaluate the effect of fungicide trifloxystrobin (200 g/L 20% m/v) + tebuconazole (100 g/L 10% m/v) at different phenological stages in controlling southern rust and Cercospora leaf spot in the maize crop and on its productivity. This work was carried out in 2013, Ertel farm, located in the city of Toledo – PR of Brasil. The experimental design was a randomized complete block in a factorial (2x4+1) with four replications. The treatments consisted of evaluating two diseases, Southern Rust and Cercospora leaf spot, and four phenological stages of fungicide application (V8, V10, VT and R1 of maize) with the presence of a control. The authors evaluated the disease incidence and severity, the Area Under Disease Progress Curve (AUDPC) and the fungicide control efficiency for foliar diseases were observed. In addition to this, some agronomic variables were also evaluated: plant height, ear insertion height, stem diameter, average diameter of ear, ear length, number of rows per ear, number of grains per row, number of grains per ear, thousand grain weight and productivity. The results showed no significant statistical difference for the variables evaluated, except for plant height. Based on these results, it can be concluded that the mixture of triazole with estrobirulina is feasible to control the severity of these diseases in maize, though it was not observed any statistical difference in the different treatments in relation to the average productivity. It is worth mentioning that the use of fungicide tends to provide greater sanity to plants and consequently it improves production rates. In general, the application of the fungicide in the pre-anthesis stage (VT) tends to exhibit better responses.

Key words: *Zea mays* L., *Puccinia polysora, Cercospora zeae-maydis*.

INTRODUCTION

The maize crop has wide geographic reach, developing in various soil and climatic conditions; therefore, being exposed to various biotic and abiotic stresses, making it difficult to exploit the maximum genetic potential for grain yield, regardless of the adopted production system (Brito et al., 2013). Thus, considering the productive potential of

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the crop, the losses of income are linked to the lack of employment of better farming techniques and agricultural technology, also added to the unfavorable weather conditions in some regions and the emergence of diseases that limit the increase in productivity (Trentin, 2007).

Especially from the 90s in Brazil, the increase in the incidence and severity of some foliar fungal diseases was observed, causing sensitive qualitative and quantitative reduction in the production of maize (Pinto, 2004). This increase has been attributed to several factors, such as successive maize crops, monoculture, irrigation without technical criteria and direct seeding system in the absence of crop rotation (Fernandes, 2000). Among the diseases with major potential reduction in the production of maize are the common rust (*Puccinia sorghi*), southern rust (*Puccinia polysora*) and Cercospora leaf spot (*Cercospora zeae-maydis*) (Juliatti et al., 2007).

The southern rust is currently one of the most important diseases of maize in Brazil, and it is considered the most destructive of rust occurring in this crop (Oliveira et al., 2004). The symptoms are characterized by the presence of circular and oval shape pustules, light brown color, mainly distributed in the upper face of the sheet (Kimati et al., 2005). The incidence and severity of the disease are favored by conditions of high humidity and relative temperatures between 23 and 28ºC (Oliveira et al., 2004). Economic damage of up to 65% has been observed in experimental areas with incidence of disease history (Pereira et al., 2005). In off-season conditions with well distributed rainfall and susceptible hybrid cultivation, losses can be really significant (Machado and Cassetari Neto, 2007).

Another foliar disease of great importance in Brazil is Cercospora leaf spot, both for damages, for its wide distribution, being found in all producing regions (Brito et al., 2008). Symptoms of the disease are characterized by elongated and irregular lesions that usually accompany the direction of the ribs. These spots are gray in color, bronze or brown and may have reddish or purple edges (Brito et al., 2007). The incidence and severity increase in conditions of high relative humidity (90%) and diurnal temperature ranging from moderate to high (22 to 32°C) as well as cold nights, with dew formation (Casella, 2006). This disease was responsible for the discontinuation of the use of various commercial hybrids susceptible, high yield potential, which came to achieve grain yield reduction levels of up to 40% (Souza, 2005).

The use of the triazole group fungicides and their mixtures with strobilurin may be an effective method to control foliar diseases and maintaining crop health, when combined with the right time application, thus enabling increased crop productivity (Casa et al., 2004). The timing of fungicide application will depend on these diseases during the crop cycle and the level of response of hybrids (Silva and Schipanski, 2006).

Bussolaro et al. (2009) evaluating the effectiveness of fungicides to control diseases at different stages of maize, found that the use of fungicides led to an increase in production compared to the control. Lago and Nunes (2008), report that fungicide in maize did not differ significantly, but had productivity gains around 195 kg ha^{-1}.

The application of these products is often performed in the pre-bolting stage of maize. However, applications in stages just before the pre-anthesis, as in V10, can contribute to inhibit the germination of the initial inoculum of pathogens and ensure that the crop is protected and successful on its production.

Taking into consideration the aforementioned information, this study aimed to evaluate the effect of fungicide trifloxystrobin + tebuconazole in different growth stages on the control of southern rust and Cercospora leaf spot in maize and on its productivity.

MATERIALS AND METHODS

An experiment was carried out in 2013, Ertel farm, located in the city of Toledo - PR, situated in the geographical coordinates 24° 42 '49' 'S, 53 44' 35 '' W and altitude of 574 m. Based on the climatic classification of Köppen, the climate is humid subtropical mesothermal, with hot summers without dry seasons and with few frosts. The average temperatures of the warmest month is above 22ºC and the coldest month is less than 18°C (Iapar, 2011). The soil of the farm was classified as Dystroferric Red Latosol, gently rolling and clayey texture terrain (Embrapa, 2012).

The experimental design was a randomized complete block in a factorial (2×4+1) with four replications. Treatments consisted of evaluating two diseases, Southern Rust and Cercospora leaf spot and four phenological stages of application of fungicide (V8, V10, VT and R1 of maize), in the presence of a control.

The size of each plot was 3.5 m wide and 6 meters long, totaling 18.9 m². The plots were composed of seven lines of maize, which is sampled with the five lines in the middle, having a useful area of 9 m².

The treatments were: T1 - control (without any chemical control); T2 - fungicide application at the V8 stage (8 fully developed leaves); T3 - application in the V10 stage (10 fully developed leaves); T4 - VT application (pre-anthesis); T5 - application in the reproductive stage (flowering).

The hybrid AG 9010 YG is considered super-young, having modern plant architecture, with erect leaves and resistance to breakage. Therefore allows the dense planting, in other words, the reduced spacing between lines, exploring the environmental and agronomic interactions, which also enables increased plant population. In the off-season crop, the AG 9010 YG flourish before possible droughts or frosts, ensuring the best results (Agroceres, 2013).

During the work it was necessary to perform some cultural practices such as drying of the previous crop, soil analysis, maize sowing, base fertilization and coverage, weed control and application of fungicide. To facilitate the sowing and early development of maize, desiccation was performed with glyphosate (potassium salt of N- (phosphonomethyl)) glycine at the recommended dosage, immediately after soybean harvest. Before the deployment, chemical analyses of soil were carried out, to subsequently fix it with 250 kg ha^{-1} NPK 08-20-20 formulation. The seeds were treated with Imidacloprid + Thiodicarb in the recommended dosage by the manufacturer Cropstar and sown on 05 February 013. For the topdressing was applied ammonium

Table 1. Grade scale used for the evaluation of the severity of Polissora rust and Cercosporiose of maize (Toledo – PR, 2015).

Scale	Infection level
1	No symptoms
2	0,5% the injured leaf area
3	10% the injured leaf area
4	30% the injured leaf area
5	50% the injured leaf area
6	70% the injured leaf area
7	80% the injured leaf area
8	90% the injured leaf area
9	100% the injured leaf area

Source: Agroceres (1996).

sulfate at a dose of 75 kg ha^{-1} in the V4 stage. The pest control was not necessary due to the hybrid resistance and also for not achieving levels of economic damage. The weeds were chemically controlled with post-emergent herbicides, such as Atrazine (5.0 L ha^{-1}) and Nicosulfuron (50 g ha^{-1}) in the V4 stage of the crop. For the experiment, the application of the fungicide trifloxystrobin + tebuconazole (60 + 120 g ai ha^{-1}) + vegetable oil was conducted, (250 mL 100 L $water^{-1}$) using a backpack sprayer of twenty liters with approximately 124 L ha^{-1} of flow and nozzle array for better coverage of the area applied.

The evaluation of the disease was performed at 15 days after each application in different phenological stages and follow fortnightly until the last application. For this, 15 plants were chosen at random from the useful area, which were demarcated, and evaluated for incidence and severity of Southern Rust and Cercospora leaf spot in the crop as its appearance. Thus, there were four evaluations in the experiment.

For the disease incidence, we counted the number of plants or parts of plants with symptoms of the disease in the randomly selected plants per plot. On the other hand, the severity evaluation was carried out using a score scale adapted from Azevedo (1997) described in Table 1.

The severity values obtained for each treatment were processed in proportion of disease to be plotted versus time and expressed in disease progress curve, in order to represent the outbreak in each study. With the severity data in each assessment, the author calculated for each plot, the values of Area Under Disease Progress Curve (AUDPC), using the equation quoted by Shaner and Finney (1977):

$$AUDPC = \sum^{n}_{i=1}(Yi+1 + Yi)/2] * [(Ti+1 - Ti)]$$

Where: n- is the number of observations; Yi - is the disease severity in the "i"-th observation and Ti - is the time in days in the "i"-th observation.

For the average severity, notes of each treatment (each assessment) were used and the averages between these values were carried out. The efficiency of control was obtained based on the average grade of severity of each treatment, stipulated by percentage calculations (%) of efficiency obtained.

To determine the effect of fungicide in the maize, it was necessary to evaluate the agronomic variables such as plant height, height of ear insertion, stem diameter, average ear diameter, ear length, number of grain rows , number of grains per row, number of grains per ear, thousand grain weight and productivity.

The data were submitted to analysis of variance and the treatment means when significant were compared by Tukey test at 5% significance, using the SASM-AGRI software (Canteri, et al., 2001).

RESULTS AND DISCUSSION

Incidence, severity, AUDPC and control efficiency of Southern Rust

Regarding the incidence of southern rust, it is observed that there was no significant difference between the different treatments evaluated ($p>0.05$); however, it should be noted that the highest percentages of infected plants of the disease are observed in VT treatment (Table 2). As for the severity score, significance is noted between treatments ($p<0.05$) and the control treatment having the largest average, demonstrating that the southern rust is one of the diseases that most attack the off-season maize crop (Table 2). Therefore, it is interesting to carry out a chemical control to minimize losses in productivity due to high infestations.

Such data can be explained by the fact that, at the time of trial deployment, the weather conditions were adequate for the disease occurrence (Figure 1). The disease was favored by high humidity conditions and relative temperatures in the range of 23 to 28°C, and in areas of altitude between 600 and 800 m, having no limitation for its development.

However, when considering the AUDPC, treatments with chemical control showed lower values when compared to the control, demonstrating the difference in control efficiency (Table 2). This response can be explained by the fact that the product applied at recommended doses has healing and anti-sporulation properties in trifloxistrobina (Estrobirulina) and tebuconazole (Triazole). Although the disease has emerged in the area of the experiment, the control efficiency was even higher in the treated plots compared

Table 2. Average values of percentage of plants of the experimental area to attack the disease (incidence), medium severity, area under the disease progress curve (AUDPC) for Polissora rust of maize and percentage of control efficiency (Toledo – PR, 2015).

Treatment	Incidence	Severity	AUDPC	Control efficiency (%)
Control	80.8[a]	1.98[b]	36.4	66.5
V8	49.6[a]	0.51[a]	18.3	93.4
V10	72.5[a]	0.75[a]	20.4	87.7
VT	90.4[a]	0.96[ab]	24.88	84.5
R1	79.5[a]	1.01[ab]	28.1	82.2
Average	74.6[ns]	1.04	21.61	84.5
CV (%)	37.54	52.72		
F	1.20	4.05**		

Averages followed by the same letter in the column, do not differ significantly at 5% in the Tukey test. [ns]: non-significant; *: significant at 5%.

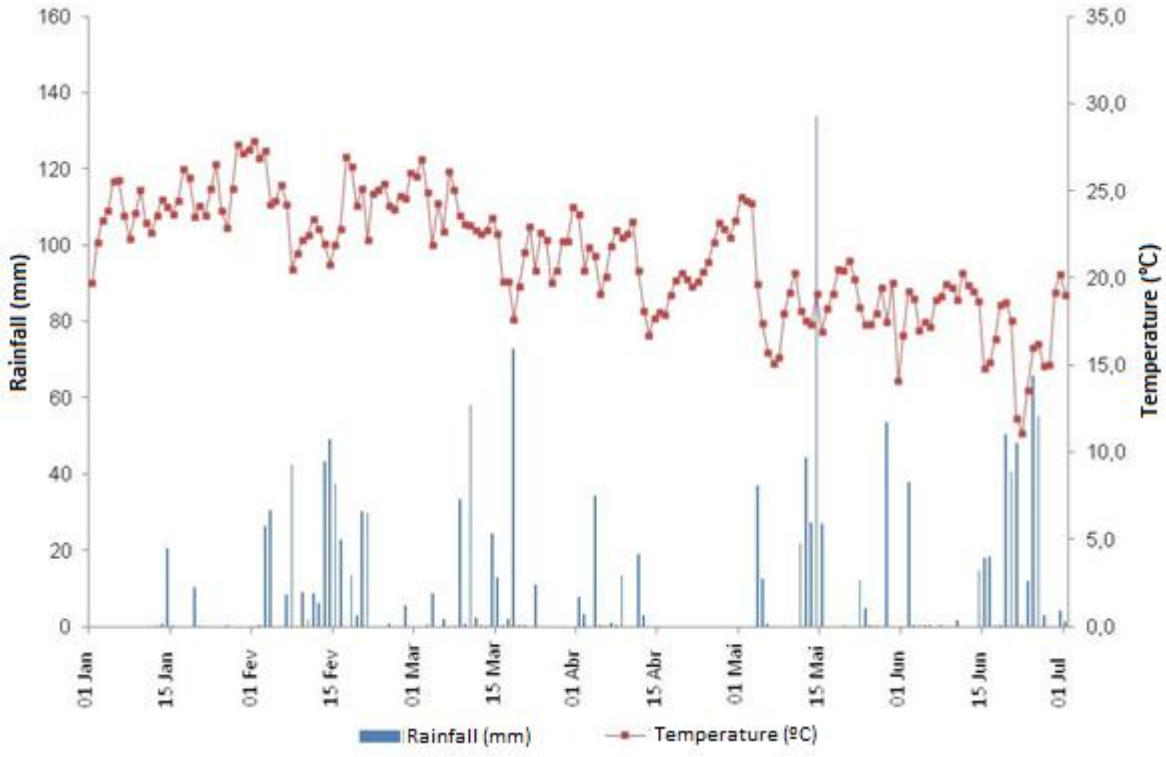

Figure 1. Weather conditions (Rainfall and Temperature) of the experimental period in 2013. Toledo – PR, 2015. Source: Weather Station from PUCPR – Campus Toledo.

to the control.

The data are in agreement with those obtained by Duarte et al. (2009), who studied the efficacy of different fungicides on maize crop in two application times (49 and 79 days after sowing). The authors found that the fungicide epoxiconazole + pyraclostrobin was effective in controlling diseases in maize, with 60% of efficiency compared to the control.

The association of estrobirulina and triazoles reduced the number of pustules or the level of severity of this in relation to the control. The same result was observed by Galli et al. (1993), wherein the application of tebuconazole (triazole), unassociated with strobilurin in doses of 0.75 kg ha^{-1} of active principle and 1.0 kg ha^{-1} of active principle, reduced significantly the number of pustules of *Puccinia polysora* in the leaves.

The efficiency of fungicides when compared with the control may be assigned the fungicidal action against the pathogen, along with the residual effect of it (Duarte et al., 2009), which may have contributed to the observed results.

Among the treatments with fungicides, the one with the highest highlight was the treatment at the V8 stage with values of 49.6; 0.51; 18.3 and 93.4 for the incidence, severity, AUDPC and control efficiency, respectively (Table 2). Picinini and Fernandes (2003) when performing treatments with fungicides had satisfactory results, having efficient control of powdery mildew and rust in relation to the control, in the wheat crop.

Duarte et al. (2009) point out that, currently, the use of fungicides in a mixture as triazoles and strobilurins or benzimidazole in agricultural production systems, is of great importance in the production of maize.

The treatments V8 and V10 obtained the greatest efficiencies in the control of *P. polissora*, reaching 93.4 and 87.7% of control, respectively (Table 2). Such highlighting cannot be observed in the other treatments, considering that clarity as the product was applied, the disease was already installed in the area.

This fact can be explained by Fancelli (1999), which states that for maize manifest its high biomass production capacity, it is necessary that the plant have adequate interception structure of available radiation, which can only be obtained when evidenced by at least 85 to 90% of its maximum leaf area.

Brandao (2002) and Appelt (2003) works showed that the effective period of the fungicide for triazoles and strobilurine is 30 days, not having the product effect on the disease after this period. The ideal to have more control in the critical period of the crop would be an application in the VT stage, as well as in the present experiment that showed better productivity results.

Incidence, severity, AUDPC and Cercospora leaf spot control efficiency

In the incidence of Cercospora leaf spot assessment, it is observed that there were significant differences between the different treatments evaluated ($p<0.05$). It is worth noting that the highest percentages of infected plants, in other words, those with highest grades of the disease are observed in the control treatments and R1, with averages of 48.5 and 39.75, respectively (Table 3).

Cercospora leaf spot severity also showed significant differences between the different treatments evaluated ($p<0.05$) (Table 3). For this parameter, the control treatment showed the highest rate of the disease (0.99); however, it was similar to R1 (0.88) treatment. This demonstrates that, Cercospora leaf spot is a major disease of maize crop in several countries, highlighting the importance of chemical control to minimize losses in productivity due to high infestations.

These results obtained in this study can be explained in the same way as for the southern rust disease, bearing in mind that at the time of the work deployment, the weather conditions were favorable for the development of the disease (Figure 1). These weather conditions had temperatures between 23 to 28°C, long periods of high relative humidity and altitude regions between 600 and 800 m, having no limitation for its development.

By observing AUDPC in the different treatments, it can be verified that the treatments in which it was carried out the application of fungicides, the values were lower compared to the control; thus demonstrating the efficiency of chemical control (Table 3). These results can be explained by the healing and anti-sporulative properties of the product when applied at recommended doses of the active ingredients trifloxystrobin (Estrobirulina) and tebuconazole (Triazole).

Thereby, the association of estrobirulina and triazoles was effective in controlling the disease or reducing the level of severity of this in relation to the control. The same result was observed by Horst and contributors (2003), who report that the fungicides azoxystrobin, propiconazole, flutriafol, trifloxystrobin + propiconazole, tebuconazole and pyraclostrobin + epoxiconazole reduced significantly the severity of cercospora leaf spot.

Table 3 presents treatments with V8, V10 and VT achieved the greatest efficiencies for Cercospora leaf spot control, all of them reaching 98% of control. These responses were not observed in the other treatments (control and R1), bearing in mind that as far as the product was applied, the disease was already installed in the area.

Ammermann et al. (2000) report that infections caused by fungi impair crops efficiency, by reducing the tissue area to inhibit photosynthetic activity and translocation of assimilates, presenting a strong impact on the physiological processes of the plant and this fact was observed in this study.

Supporting this study, Koguishi (2011) when evaluating Cercospora leaf spot control at different growth stages, noted that, as in the present work, the application for R2 could not handle Cercospora leaf spot, getting similar severity to the control. This response was due to the late application, period in which the disease was already with high severity, with no significant effect of fungicide on the disease.

The results agree with those obtained by Barros and Lourenção (2009), which studied different fungicides and application times in the off-season maize in Mato Grosso do Sul and found that Cercospora leaf spot control with spraying in pre-bolting (stage VT) was more effective, independently of the fungicide used.

Maize production components

According to the obtained results, it is observed that there

Table 3. Average values of percentage of plants of the experimental area to attack the disease (incidence), medium severity, area under the disease progress curve (AUDPC) for Cercosporiose of maize and percentage of control efficiency (Toledo – PR, 2015).

Treatment	Incidence	Severity	AUDPC	Control efficiency (%)
Control	48.5[c]	0.99[b]	33.86	83
V8	5.28[a]	0.08[a]	3.60	98
V10	7.5b[a]	0.14[a]	4.25	98
VT	10[ba]	0.18[a]	2.12	98
R1	39.75[b]	0.88[ab]	30.82	84
Average	22.2	0.454	14.93	92
CV (%)	69.6	85.9	-	-
F	6.92	5.11**	-	-

Averages followed by the same letter in the column, do not differ significantly at 5% in the Tukey test. [ns]: non-significant; *: significant at 5%.

Table 4. Summary of the variance analysis for the production components: ear insertion height (IEA), stem diameter (DC), ear length (EL), number of rows per ear (NRE), number of grains per row (NGR) in the hybrid AG 9010 plants due to the chemical control application at different growth stages in maize (Toledo – PR, 2015).

Treatment	IEA (cm)	DC (mm)	EL (cm)	NRE	NGR
Control	80.30[a]	23.39[a]	17.95[a]	14.5[a]	36.2[a]
V8	81.22[a]	23.93[a]	18.58[a]	15.1[a]	35.9[a]
V10	82.14[a]	22.00[a]	18.66[a]	14.7[a]	37.0[a]
VT	83.27[a]	24.36[a]	19.29[a]	14.4[a]	37.5[a]
R1	78.08[a]	23.41[a]	18.48[a]	14.6[a]	35.6[a]
Average	81	23.58	18.59	14.68	36.50
CV (%)	4.12	3.82	3.63	2.5	3.6
F	1.39 [ns]	1.74 [ns]	1.99[ns]	2.04[ns]	1.32[ns]

Averages followed by the same letter in the column, do not differ significantly at 5% in the Tukey test. [ns]: non-significant; *: significant at 5%.

was no significance ($p<0.05$) for the production components: ear insertion height (EIH), stem diameter (SD), ear length (EL) number of rows per ear (NRE), and number of grains per row (NGR) (Table 4).

For EIH, it can be noted that when the application was given in the early stages of the crop, better answers were obtained; however, having no significant difference between the different treatments ($p>0.05$) (Table 4). This result can be explained by Ritchie et al. (2003), which reported that the application does not influence this variable, since the morphological characters tested are initially set in the crop cycle.

The values obtained in this experiment are considered low when compared to the ones in the literature. An example is the work of Vilela et al. (2012), which present values around 1.30 m, when various hybrids were studied together.

The factors that may explain the low ears insertion are the population distribution, the characteristic of the hybrid (it has lower size and is super-young) and even the planting season, because in off-season conditions, maize cannot find its ideal conditions for development as temperature, solar radiation and relative humidity.

Sangoi et al. (2001) report that the shortest distance between the ground and the ear insertion point is desirable, because it contributes to better balance of the plant while minimizing disruption of thatch, especially at higher populations.

When it comes to stem diameter SD (Table 4), there is positive behavior for the treatment means in V8 and VT (23.93 and 24.36 mm), but not differing from the other treatments ($p>0.05$). The results can already be explained by the fact that the definition of the stem diameter occurs in the early stages of crop, as reported by Fancelli and Dourado Neto (2000). The authors state that this variable is also related with the support of the plant, acting as a soluble solids storage structure that will later be used in the formation of the grains.

Brachtvogel (2008) also states that the stem diameter is defined in the early stages of crop, having as one of

Table 5. Summary of the variance analysis for the production components: height of plant (HP) number of grains per ear (NGE) middle ear diameter (MED), thousand grain weight (TGW) and productivity (P) in the hybrid AG 9010 plants due to the chemical control application at different growth stages in maize (Toledo – PR, 2015).

Treatment	HP (cm)	NGE	MED (mm)	TGW (g)	P (kg ha^{-1})
Control	2.13^{ab}	527.2^{a}	45.93^{a}	350.91^{a}	7.399.01^{a}
V8	2.17^{a}	543.4^{a}	47.38^{a}	390.87^{a}	7.446.43^{a}
V10	2.13^{ab}	544.7^{a}	46.75^{a}	352.51^{a}	7.936.37^{a}
VT	2.10^{ab}	540.0^{a}	47.06^{a}	383.83^{a}	8.208.81^{a}
R1	2.06^{b}	522.3^{a}	46.64^{a}	355.64^{a}	8.030.08^{a}
Average	2.12	535.53	46.75	366.75	7.804.14
CV (%)	1.94	4.53	2.37	7.24	6.23
F	3.60**	0.70^{ns}	0.96^{ns}	2.06 ^{ns}	2.22^{ns}

Averages followed by the same letter in the column, do not differ significantly at 5% in the Tukey test. ^{ns}: non-significant; *: significant at 5%.

the preponderant factors the population increase. Thereby, if the goal is to increase the stem diameter, then it would be necessary an application at the early stages of crop, favoring this variable.

For the EL's behavior, it is observed that there was no significant difference between treatments ($p>0.05$), but it can be seen that the application of chemical control promotes a greater length compared to the control, which presented the lowest value for this observation (Table 4). Corroborating the results of the work, Ramos et al. (2012) found in their experiment with fungicide application in maize, that there was no difference between treatments for this variable.

Magalhães et al. (1994) report that the ear size is defined in the V12 stage, this can be one of the explanations for which the treatments were not significantly different, since the applications after this stage would have more influence on this variable. As for the NRE, it is observed that the application is not influenced in great number in this variable (Table 4), since the higher average was obtained for V8 treatment, but did not differ from other groups ($p>0.05$).

Similar results were found by Vilela et al. (2012) when studying the agronomic performance of maize hybrids according to foliar application of fungicides, they have reported no statistical difference for this variable. Fancelli and Dourado Neto (2004) report that the number of grain rows on the ear is defined in the vegetative phase, which in some cases may warrant early application of fungicides. This fact can be justified with productivity increase by the increase in number of rows have been higher in V8 and V10 stages.

In Table 4, the NGR tends to be higher in V10 and VT stages; however there was no significant difference between treatments ($p>0.05$). Nevertheless, you can notice that the fungicide application favored the best average when compared to the control. Similar results were observed by Vilela et al. (2012) when studying the application of fungicide (pyraclostrobin + epoxiconazole and azoxystrobin + cyproconazole) belonging to the chemical group of triazoles and strobilurins in maize crop in the pre-bolting stage.

Balbinot et al. (2005) observed different results from the ones presented in this paper. These authors report that one of the most important yield components for maize is the number of grains per row. The authors point out that, besides the fungicide prevent and control diseases, it would also be related to the increase of grains per row, and consequently would influence on productivity. Magalhães et al. (1994) report that the number of grains per row on the maize crop is established around the V17 stage (predecessor R1 stage). Thus, the authors report that the treatments later applied to that stage, do not influence this variable, explaining the results presented. One of the fungicide application forms to influence positively this variable would be an earlier application, but it cannot be positioned after bolting.

According to the results, it is observed that there was significance ($p<0.05$) only for plant height (PH) according to the fungicide application at different growth stages on off-season maize. For other production components, number of grains per ear (NGE), the average diameter of the ear (ADE), the thousand grains weight (TGW) and productivity no significant differences were observed ($p>0.05$) (Table 5).

In the PH variable, it can be observed an average downward trend in relation to the advancement of application times, reaching its highest value in V8 and its lowest in R1, 2.17 and 2.06 cm, respectively (Table 5). Different results were found by Ceccon et al. (2007), in which plant height had no significant effect with the application of fungicides in the off-season maize crop. This may have occurred due to the different times of applications. In the treatments that the application proceeded in the early stages, there was a further growth due to maintenance for longer periods of active leaf area; thus allowing further growth of plants. Moreover, when applied later, this behavior was not observed due to pathogen attack in plants, resulting in reduction in size, or

population increased. Furthermore, because of difficulties encountered during the period of the off-season, the maize did not have the ideal conditions for its best development.

Campos et al. (2010) state that the best results in relation to plant height depend on the environmental conditions of the experiment site and may be influenced by temperature, humidity and solar radiation, favoring greater plant growth. This factor can be observed in this experiment. Currently, the smallest height of the plant is one of the changes involved in the architecture of maize plants (Almeida et al., 2000). This is a desirable feature of maize producers because it allows the crop in higher density and higher mechanical harvesting efficiency, while it reduces problems relating to breakage and bedding plants before the harvest point, usually evidenced high-growing plants (Mundstock, 1977).

According to Sangoi et al. (2000) and Sangoi (2001), in general, the plant height is greater, the larger is the population of plants, due to the effect of intra-specific competition for light, with consequent stimulation of apical dominance of the plants. In addition to this, Kappes (2010) reports that the smallest plant height has allowed greater light penetration in the canopy (even with high leaf area index) and decreased intraspecific competition for natural resources in high plant populations.

The data obtained for NGE (Table 5) indicate that there was no significant difference for this variable ($p>0.05$). Agreeing with the results presented, Ramos (2012) reported that in the fungicide application in hybrid 30F53 there was no difference between treatments for the variable number of grains per ear. Magalhães et al. (1994) reported that the number of grains per ear is defined in the V12 stage as part of the treatments used in the experiment were quoted after the aforementioned stage, a fact that eventually contributed to that there was no difference between the treatments.

For the variable Ear Diameter, data were not statistically different ($p>0.05$), but it is possible to see that the applications of chemical control in different stages favored a rapid increase of this variable in relation to the control (Table 5). Different results were reported by Kappes et al. (2009), which studied the off-season maize crop, verified that there was a difference between the fungicide application timing in this culture, along with the application of nitrogen sources and doses. The authors report that this is one of the characters that are defined in the early stages of the crop, a fact that contributed to no difference between treatments in this experiment.

On Table 5, for TGW variable has no statistical difference between the different treatments that ($p>0.05$) was found. The values of this variable were superior when there was application of chemical control in V8 and VT stages in relation to the control, in other words, the fungicide application timing in this work did not interfere positively in this variable. Vilela et al. (2012) when studying the fungicide application in maize crop, also found no significant positive responses for this variable compared with the control.

Disagreeing with Swartz and Marchioro (2009), which in an experiment conducted in the city of Cascavel-PR in disease control with fungicide used in off-season maize, concluded that the application of fungicides increased significantly the yield and thousand grain weight. The application of fungicide in VT stadium considering the PROD (Table 5) differed about 869 kg ha^{-1} (higher productivity between treatments) compared to the control, but not significantly between treatments ($p>0.05$).

Corroborating the results, Lago and Nunes (2008) report that fungicide application in the maize crop did not differ significantly, but had productivity gains around 195 kg ha^{-1}. As Bussolaro et al. (2009), evaluating the effectiveness of fungicides to control diseases at different stages of maize, found that the use of fungicides led to an increase in production compared to control. Jardine and Laca-Buendía (2009), as in this study, report that when testing various active ingredients of fungicides, including Tebuconazole and Epoxiconazole + Pyraclostrobin did not find statistically significant differences in grain yield compared to the control.

Lourenção and Barros (2008) also observed greater response tendency to fungicide application in the pre-bolting stage with a gain of 4.0 bags ha^{-1}, although there was no significant difference compared to the control. According to BASF (2011), this increased productivity provided by the fungicide use in the stages of maize development, can be attributed to the physiological effect of the product, which provides increased net photosynthesis and the activity of the enzyme nitrate-reductase, combined with the decrease in ethylene production.

Duarte et al. (2009) point out that nowadays the use of fungicides in a mixture as triazoles and strobilurins and or benzimidazole in agricultural production systems is of great importance in the maize production. Thus, the foliar diseases present in this work had significant negative correlation with productivity, in other words, with increasing severity that they occur the grain yield is reduced, which was verified by Pires et al. (2011) with a work with off-season maize in Montividiu, Goiás.

Conclusion

It can be concluded that the mixture of triazole with estrobirulina is feasible for the management of the severity of these diseases in maize, though not statistical difference was observed in the treatments compared to the average productivity.

It is worth mentioning that the use of fungicide tends to provide greater sanity to plants and consequently it improves production rates. In general, the application of the fungicide in the pre-anthesis stage (VT) tends to show better responses.

Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(38), pp. 3696-3703, 17 September, 2015
DOI: 10.5897/AJAR2014.9221
Article Number: F5B8BB855556
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Evaluation and ranking of Macadamia genotypes using mixed models

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Received 9 October, 2014; Accepted 21 August, 2015

The annual yield of kernels in a population of macadamia (*Macadamia integrifolia* MAIDEN and BETCHE) were assessed with the aims of identifying the best genotypes relative to this trait to establish a base population for breeding program and focusing in the macadamia crop yield increase. Kernel production from 46 plants of 23 genotypes at different ages was analyzed using mixed models with REML/BLUP methodology by WOMBAT software. Age of the plant has direct and significant association with the production during the juvenile period. Estimated heritability was low. The genotypes IAC-920, HAES 741-MAUKA, HAES 344-KAU and AFRICANA are highlighted by different selection strategies, weighted by genotypic and/or phenotypic value. By the first criterion it was also stand out the genotypes HAES 791, GUARANI I, HAES 816, PALMEIRAS, IAC-412-B, GUARANI II, 772, DOROTHY and FLOR ROSA MG and the genotype IAC-412-B by the second criterion of selection. These results of this study demonstrate the importance of using BLUP predictors as a tool for breeding programs in this case study.

Key words: *Macadamia integrifolia,* genotypic value, yield, kernel, REML/BLUP.

INTRODUCTION

Macadamia (*Macadamia integrifolia*) is an arboreal species belonging to the Proteaceae family. The natural habitat is the east coast of Australia distributed in Queensland and New South Wales (Johnson, 1954; Smith, 1956). The macadamia geographical distribution includes Australia, USA, Hawaii, Africa, Guatemala, Costa Rica, Colombia, Paraguay and Brazil (Dierberger and Marino, 1985). The main commercial product of macadamia is the kernel, which are classified into different grading for different consuming markets. The refined flavor of kernels has aroused the interest of international markets for consuming *in natura*, roasted as snack or as a fine ingredient in the chocolate industry. The second grade quality kernels from the processing line are destined for oil extraction to be used in the cosmetics and pharmaceutical, its highly valued

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(Stephenson, 2005). Macadamia was introduced into Brazil in 1931 by Henrique Jacobs (Simão, 1998).Since then it has spread throughout the country to become an important agribusiness commodity due to international demand of the different consumers markets. In 2012, Brazil assumed the 7th position among producers of macadamia in the world, with largest production situated in São Paulo State (Poltronieri et al., 2005). Macadamia breeding program began in Brazil in the 1940's as an initiative of Instituto Agronômico de Campinas (IAC) using seed imported from Hawaii (Sobierjaski et al., 2006).

Although macadamia breeding began more than 70 years ago there is little information available on the characterization of genetic variability of the genotypes used in Brazil. One of these initial actions in the current breeding program is the evaluation and characterization of superior genotypes. However this task is slow and arduous when working with a perennial tree crop like macadamia with a long juvenile period. Macadamia species have a long (12 years) juvenile period (Pimentel, 2007), which together with a lack of genetic information motivates breeders to study the relationship between agronomical and genetic traits for developing breeding strategies. Breeding programs commonly employ repeated cycles of selection and recombination of genotypes from existing breeding populations and germplasm collections (Peace et al., 2003). In the beginning of the macadamia breeding program is necessary to establish genotypes which will be used as potential parents in new recombination. The second stage is clonal the selected candidate cultivars from the progeny trials. Another selection of parents for mating to produce the next breeding generation is established, maintenance and assessed for selecting cultivars for commercial release (Hardner et al., 2009). Breeding programs commonly employ repeated cycles of selection and recombination of genotypes from existing breeding populations and germplasm collections (Peace et al., 2003).

For development of new cultivars, the knowledge of interest genetic characteristics is crucial. One of the ways to identify the individuals carrying desirable genes is the genetic evaluation of selection candidates, which must be grounded in their additives genetic values, for use in recombination, and in genotypic values to be reproduced. This requires the estimation of additive and non-additive genetic variance, for the sexual and asexual reproduction respectively (Cruz and Carneiro, 2003). ANOVA (Analysis of Variance) and technique REML/BLUP (Restricted Maximum Likelihood/ Best Linear Unbiased Prediction) are the main procedures to estimate genetic parameters in testing and predicting of progenies. When unbalanced data sets are used, such as genetic selection procedure, the classical ANOVA models are inadequate, because estimated differences are biased (Mcgilchristt, 1994; Henderson, 1975).

Henderson (1973) has introduced the mixed models methodology, which includes fixed and random effects, serving both to estimate averages of blocks by the Generalized Least Squares (GLS) method, and to predict additive genetic values, in tests of half-sib progeny. The restricted maximum likelihood method in the mixed models is very important by generate unbiased estimates of parameters (Henderson, 1973).

The REML/BLUP method estimates fixed effects as the Best Linear Unbiased Estimator (BLUE) and, simultaneously, predict the value of random genetic effects (BLUP) and random effects uncorrelated included in this model (Resende, 2002), without the necessity of a classical statistical design.

The objective of this study was to identify the best genotypes relative to the annual yield of kernels in a population of macadamia germplasm, using mixed models, for grouping individuals aiming to establish a base population for breeding program and to improve results in the production systems based on vegetative propagation.

MATERIALS AND METHODS

For this study the nut tree crops were used from a commercial orchard managed by the Macadamia Brasilis Industry. The annual yield for each tree was expressed in kilograms (kg) during the three years of the study.

The harvest data was recorded from an orchard, four kilometers from Itapira in the subtropical region of São Paulo State, Brazil. Average annual temperature is 26°C, 72% relative humidity and 1390 mm rainfall. The trial consisted of 46 individuals of different ages grafted onto selected root stocks, located at six different sites on the orchard, from the germplasm collection, comprising 23 genotypes. Each orchard was installed in different year. 344, 920, 920x, 246, 412B, 741 at Velha/Coqueiro was planted in 2000. In 2001 was established the orchard Chanflora with the genotypes: 920x, 246, 741, 920, Camp B and 344. The Organica orchard was implanted in 2002 with the genotypes: 344, 741, 920 and Camp B. In 2003 the Porteira orchard was planted with 695, Cannon, Africana and Guarani I. The Mangueira Esquerda orchard was set up in 2004 with 772, 791, 814, 849, Camp B, 920-x, 920, 816 genotypes. 842, 920, 344, Camp B, 849, 920x was established in 2004 at Mangueira Direita orchard. In 2005, Guarani II, 788, Dorothi, F. Rosa MG was planted at Porteira orchard, 741 Edson in 2005 at Velha/Coqueiro and Palmeiras in 2008.

Information was recorded from harvests (January to Last June/First week of July) of 2009, 2010 and 2011, including plant identification, location (planting site), planting date and, for each picking, date and weight of harvest. The last two items were used to determine the annual kernel production and the number of pickings. Environmental effects on phenotypic expression were reduced by: standardizing tree spacing (6 m between plants and 8 m between rows) in all locations; pruning side branches or inside the canopy for better lighting and aeration (held during the month of June) and spraying in pre-bloom for preventing pests and diseases. The collected data are unbalanced due to several factors: starting year of harvesting for each plant, replication of the experiment subjects, presence of the genotypes at the sites and numbers of pickings per year per individual.

The trait annual production was analyzed by mixed linear model methodology using REML implemented by WOMBAT software (Meyer, 2007), assumed the following model:

Table 1. Means and estimates of variance components.

Statistic	Estimate	ASE(1)
Mean of Annual Production (kg)	10.027	-
Mean of Age	7.044	-
Phenotypic variance ($\hat{\sigma}^2_{\mathbf{p}}$)	38.107	18.226
Genotypic variance ($\hat{\sigma}^2_{\mathrm{g}}$)	4.800	2.831
Year variance ($\hat{\sigma}^2_{\mathbf{pe}}$)	13.206	17.959
Residual variance ($\hat{\sigma}^2_{\mathbf{e}}$)	20.101	2.922
Heritability (h^2)	0.126	0.089
Intraclass correlation (c^2)	0.347	0.311
Log_eL(1)	-260.010	-
AIC(1)	526.020	-
BIC(1)	534.204	-

(1) ASE: approximate sampling error (only where it is applicable); Log_eL: Logarithm of the likelihood function; AIC: Akaike's Information Criterion; BIC: Bayesian Information Criterion.

$$\mathbf{y} = \mathbf{Xb} + \beta\mathbf{t} + \mathbf{Zg} + \mathbf{Wp} + \varepsilon,$$

where: y: is the vector of annual kernel production in kg; X: is the (design) incidence matrix of fixed effects; b: is the vector of fixed effects (location, number of pickings in the year and grand mean); t: is the vector of values for the fixed covariable (plant age in the year of production); β: represents the linear regression coefficients associated with the covariable t; g, p are the vectors of genetic and permanent environmental random effects; Z, W: are the design matrices corresponding to random effects; ε: is the vector of random residuals.

It was assumed that the unique trait (annual production) has normal distribution centered in the mean, given fixed parameters (location, age and number of pickings). In addition, the genetic and production year effects and residuals were assumed independently and normally distributed with mean zero and (co)variance matrix equal to $\mathbf{I}\sigma^2_{\mathbf{g}}$, $\mathbf{I}\sigma^2_{\mathbf{pe}}$ and $\mathbf{I}\sigma^2_{\mathbf{e}}$, respectively, where I is the identity matrix of corresponding order and $\sigma^2_{\mathbf{g}}$, $\sigma^2_{\mathbf{pe}}$ and $\sigma^2_{\mathbf{e}}$ are the genetic, permanent environmental and residual variances, respectively. For the purpose of this analysis, genotypes were considered unrelated.

The covariable age has been adjusted only with linear effect, due to the age period of the data available coincide with the juvenile period, for all plants used. Estimates of broad-sense heritability (h^2) and intraclass coefficient (c^2) have been determined according to the following equations:

$$h^2 = \frac{\hat{\sigma}^2_{\mathrm{g}}}{\hat{\sigma}^2_{\mathrm{g}} + \hat{\sigma}^2_{\mathrm{pe}} + \hat{\sigma}^2_{\mathrm{e}}} \quad \text{and} \quad c^2 = \frac{\hat{\sigma}^2_{\mathrm{pe}}}{\hat{\sigma}^2_{\mathrm{g}} + \hat{\sigma}^2_{\mathrm{pe}} + \hat{\sigma}^2_{\mathrm{e}}}.$$

The genotypic value was calculated for each genotype by adding the corresponding value of BLUP (genetic effect) to the grand mean of the trait.

RESULTS AND DISCUSSION

In the present study, the variance components, the means of annual individual production and corresponding tree age, the indicators of the Logarithm of the Likelihood function (Loge L), the Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC), were estimated (Table 1).

The heritability coefficient estimated by genetic parameter was low (12.60%) which shows that much of the variation of the characteristic among individuals is due to environmental differences and interactions among genotypes and environments. The estimate for the intraclass correlation coefficient (c^2 = 34.6) was relatively moderate (Resende, 2002). Hardner et al. (2002) reported low heritability in a broad sense for the production of plants (6% < H^2 < 22%). There is little published works about studies assessing macadamia heritability in relation to production. However studies conducted on characteristics that influence the final factor production, such as fruit size and nut size, reported that the heritability is high for these traits (Hardner et al., 2001; 2009). In these studies, difference among cultivars was reported, confirming the existence of genetic variation which is difficult to appraise. This is attributed to the major selection objective, usually on the basis of phenotypic performance, without the control of environmental variation, implying low accuracy in the estimation of the genetic effects, especially for traits of low heritability like kernel production.

The 23 genotypes are classified in decreasing order of genotypic performance (Table 2) by BLUP of random effects represented in the model. Predictors for relative genetic effect are shown in Table 2 and predictors for relative effect of production year match to 2.328 kg in 2009, 1.4 kg in 2010 and -3.728 kg in 2011. The knowledge of the genetic and phenotypic variance has a significant effect in the premature selection (Carvalho et

Table 2. Evaluated genotypes and their performance parameters obtained from the linear model applied using REML/BLUP, in decreasing order of genotypic value.

Genotype	Mean of annual production (kg)	Genetic effect (BLUP) (kg)	Genotypic value (kg)	Relative performance (%)	
				Genotypic	Phenotypic
IAC-920	15.626	3.883	13.911	100.0	73.8
HAES 741-MAUKA	19.061	2.098	12.126	87.2	90.1
HAES 344-KAU	15.316	1.652	11.680	84.0	72.4
AFRICANA	11.758	0.876	10.903	78.4	55.6
HAES 791	7.420	0.821	10.849	78.0	35.1
GUARANI I	0.358	0.542	10.569	76.0	1.7
HAES 816	4.109	0.423	10.451	75.1	19.4
PALMEIRAS	0.969	0.354	10.382	74.6	4.6
IAC-412-B	21.162	0.338	10.366	74.5	100.0
GUARANI II	1.093	0.323	10.350	74.4	5.2
772	6.290	0.139	10.166	73.1	29.7
DOROTHY	5.966	0.134	10.162	73.0	28.2
FLOR ROSA MG	7.841	0.034	10.062	72.3	37.1
BEUAMONT (695)	8.680	-0.352	9.676	69.6	41.0
IAC-920 X	9.159	-0.411	9.617	69.1	43.3
CANNON	9.129	-0.516	9.511	68.4	43.1
741 EDSON	4.619	-0.787	9.241	66.4	21.8
HAES 842	5.061	-0.935	9.093	65.4	23.9
IAC-CAMPINAS B	10.851	-0.944	9.083	65.3	51.3
HAES 788-PAHALA	6.589	-1.041	8.987	64.6	31.1
HAES 849	5.291	-1.470	8.557	61.5	25.0
HAES 814	5.458	-1.473	8.555	61.5	25.8
HAES 246-KEAUHOU	11.956	-3.689	6.338	45.6	56.5

al., 2008). By adopting this order, each genotype can be checked in relation to phenotypic value (average annual production) and genotypic value (BLUP), along with genotypic and phenotypic relative performance.

A comparative approach between the genotypic and phenotypic values is shown in Figure 1. The first quadrant highlights the five genotypes that simultaneously represent the best performances with respect to genotypic and phenotypic values. The contradictory results between the genotypes 246 (fourth quadrant) and AFRICANA (first quadrant) can be used to emphasize the differences revealed by BLUP usage, given that although both of them presented good phenotypic performance, its genotypic values are opposite. The superior phenotypic value produced by the interaction genotype versus environment does not guarantee to know the genetic value for these individuals. Thereby, the genotypic value predictor obtained by BLUP allows the breeder to select the superior genotypes which will maximize the possibility of a genetic progress in the selection (Sölkner et al., 2008).

An exploratory analysis using the Spearman correlation among the observed means (phenotypic value) and BLUP obtained for genotypes (genotypic value) showed low correlation coefficient (r=0.2065) and low level of reliability of this association (t test not significant at 5%). This represents the absence of a strong association between the phenotypic and genotypic values in this evaluated population and strongly demonstrates the importance of using the BLUP for the prediction of genetic values. Three groups of interest are presented in Table 3 to explore the best genotypes, correlating them to equivalent groups with highest phenotypic means, by composition and order. In the highlighted central columns are included the elements related to criteria for group formation and correlations among the selection criteria. The resulting classes are shown in two columns left and right, including the group average phenotypic value and the relative degree of performance corresponding to the selection criterion (genotypic or phenotypic). For each criterion, the groups were composed by seven, 10 and 13 genotypes with the best performances, determined by BLUP or average production, respectively. Comparing equivalent groups between the two selection criteria in terms of composition, result in coincidences of 57, 50 and 54% of its members, respectively. These degrees of coincidence are obtained both in the overall assessment of the three years, as the separate assessment for each year of production, except for the comparison of groups of seven individuals in the first crop, with only 29% of

Table 3. Grouping genotypes by selection strategy: genotypic classes, phenotypic classes and correlations between the corresponding groups of two strategies.

Selection by Genotype						Selection by Phenotype	
Genotypic class	Average phenotypic value	Number of selected	Proportion of selected (%)	Correlation (Spearman) (%)	Coincidence grade[(1)] (%)	Average phenotypic value	Phenotypic class (%)
>= 75%	13.003	7	30.43	92.86	57.10	14.394	>= 50
>= 74%	12.286	10	43.48	44.24	50.00	13.577	>= 40
>= 70%	11.411	13	56.52	40.66	53.85	12.769	>= 30

(1) Coincidence between members in the genotypic and phenotypic classes in the same level.

coincidence. Selection based only on individual phenotypes can lead to discarding genotypes that have a high genotypic value for the trait. In the case of the group of top 10 elements, individuals such as 791, GUARANI I, HAES 816, PALMEIRAS and GUARANI II would be discarded. Analyzing the results for genetic value (Table 3), it can be observed that the groups selected have average rates of relative performance (70 to 75%) higher than the equivalent rates of selected groups by phenotypic value (30-50%).

Two approaches must be considered to advise the selection of the best genotypes in this study: (a) the selection for vegetative propagation (SelecVP) and (b) the selection for establishment of a base population (SelecBP). Species that can be vegetative propagated allow increasing the efficiency of the selective process (Maia et al., 2011). This facility factor in the breeding program is essential for accelerate the propagation of superior genotypes and its variance, in special, for species which has a long time to obtain results about aimed characteristics. In the SelecVP case, aimed at formation of production orchards or its improvement, it is recommended the selection of individuals regarding the genotypes whose relative performances were estimated 75% or more (first genotypic class as characterized in Table 3). This strategy represents the selection of approximately 30% of the evaluated genotypes and results in the following top seven genotypes (Table 2): IAC-920, HAES 741-MAUKA, HAES 344-KAU, AFRICANA, HAES 791, GUARANI I and HAES 816. Among these it is found two of the mostly cultivated genotypes: HAES 344 and HAES 741 (Wallace, 2012).

For the SelecBP case, aimed at implementation of a breeding program, the selected group should be expanded because the genetic variability is highly important for any breeding program, implying in a necessary reduction of the selection differential. Therefore, in the present case study, it is recommended to select genotypes by adopting the relative performance of 70% at least (third genotypic class as characterized in Table 3). With this strategy, the 13 top genotypes are indicated, representing approximately 57% of the evaluated genotypes. This includes those seven already listed and over the following six (Table 2): PALMEIRAS, IAC-412-B, GUARANI II, 772, DOROTHY and FLOR ROSA MG. In a study with a similar purpose and circumstances, but using big number of plants from 312 clones of *Eucalyptus spp*, Garcia and Nogueira (2005) has adopted a greater selection differential for representative clones from the best genotypes. Thus, the relative performances were bounded to 80%. The less restrictive selecting factors adopted in this macadamia study were fixed due to the small number of plants assessed.

Considering that the available data have limitations to get a better level of accuracy related to exclusively genotypic selection, a mixed strategy, more parsimonious, is also applicable, taking as criterion the combination of genotypic and phenotypic best performances simultaneously. Using this strategy, as noted earlier (Figure 1), the top five genotypes are: IAC-920, HAES 741-MAUKA, HAES 344-KAU, AFRICANA and IAC-412-B.

According to U.S. International Trade Commission (1998), the macadamia has its first crop economically viable between six to eight years after planting. Topp et al. (2012) emphasize the high cost for assessing macadamia yield and tried to develop a breeding strategy for reducing it for the macadamia breeding program. All plants used in this study were aged between six and 11 years in the final harvest of the evaluation period, except of the single individual of the genotype PALMEIRAS, three years old. For all plants, the harvest periods coincide with the juvenile period, when it is expected a direct relationship between increasing age and production growth. It is possible clearly infer the occurrence of this relationship in this study (Figure 2a). This finding

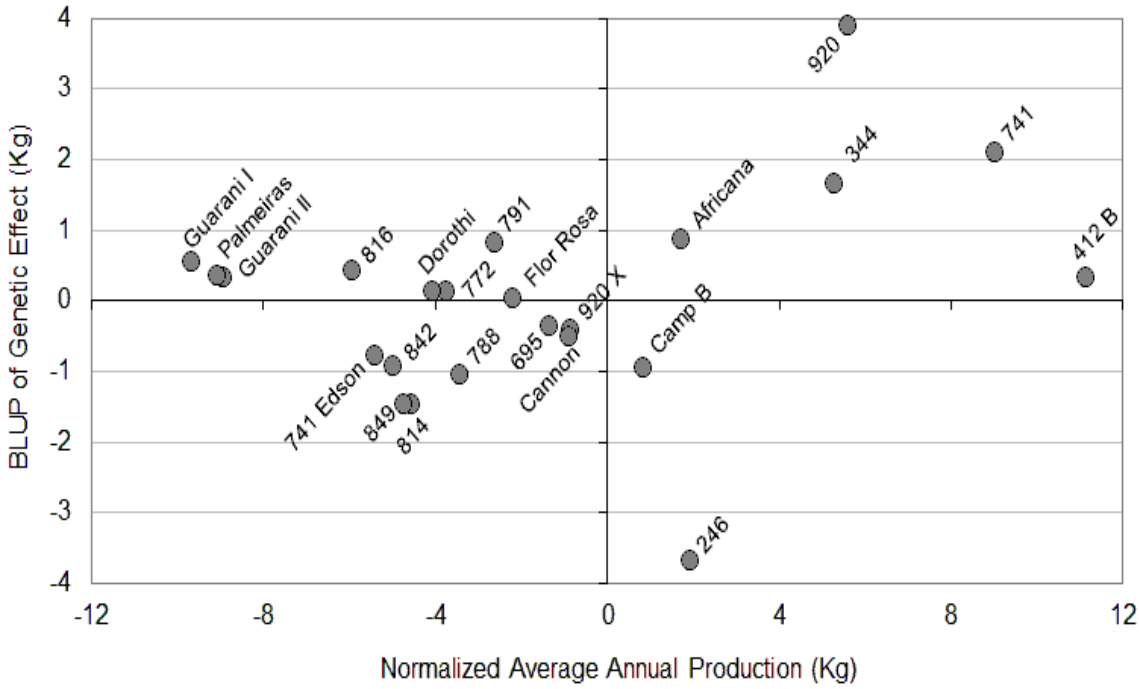

Figure 1. Performances of the genotypes: Genotypic BLUP versus Normalized Phenotypic Mean. The point labels refer to genotype designations (in reduced form, for some cases, in order to clarify the graphic).

was confirmed in the applied model by the highly significant (P=0.01) coefficient of 0.737 in the regression between covariable "age" and the trait "production". All plants suitable for group selection SelecVP were aged between seven and 11 years in the last year of harvesting and most aggregated to the formation of group SelecBP were younger, indicating that the results obtained are strongly related with the trait production.

Although, the management practices have been identical in all locations (planting sites), the estimators for the influence of this component (Figure 2b) highlighted CHANFLORA and VELHA as the locations in the orchard with best performances for macadamia production. It was observed that both the locations, CHANFLORA and VELHA, had a high incidence of the best individuals, both in relation to the phenotypic mean and in relation to genotypic predictor (BLUP), highlighting the presence of the three best BLUP (IAC-920, HAES 344-KAU e HAES 741-MAUKA). Figure 2c allows checking the relationship between the effect of number of pickings per harvest in the average of production and in the used model. It is emphasized that, for this fixed effect, the model has presented estimators with production levels higher than the observed means, for nearly all the 18 layers of number of pickings.

Conclusions

The genotypes IAC-920, HAES 741-MAUKA, HAES 344-KAU and AFRICANA are highlighted by different selection strategies, weighted by genotypic and/or phenotypic performance. The genotypes HAES 791, GUARANI I, HAES 816, PALMEIRAS, IAC-412-B, GUARANI II, 772, DOROTHY and FLOR ROSA MG were the genotypes with the greater genetic value. The genotype IAC-412-B also stands out by the criterion of greater phenotypic value.

The age of the plant has direct and significant variation in production during the juvenile period, with an estimated average increase of 0.737 kg per year of age. The results obtained by mixed model methodology (REML/BLUP) and the correlation between genotype and phenotype demonstrate the importance of using BLUP predictors for genetic values in the selection of macadamia genotypes in the population studied.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

To the Postgraduate Program in Plant Physiology of UFPel and CAPES, institutions that developed and funded the project, respectively. To the Company Macadamia Brasilis, by using their orchards and data collection to develop this study.

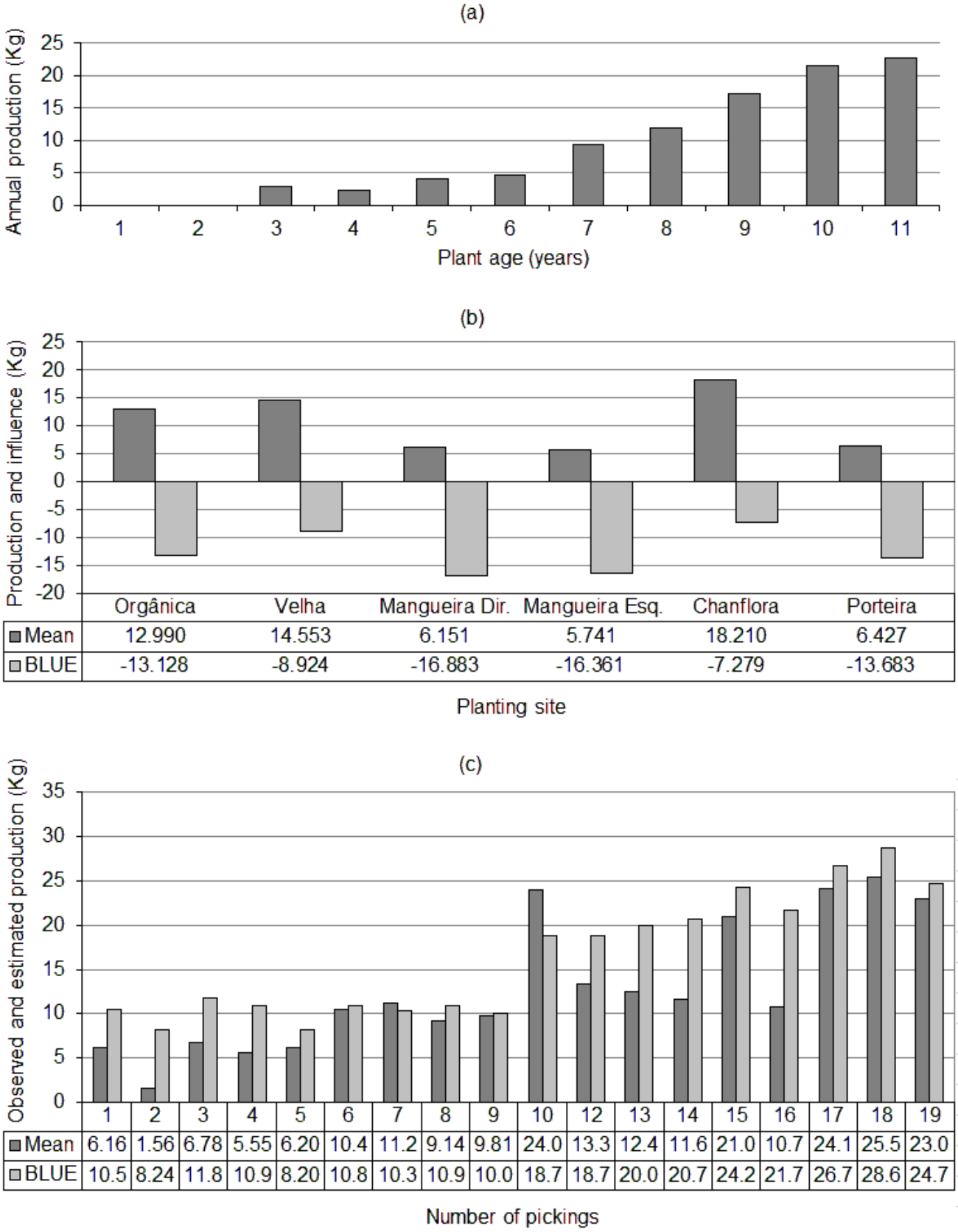

Figure 2. Annual production of macadamia nuts in the study population represented by the evolution during juvenile period (a) and observed means and fixed effects estimators (BLUE) in relation to planting sites (b) and number of pickings per harvest (c). Itapira-SP-Brazil.

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academicJournals

Vol. 10(38), pp. 3704-3717, 17 September, 2015
DOI: 10.5897/AJAR2015.9597
Article Number: 96F558E55558
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Reactivity of a blast furnace slag in latosols

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Received 10 February, 2015; Accepted 4 August, 2015

Two experiments were conducted to study reactivity for a blast furnace slag, both developed in a greenhouse, in pots planted with *Brachiaria brizantha*. A 3 x 4 + 3 factorial was used with four replications, with three slag doses corresponding to 0.6, 1.2 and 2.4 g dm^{-3} for the clay soil and 2.2, 4.4 and 8.8 g dm^{-3} for the medium texture soil, four particle sizes (ABNT 5-10, 10-20, 20-50 and <50) and three controls (without corrective application, slag and dolomitic limestone in a dose corresponding to V=70%). In the clayey soil, there was a low efficiency of Ca and Mg release to the soil with the use of slag. It was concluded the slag, in its different particle size fractions influenced differently the pH, Ca and Mg of medium texture soil, where the fraction that passed through the ABNT 50 sieve had a greater effect on the chemical attributes evaluated. The corrective agents, slag and limestone, acted similarly on pH, Ca, Mg and V%. For greater liberation of silicon to the soil and absorption by plants it is necessary to use smaller particle sizes in the medium texture soil and intermediate particle sizes in the soil with clayey texture.

Key words: Limestone, silicate, *Brachiaria brizantha*, particle size.

INTRODUCTION

Tropical soils usually have limitations due to their high degree of acidity, affecting crop productivity (Quaggio, 2000). In this scenario, the correction of soil acidity is key to optimizing both agronomic and economic results in agriculture. The use of corrective materials such as limestone or slag can provide benefits for the agricultural sector by correcting soil acidity and providing calcium, magnesium and silicon. The availability of silicon from slag is attracting great interest in the scientific community, because it is a beneficial element that can contribute to increased crop development and production (Neto, 2009).

Currently, the same legislation applied to limestone is applied to the marketing of slag (Brasil, 2004), since both have shown similar behavior with regards to their ability to change the chemical properties of soils, as shown by other authors including Chaves and Farias (2008) and Oliveira et al. (2010).

According to legislation in Brazil about alkaline compounds, the relative reactivity (RR), which corresponds to the capacity to neutralize soil acidity over a period of three months, depends on the granulometry of these materials, that is, considers only the particle size. For the fraction larger than 2 mm (ABNT No. 10 sieve)

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Table 1. Chemical properties of the soils used in the experiment.

Texture class	pH	O.M.	Si	P	K	Ca	Mg	(H+Al)	SB	T	V
		g dm^{-3}	- mg dm^{-3}-			----------mmol$_c$ dm^{-3}----------					%
Clayey	4.3	6	-	5	0.4	3	2	18	5.4	23.4	23
Medium	4.2	17	3.1	5	0.5	4	2	58	6.5	64.5	10

pH $CaCl_2$ (1:2.5); Calcium, Magnesium (KCl 1N); Potassium (Mehlich 1); Silicon $CaCl_2$ 0.01 mol L^{-1} (1:10); P resin.(Raij et al., 2001).

and smaller than 0.30 mm (ABNT No. 50 sieve) reactivity values of 0 and 100% were attributed, respectively. From these, corresponding efficiencies were assigned to the intermediate grain sizes between 2 and 0.30 mm. In calculating the reactivity of limestone, the fraction of particles retained between the ABNT 10 and 20 sieves conventionally has 20% RR and the particles retained between the ABNT 20 and 50 sieves has a RR of 60%, as indicated in legislation (Brasil, 1986).

Thus, in the case of slag, it is believed that the use of smaller particles results in greater reactivity with the soil, due to the greater surface area of the slag particle in contact with the soil (Novais et al., 1995). In a study of blast furnace slag, Oliveira et al. (1994) demonstrated that smaller particles are more effective in providing Ca and Mg to the soil than large particles. The corrective materials limestone and silicate slag are similar because both have effects on neutralization of soil acidity. However, it can be considered that rates of relative reactivity (RR) used for limestone may not express the same effect on soil chemical properties in the case of slag. This may occur because slags present a chemically and physically complex and distinct composition with respect to limestone. This difference arises from the composition of slag (calcium and magnesium silicates associated with Fe, Al and Mn compounds) and the production phase of these residues (Prado et al., 2001), because the industrial process of iron and steel extraction promotes the acquisition of various slag types with different recrystallization in function of the Ca and Mg quantities and cooling time, which can reduce their solubility (Pereira et al., 2010).

Thus, it is highlighted that the intrinsic characteristics of specific surface, such as porosity and shape of the particles, differ greatly in function of their origin. Silicates from steelmaking slag present, in general and for the same particle size, specific surface and porosity much larger than particles of a corrective material obtained from limestone (Neto, 2009). Steel slag is considered a source of silicon for different crops (rice, sugarcane and Brachiaria) (Prado et al., 2003; Pereira et al., 2004; Ramos et al., 2008; Fonseca, et al., 2009; Vidal and Prado, 2011). However, little is known regarding the interaction of different particle size fractions of the material with soils of different textures and how these fractions could affect silicon availability.

Based on the information above, a hypothesis was suggested that there are no differences in reactivity of the silicate size fractions on chemical attributes related to soil acidity and the availability of silicon. The objective was thus to study the reactivity of a blast furnace slag, in different size fractions, on chemical attributes of a dystrophic Red Latosol with clayey texture and a dystrophic Red Latosol with medium texture, cultivated with *Brachiaria brizantha*.

MATERIALS AND METHODS

The experiments were conducted in a greenhouse at the Faculty of Agricultural and Veterinary Sciences/UNESP – Jaboticabal Campus. Soil samples were collected in 0 to 20 cm depth, of a dystrophic Red Latosol with clayey texture collected in private property, near Jaboticabal city and the other of dystrophic Red Latosol with medium texture obtained in experimental farm of FCAV (Embrapa, 1999).

Physical characterization was performed according to the method proposed by Camargo et al. (1986) and the result of the dystrophic Red Latosol with clayey texture was clay: 420 g kg^{-1}, silt: 60 g kg^{-1}, fine sand: 310 g kg^{-1} and coarse sand: 210 g kg^{-1} and the dystrophic Red Latosol with medium texture was clay: 310 g kg^{-1}, silt: 90 g kg^{-1}, fine sand: 250 g kg^{-1} and coarse sand: 350 g kg^{-1}. Chemical analysis of soil for purposes of fertility followed the method described by Raij et al. (2001) and Si by calcium chloride 0.01 mol L^{-1} (Camargo et al., 2007) (Table 1).

Two corrective materials were used: one blast furnace slag with different particle sizes (total Si in hydrofluoric acid: 152 g kg^{-1}, Si soluble in NH_4NO_3 + Na_2CO_3: 4.1 g kg^{-1}, CaO: 270.7 g kg^{-1}; MgO: 48.4 g kg^{-1}; NP - neutralizing power: 604.5 g kg^{-1}, RTNP - relative total neutralization power: 443.6 g kg^{-1}) and one dolomitic limestone with original grain size (total Si: 68 g kg^{-1}, soluble Si: 0.1 g kg^{-1}, CaO: 402.3 g kg^{-1}, MgO: 58.4 g kg^{-1}, NP - neutralizing power: 865 g kg^{-1}, RTNP - relative total neutralization power: 753.2 g kg^{-1}).

The experiments were performed in one clayey soil and the other in medium texture soil. In both trials, randomized block designs were setup in a 4x3+3 factorial, with four replications. The treatments consisted of four granulometric fractions of blast furnace slag (ABNT 5-10, 10-20, 20-50 and <50), three doses of the slag corresponding to 1.25, 2.50 and 5.00 t ha^{-1}, that is, 0.6, 1.2 and 2.4 g dm^{-3} for the clay soil and 2.2, 4.4 and 8.8 g dm^{-3} for the medium texture soil. In both experiments three controls were used (limestone, blast furnace slag, without correction) at the dose corresponding to V = 70%, that is, 0.63, 2.22, 1.2 and 4.4 g dm^{-3}, respectively, for each material and soil type.

Different slag particle sizes were obtained by sieving. However, in the coarser fractions (ABNT 5-10, 10-20 and 20-50) the “dust” was removed, that is, very fine fractions of the slag to avoid possible contamination. For defining the doses the base saturation method was adopted (Raij et al., 1996), considering the RTNP value of slag and limestone. This procedure was used to compare the controls (slag and limestone), only as a preliminary evaluation

and certification of the differences between materials in the soil reaction, based on the same reactivity rates adopted by legislation for limestone.

In evaluation of the factors particle size and slag doses, which was the main object of this work, a dose of 1.2 g dm^{-3} was used for the clayey texture soil and 4.4 g dm^{-3} for medium texture soil, as well as half and double these values to enable increasing doses with no intention of reaching predetermined correction levels, since determination of the slag reactivity rates is the main object of this study.

The corrective agents, at the different doses and particle sizes, were homogenized with the soil and stored for 90 days in plastic bags with moisture content maintained at 60% of field capacity using distilled water (no silicon). After the incubation period, the soils were distributed in 5 dm^3 pots that constituted the experimental units and were planted with five seedlings of *B. brizantha* cv. Marandu, previously germinated in plastic trays containing washed sand.

The basic fertilizations applied for proper development of plants were performed according to the recommendations of Mesquita et al. (2004) and Bonfim et al. (2004), followed by application of 305 mg of P dm^{-3} in the form of single superphosphate, 200 mg dm^{-3} of K (KCl p.a.), 100 mg dm^{-3} of N [NH_4NO_3 and $(NH_4)_2SO_4$ p.a.], 1.2 mg dm^{-3} of Cu ($CuSO_4.5H_2O$ p.a.), 0.8 mg dm^{-3} of B (H_3BO_3 p.a.), 1.5 mg dm^{-3} of Fe ($FeCl_3.6H_2O$ p.a.), 3.5 mg dm^{-3} of Mn ($MnCl_2.6H_2O$ p.a.), 0.15 mg dm^{-3} of Mo ($NaMoO_4.2H_2O$ p.a.) and 4 mg dm^{-3} of Zn ($ZnSO_4.7H_2O$ p.a.). At 10 days after transplantation, 50 mg dm^{-3} of N and 20 mg dm^{-3} of S [$(NH_4)_2SO_4$ p.a.] were spread on the plants.

Two plant growth cycles were evaluated. In the first cycle, the plants were cut at three months after planting, at a height of 5 cm from the ground, and the second three months after the first cutting. Soil samples were collected from the pots. They were later dried and sieved (2 mm sieve) for fertility evaluations according to the methodology proposed by Raij et al. (2001). The plant material was dried in a forced-air oven at 65°C for approximately 48 h until reaching constant weight. Then the dry mass of the plants was determined and all plant mater was ground, analyzing the concentrations of calcium and magnesium according to the methodology of Bataglia et al. (1983). Silicon in the soil was analyzed according to Camargo et al. (2007) and silicon in the plant by the methodology proposed by Bataglia et al. (1983). The results of each variable studied were submitted to analysis of variance. When the F-test was significant for interaction of the treatments, polynomial regression studies were conducted.

RESULTS AND DISCUSSION

It was observed that only particle size of the material influenced pH of the clayey soil, obtaining higher values when using the finer of the sieves (ABNT 20-50 and <50) (Table 2). The major effect of the corrective material with finer particle size on increasing the pH value was also confirmed by Pereira et al. (2010), with use of blast furnace slag 1 applied to a dystrophic Red Latosol with clayey texture, incubated for 90 days. It is highlighted that the material evaluated by these authors had similar characteristics to that used in the present study. No significant difference was observed for the doses applied and the controls (Table 2). Despite the significant interaction for pH $CaCl_2$, no polynomial regression was statistically significant (Figure 1a).

The similarity between the controls with regards to pH value, Ca and Mg, even among those that received no corrective compounds (Table 2), may be explained by the use of fertilizers containing calcium, magnesium and potassium in their formulations. These were applied at planting and in coverage during the assays, noting that the fertilizers to nourish the plants were the same in all treatments, differing only with regards to the corrective compound utilized particle size and dosage. Unlike the clayey soil, increases in $CaCl_2$ pH were observed with the slag doses, where 8.8 g dm^{-3} was the dose presenting the highest pH value (Table 2). Similar to the results obtained, Neto (2009) studied the relative efficiency of different particle size fractions of silicates on the correction of acidity for soils ranging from clayey to sandy and found a large variation in pH for soils of medium texture after application of corrective doses. Thus, it was emphasized that the clayey soils, in comparison with medium texture and even sandy soils, have a higher buffering capacity and hence greater resistance to variations in pH (Furtini et al., 2001).

Use of the finer particle size also favored an increase in pH $CaCl_2$, where the material retained on the sieve ABNT <50 presented the highest values (Table 2). No significant difference was observed between the controls. The same behavior was observed by Neto (2009) who found that at 30 and 90 days after the incubation of three calcium silicates and one limestone sample in a typical dystrophic Red Latossol of medium texture, smaller particle sizes of the corrective material resulted in greater increases of pH $CaCl_2$ values.

Behavior similar to that of pH $CaCl_2$ was observed for magnesium in soil with regards to the doses applied (Table 2). Santana et al. (2010) also reported the effect of limestone and silicate slag application on chemical attributes of the soil, and production and quality of brachiaria forage; increases in soil magnesium were also observed in function of the corrective levels, after application of slag.

The doses of 0.6 and 1.2 g dm^{-3} showed the highest concentrations of calcium and the dose of 0.6 g dm^{-3} resulted in the highest concentration of magnesium in the clayey soil (Table 2). There was also increased calcium concentration in soil of the treatment with particle size ABNT 10-20 and magnesium in the treatment with particle size ABNT <50. Considering the interaction of factors (Figure 1b and c), the slag dose provided in each particle size treatment reduced the availability of calcium and magnesium in the soil. Similarly, Pereira et al. (2010) noted low efficiency of two blast furnace slags (AF1 and AF2) with regards to available calcium and magnesium in a dystrophic Red Latosol, at a dose of 1500 mg kg^{-1} of $CaCO_3$ equivalent, independent of the particle size fraction used. Concordance verified among the controls with regards to chemical alterations of the clayey soil indicated that both the limestone and slag showed the same behavior for neutralization of soil acidity, availability of Ca^{2+} and Mg^{2+}, and V% after three months of

Table 2. Results of pH, Ca, Mg, V and Si in the soil after application of blast furnace slag and limestone to two soils – 1st cutting.

Treatment	pH $CaCl_2$	Ca^{+2}	Mg^{+2}	V	Si
		$mmol_c\ dm^{-3}$		%	$mg\ dm^{-3}$
Dystrophic Red Latosol – clayey texture					
Slag doses (D) ($g\ dm^{-3}$)					
0.6	5.7	69.1 ^{a}	2.6 ^{a}	73	6.4
1.2	5.8	66.4 ^{a}	1.9 ^{b}	76	6.8
2.4	5.8	59.2 ^{b}	2.4 ^{ab}	75	6.9
Dms	0.18	5.61	0.63	4.07	0.85
Different particle sizes of the blast furnace slag (G)					
ABNT 5-10	5.6 ^{c}	56.9 ^{c}	1.2 ^{c}	71 ^{b}	6.2
ABNT 10-20	5.7 ^{bc}	72.6 ^{a}	2.0 ^{bc}	74 ^{ab}	6.6
ABNT 20-50	5.9 ^{a}	67.6 ^{ab}	2.3 ^{b}	77 ^{a}	7.1
ABNT <50	5.8 ^{ab}	62.6 ^{bc}	3.7 ^{a}	76 ^{a}	6.9
Dms	0.23	7.13	0.80	5.18	1.08
Controls					
Limestone	5.9	58.5	2.7	74	7.4ab
Slag	6.0	62.7	1.7	73	8.2a
No correctives	5.6	62.7	1.5	71	6.3b
Dms	0.23	11.2	1.2	8.15	1.70
F-Test					
Test x Trat	0.41^{ns}	3.30 ^{ns}	1.72^{ns}	1.81 ^{ns}	3.35^{ns}
Between Tests	3.05 ^{ns}	0.48 ^{ns}	3.20*	0.34 ^{ns}	3.80*
Doses	0.76 ^{ns}	9.90**	3.55*	2.25 ^{ns}	1.11 ^{ns}
Particle sizes	4.43 **	12.67**	22.42**	3.61*	1.63 ^{ns}
D x G	2.42*	8.45**	9.45**	3.72 **	1.21 ^{ns}
C.V.(%)	3.66	10.19	32.84	6.40	14.55
Dystrophic Red Latosol – medium texture					
Slag doses (D) ($g\ dm^{-3}$)					
2.2	5.4 ^{b}	77.5 ^{a}	2.6 ^{b}	70 ^{b}	5.3 ^{b}
4.4	5.6 ^{ab}	73.0 ^{a}	3.0 ^{b}	73 ^{b}	6.1 ^{b}
8.8	5.8 ^{a}	67.2 ^{b}	7.2 ^{a}	79 ^{a}	7.4 ^{a}
Dms	0.20	5.57	0.83	4.07	0.95
Different particle sizes of the blast furnace slag (G)					
ABNT 5-10	5.4 ^{b}	57.1 ^{b}	1.5 ^{c}	67 ^{b}	4.9 ^{b}
ABNT 10-20	5.6 ^{ab}	81.2 ^{a}	6.3 ^{a}	74 ^{a}	6.1 ^{b}
ABNT 20-50	5.6 ^{ab}	75.3 ^{a}	6.4 ^{a}	78 ^{a}	6.0 ^{b}
ABNT <50	5.8 ^{a}	76.7 ^{a}	2.7 ^{b}	77 ^{a}	7.9 ^{a}
Dms	0.26	7.08	1.06	5.87	1.21
Controls					
Limestone	5.6	72.0 ^{a}	2.3 ^{b}	72 ^{a}	5.4
Slag	5.6	79.5 ^{a}	4.2 ^{a}	78 ^{a}	5.7
No correctives	5.2	54.7 ^{b}	1.5 ^{b}	59 ^{b}	4.2
Dms	0.41	11.14	1.67	9.23	1.91
F-Test					

Table 2. Results of pH, Ca, Mg, V and Si in the soil after application of blast furnace slag and limestone to two soils – 1st cutting. (Contd.).

Test x Trat	2.43^{ns}	3.31 ^{ns}	25.21**	5.99*	9.96**
Between Tests	3.36*	15.29**	8.47**	0.34 ^{ns}	2.00 ^{ns}
Doses	8.79**	10.15**	109.25**	2.25 ^{ns}	14.54**
Particle sizes	7.32**	32.10**	78.96**	3.61*	15.07**
D x G	2.60*	7.74**	25.52**	3.72 **	3.79**
C.V. (%)	4.36	9.04	24.84	6.40	18.50

Means followed by the same lower-case letter in the same column indicate no significant difference by the Tukey test (p< 0.5).

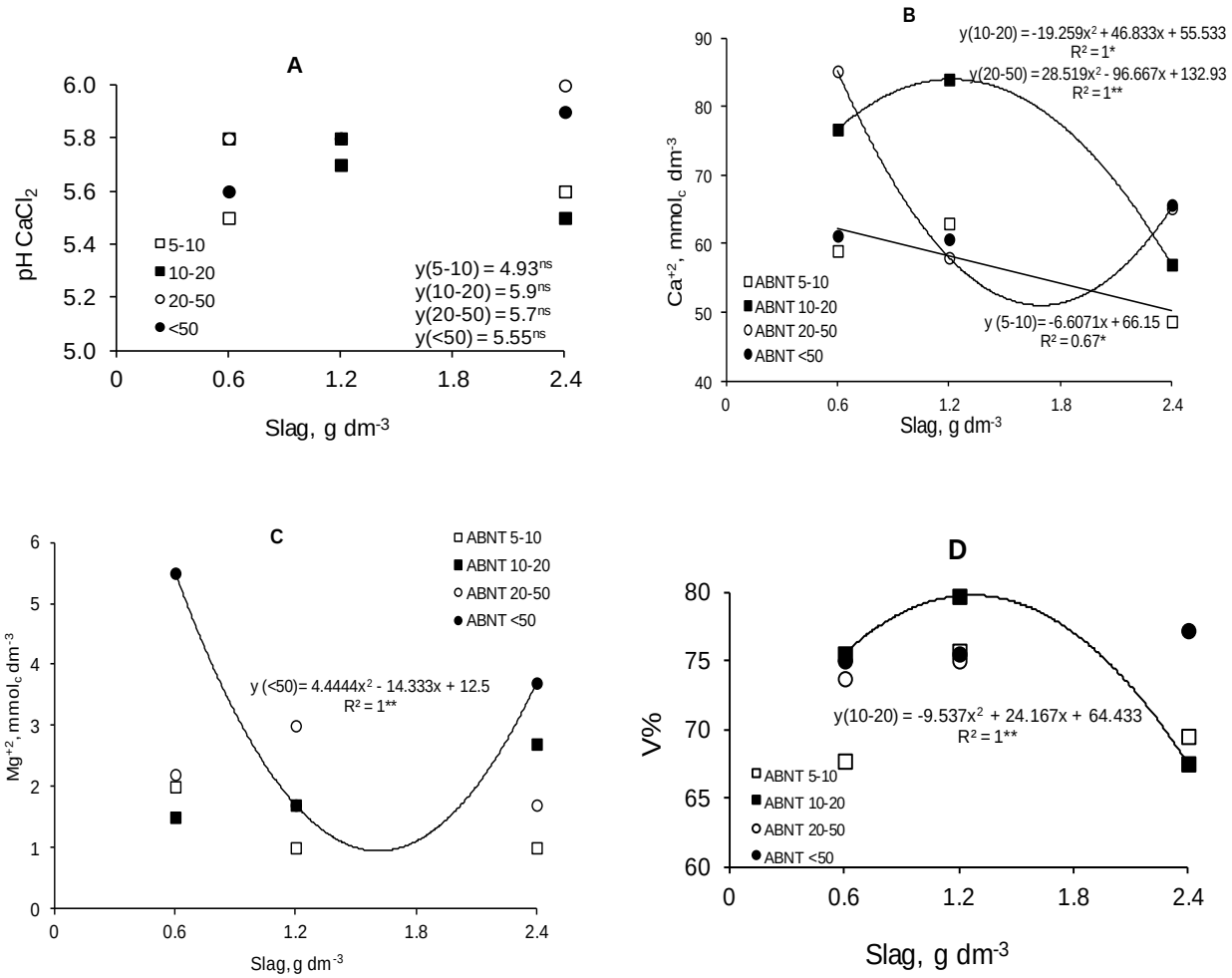

Figure 1. Values of pH $CaCl_2$(A), calcium(B), magnesium(C) and base saturation(D) in dystrophic Red Latosol with clayey texture, in function of the slag doses and particle sizes evaluated – 1st cutting (** p<0.01; * p<0.05; ^{ns} – non-significant).

cultivation (Table 2), although the materials (silicate and carbonate) are chemically different.

Considering the indications of similarities between the two corrective compounds (silicate and carbonate) and the observations made by Pulz et al. (2008), when considering the influence of calcium and magnesium silicate compared to dolomitic lime with regards to nutrition, productivity and quality of potatoes under water stress conditions, it was also noted that the Ca and Mg silicates resulted in the same levels of soil correction and supply of these nutrients as dolomitic lime, thus permitting that it be used to substitute limestone.

In the case of limestone, with a decrease in particle size there was greater availability of calcium in the

medium texture soil (Table 2). However, for magnesium the intermediate sieves (ABNT 10-20 and 20-50) were responsible for the highest values of this element in the soil. Therefore, Deus et al. (2014) indicated that the smaller the particle size of the corrective materials, high was the availability of calcium due to increased contact of the material with the soil, resulting in higher specific surface area and thus greater solubility. Regarding the controls, the treatment receiving slag presented higher magnesium availability in soil and both were similarly able to provide calcium to the soil. For base saturation data, the particle size influenced this result (Table 2). It was verified that application of the first dose (0.6 g dm^{-3}) was sufficient to achieve the V% recommended for *B. brizantha*. It was also observed that the material retained in the ABNT 5-10 sieve showed the lowest V% compared to the other sieves. This last result may be validated by the observations made by Prado et al. (2004) who found a decrease in efficiency of steel slag to increase base saturation of a dystrophic Red Latosol as the particle size of the material became coarser. The interaction between the two factors studied was significant only for the particle size of 10 to 20 (Figure 1d) and contributed to the increase in base saturation only up to a dose of 1.2 g dm^{-3} of slag. An increase in V% was noted for the doses with decrease in particle size of the slag in medium texture soil (Table 2). Among the controls, both limestone and slag obtained V% values higher than the absolute control.

The shoot dry mass varied according to the doses and particle size of the slag, being higher for the dose of 1.2 g dm^{-3} which was calculated to reach a base saturation equivalent to 70% (recommended for *B. brizantha*) and for the particle sizes of 10-20 and 20-50 (Table 3). The sieves with coarser (ABNT 5-10) and finer mesh (ABNT <50) indicated the lowest production, while the corrective materials used in the experiment with original particle size (limestone and slag) showed the same behavior. There was no difference from the control without corrective. From the interaction between the factors evaluated, it was found that increasing the slag doses for the particle sizes of 5-10 and 20-50 resulted in a reduction of the plant dry mass (Figure 2a). These results can be explained by the observations made by Oliveira et al. (2000) when studying the effect of soil fertility correction on the development of *B. brizantha* cv. Marandu in a Latosol. The authors reported that these plants have little response of dry matter production after correction of soil acidity, attributing this behavior to the intrinsic tolerance of these plants to the components that make up soil acidity and good adaptability to soils poor in nutrients.

The calcium content in the shoots was not affected by the treatments, probably because in all situations calcium is within the proper range, which according to Malavolta (1992) varies from 1.5 to 6.0 g kg^{-1} (Table 3). However, the magnesium content was higher in the doses of 1.2 and 2.4 g dm^{-3} of slag. The finer particle sizes of the slag resulted in higher magnesium content in the plant shoots in accordance with the increased availability of soil nutrients under the same conditions. Analyzing the interactions, it was noted that for both calcium (Figure 2b) and magnesium (Figure 2c), the slag doses in the finer particle sizes increased levels in the plants.

In the soil with clayey texture, Si contents in the soil and plant did not differ as a function of the dose and particle size of the corrective material employed (Tables 2 and 3). In turn, Pereira et al. (2004) highlighted that blast furnace slag is less reactive than steel slag, and for increase silicon release to the soil from blast furnace slag it is necessary to use smaller particle sizes <0.3 mm. However, Prado et al. (2001) emphasized that the slag is a more abrasive material than limestone, reporting that Brazilian mills do not have the technical and economic capacity to grind this residue to such a small size, beyond that commonly used for limestone. Among the controls, slag showed higher availability of silicon in the soil compared to limestone and the control without correction, due to the chemical composition of the slag in the present study of 4.1 g kg^{-1} of soluble Si (Table 2). It was also observed that the interactions were not significant between the slag doses applied and particle size for the variables of silicon in the soil and the plants (Tables 2 and 3). For the medium texture soil (Table 3), the factors of slag dose and particle size did not influence production of plant dry mass. However, among the means it was observed that slag application resulted in increased dry mass in comparison with limestone and the absolute control. When analyzing silicon in the soil, it can be observed that both the largest as well as the finest particle sizes of the material resulted in greater availability of the element (Table 2) (Figure 3e). In the plant, it was observed that despite the increase in availability of this element in the soil with the slag doses, there was no significant difference of the levels in the plant. For the particle size evaluations, it was found that the greater availability of Si in the soil was obtained in the treatment with the sieve ABNT <50, that is, in the finer material of this treatment, where a higher Si content in the plant was observed. Comparing the behavior of the soils with regards to reactivity of the slag, the medium texture soil favored reaction of the material compared to the clayey soil.

The interactions were significant for pH, Ca, Mg, V% and Si in the soil with medium texture and calcium in the plant (Figure 3a, b, c, d, e). After six months of conducting this test, the effects of dose and particle size were verified on the concentrations of Mg, V% and Si in the soil (Table 4). The alteration of Mg^{2+} was directly reflected in base saturation, but without great efficiency to differentiate the effects of each particle size in this evaluation, thus disagreeing with the findings of Natale and Coutinho (1994) and Prado et al. (2004) with regards to greater base saturation in discriminating the efficiency of the limestone and slag size fractions, respectively.

Table 3. Dry mass, contents of calcium, magnesium and silicon in the plant, after application of the blast furnace slag and dolomitic lime in two soils – 1st cutting.

Treatment	Dry mass	Ca	Mg	Si
	g per pot		-------g kg^{-1}---------	
dystrophic Red Latosol – clayey texture				
Slag doses (D) (g dm^{-3})				
0.6	28.4 ^{ab}	6.5	3.0 ^{b}	8
1.2	31.0 ^{a}	7.0	3.8 ^{a}	8
2.4	24.6 ^{b}	6.5	3.7 ^{a}	8
Dms	4.67	0.98	0.42	0.19
Different particle sizes of the blast furnace slag (G)				
ABNT 5-10	24.5 ^{b}	7.0	3.1 ^{c}	8
ABNT 10-20	33.8 ^{a}	6.3	3.3 ^{bc}	8
ABNT 20-50	29.3 ^{ab}	6.8	4.0 ^{a}	8
ABNT <50	24.3 ^{b}	6.8	3.6 ^{ab}	8
Dms	5.94	1.24	0.54	0.24
Controls				
Limestone	26.8	6.5	3.6	8
Slag	23.6	6.3	3.6	10
No corrective	24.1	5.9	3.1	9
Dms	9.34	1.96	0.85	0.38
F-test				
Test x Trat	3.20^{ns}	1.79 ^{ns}	0.11 ^{ns}	1.17^{ns}
Between Tests	0.41^{ns}	0.28 ^{ns}	1.10 ^{ns}	0.31^{ns}
Doses	5.56**	0.91 ^{ns}	10.19**	0.45^{ns}
Particle sizes	8.20**	0.86 ^{ns}	7.32**	0.09^{ns}
D x G	3.94**	3.20 *	8.40**	2.15^{ns}
C.V.(%)	19.89	17.24	14.12	26.81
Dystrophic Red Latosol – medium texture				
Slag doses (D) (g dm^{-3})				
2.2	21.4	6.7 ^{b}	3.4 ^{b}	7.7
4.4	23.5	7.2 ^{ab}	3.7 ^{ab}	8.1
8.8	24.6	7.4 ^{a}	4.1 ^{a}	8.3
Dms	4.24	0.75	0.64	0.1
Different particle sizes of the blast furnace slag (G)				
ABNT 5-10	18.9	7.3	2.67 ^{c}	8.0 ^{ab}
ABNT 10-20	21.9	7.1	3.0 ^{bc}	6.8 ^{b}
ABNT 20-50	23.4	7.0	3.7 ^{b}	7.9 ^{ab}
ABNT <50	23.8	6.9	5.5 ^{a}	9.4 ^{a}
Dms	5.40	0.95	0.81	0.2
Controls				
Limestone	21.2 ^{ab}	7.8 ^{a}	5.4 ^{a}	6.5 ^{b}
Slag	25.6 ^{a}	6.3 ^{ab}	5.4 ^{a}	9.7 ^{a}
No corrective	15.7 ^{b}	5.2 ^{b}	2.7 ^{b}	6.5 ^{b}
Dms	8.49	1.50	1.28	6.5 ^{b}
F-test				
Test x Trat	0.56^{ns}	5.40*	10.49**	0.73^{ns}

Table 3. Contd.

Between Tests	3.98*	8.57**	18.06**	5.07*
Doses	1.18^{ns}	3.20*	3.77*	0.59^{ns}
Particle sizes	2.44^{ns}	0.42 ^{ns}	35.03**	4.85**
D x G	1.12^{ns}	5.82 *	1.55^{ns}	2.26^{ns}
C.V.(%)	22.71	12.57	19.12	20.96

Means followed by the same lower-case letter, in the same column, indicate no significant difference by the Tukey test (p< 0.5).

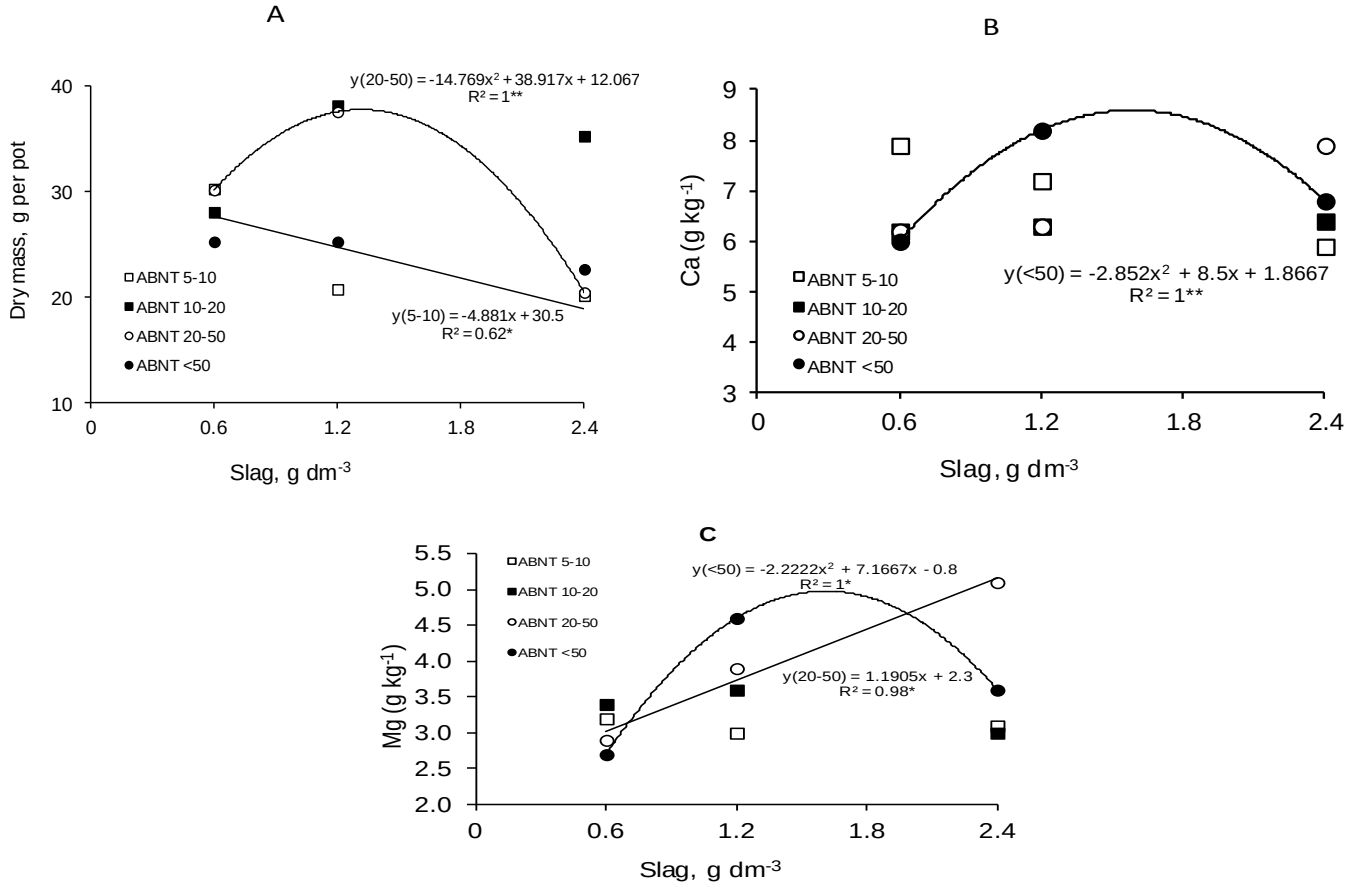

Figure 2. Dry mass (A) and concentrations of calcium (B) and magnesium (C) in plants of *B. brizantha* in function of the slag doses and particle size fractions in dystrophic Red Latosol with clayey texture – 1st cutting (** p<0.01; * p<0.05; ^{ns} – non-significant).

It was also highlighted that although the results of base saturation found in this study are inefficient in discriminating the reaction of the different slag size fractions, this variable becomes important because the pH was not influenced by the different particle sizes. Moreover, base saturation is presented as an additional practical benefit, since one of the liming methods is based on the V% value (Prado et al., 2004).

With respect to silicon in clayey soil, a greater reaction of slag was observed at six months after planting *Brachiaria brizantha* (Table 4). It was found that increasing the doses and the finer particle size fractions resulted in the highest Si concentrations in the soil (Figure 4e), corroborating with the results of Neto (2009), who observed that at 90 days of incubation the differences between the blast furnace slag particle sizes for Si concentrations were greater in relation to 30 days in a clayey soil.

It was found that although the doses influence Si availability in the soil, they did not interfere with its

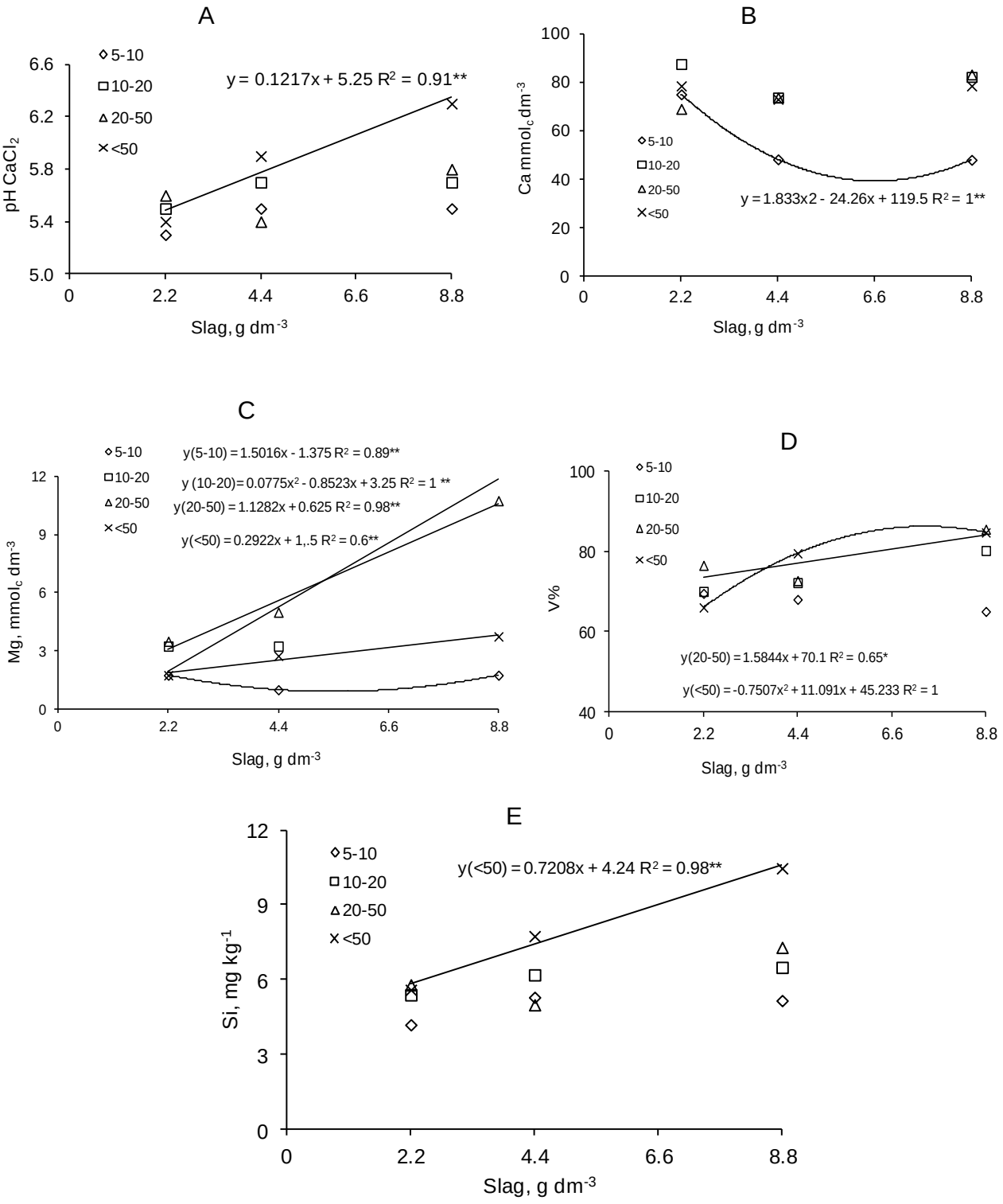

Figure 3. Effect of slag doses and particle size fractions on pH $CaCl_2$ (A) value, calcium (B), magnesium (C), V% (D) and available silicon (E) in dystrophic Red Latosol with medium texture – 1st cutting (** p<0.01; * p<0.05; ns – non-significant).

concentration in the plant (Table 4). The opposite effect was observed by Fonseca et al. (2009) when studying the behavior of slag, limestone and nitrogen in silicon absorption and production of marandu grass after application of corrective doses, finding that in the second cutting of the plants the Si content in the plant material

Table 4. Dry mass, pH, Ca, Mg, V and Si in the soil and plants after application of the blast furnace slag and limestone in the two soils – 2nd cutting.

Treatment	Dry mass	pH $CaCl_2$	Ca^{+2}	Mg^{+2}	V	Soil Si	Plant Si
	g per pot		$mmol_c\ dm^{-3}$		%	mg kg^{-1}	g kg^{-1}
Dystrophic Red Latosol – clayey texture							
Slag dose (D) (g dm^{-3})							
0.6	15.6	5.6	65.3	1.4 b	73.8 b	6.5 b	10.5
1.2	14.8	5.7	65.0	1.7 b	77.0 a	6.5 b	9.8
2.4	14.7	5.7	60.1	2.6 a	74.7 ab	7.3 a	9.7
dms	2.05	0.15	5.76	0.38	2.63	0.55	1.4
Different particle sizes of the blast furnace slag (G)							
ABNT 5-10	15.5	5.6	53.5	1.3 b	72.2 b	5.8 b	10.2 ab
ABNT 10-20	14.4	5.6	71.2	1.9 a	75.0 ab	6.9 a	11.0 a
ABNT 20-50	14.3	5.8	64.3	2.2 a	77.2 a	7.2 a	10.0 ab
ABNT <50	16.0	5.8	64.9	2.2 a	76.2 a	7.1 a	8.9 b
dms	2.61	0.19	7.33	0.49	3.35	0.70	1.8
Controls							
Limestone	15.1	5.8 a	49.7 ab	2.2	77.5	7.8 a	11.5 a
Slag	17.2	5.7 a	55.0 a	2.2	75.0	8.4 a	11.7 a
dms	4.15	0.19	12.11	0.64	4.37	1.11	2.93
F-test							
Test x Trat	2.87 ns	3.58 ns	40.40 **	3.78 ns	0.83 ns	9.39**	0.46 ns
Among Tests	0.79 ns	11.31**	3.30 *	0.00 ns	1.34 ns	15.12**	15.73 **
Doses	0.61 ns	0.42 ns	2.72 ns	32.68 **	4.49 *	9.01**	1.12 ns
Particle sizes	1.45 ns	3.90 ns	12.97 **	10.20**	5.72 **	12.89**	3.04 *
D x G	3.60**	4.00**	8.58 **	14.34**	11.06**	3.37**	7.74**
C.V.(%)	15.84	3.2	11.65	22.8	4.06	9.33	17.17
Dystrophic Red Latosol – medium texture							
Slag dose (D) (g dm^{-3})							
2.2	16.2	5.3 b	69.5	2.5 b	71.1 c	5.4 c	8.6 b
4.4	17.3	5.6 a	71.7	3.4 b	75.2 b	6.3 b	10.5 a
8.8	17.0	5.7 a	79.2	7.5 a	79.4 a	7.5 a	11.7 a
dms	1.94	0.20	11.19	1.12	3.56	0.49	1.44
Different particle sizes of the blast furnace slag (G)							
ABNT 5-10	14.9 b	5.3 b	58.5 b	1.3 c	67.6 b	4.9 d	8.0 b
ABNT 10-20	17.6 a	5.5 ab	63.1 b	6.1 a	76.2 a	5.9 c	11.2 a
ABNT 20-50	17.2 ab	5.6 ab	82.7 a	7.4 a	77.4 a	6.6 b	10.6 a
ABNT <50	17.6 a	5.7 a	89.7 a	3.0 b	79.7 a	8.0 a	11.4 a
dms	2.47	0.25	14.24	1.43	4.53	0.63	1.83
Controls							
Limestone	17.3 ab	5.5	61.2 ab	4.0	71.2	5.4 ab	7.7 ab
Slag	19.7 a	5.6	80.0 a	4.2	76.7	5.8 a	10.5 a
dms	3.94	0.40	22.39	1.86	5.92	0.99	2.88
Teste de F							
Test x Trat	0.94 ns	4.51 *	3.84 ns	0.45 ns	0.62 ns	38.16**	3.39 ns
Among Tests	3.26 *	2.18 ns	4.10*	0.07 ns	3.53 ns	5.89**	5.50*

Table 4. Contd.

Doses	1.10 ^{ns}	11.82**	2.45 ^{ns}	66.92**	16.12**	54.47**	13.96**
Particle sizes	3.78 *	6.07**	16.00**	54.64**	19.76**	60.42**	10.72**
D x G	0.70 ^{ns}	3.20*	2.25^{ns}	15.33**	1.50 ^{ns}	15.85**	3.86**
C.V	13.52	4.27	18.15	29.60	5.52	9.39	16.38

Means followed by the same lower-case letter, in the same column, indicate no significant difference by the Tukey test (p< 0.5).

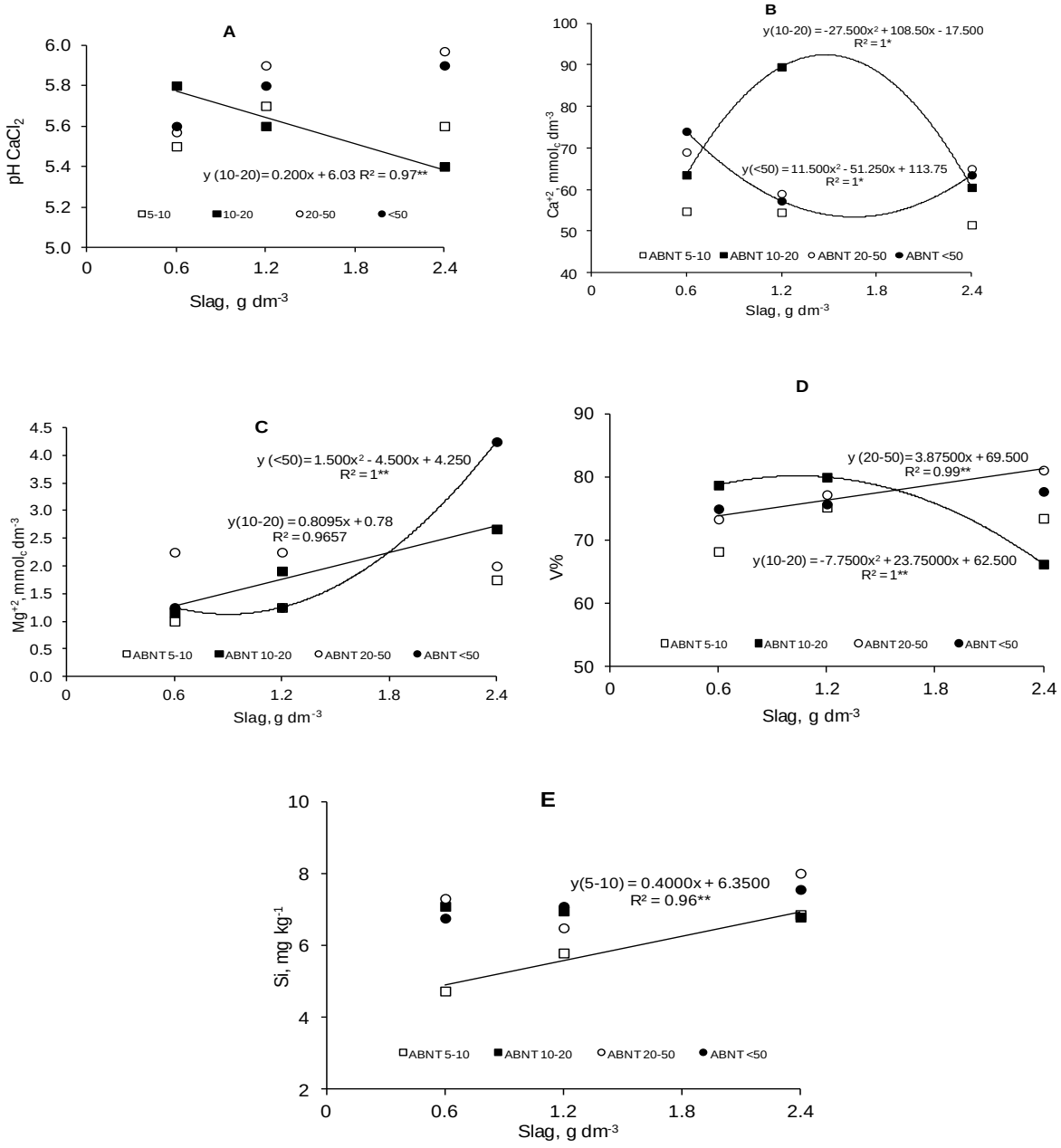

Figure 4. Effect of the slag doses and particle size fractions on the pH $CaCl_2$ value (A), calcium (B), magnesium (C), V% (D) and available silicon (E) in a dystrophic Red Latosol with clayey texture – 2nd cutting.

increased with the silicate doses. It was also observed that the intermediate particle sizes decreased dry mass (Figure 5a) and the finer particle sizes favored higher silicon contents in the leaves of brachiaria (Figure 5b).

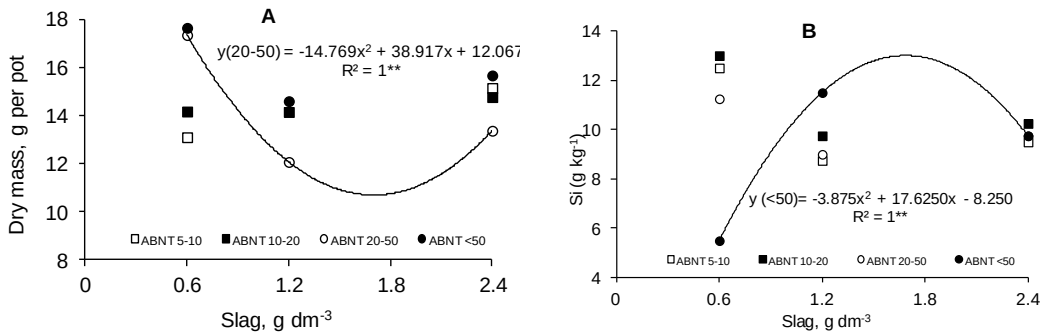

Figure 5. Dry mass (A) and silicon (B) content in plants according to the slag doses and particle size fractions of a dystrophic Red Latosol with clayey texture - 2nd cutting.

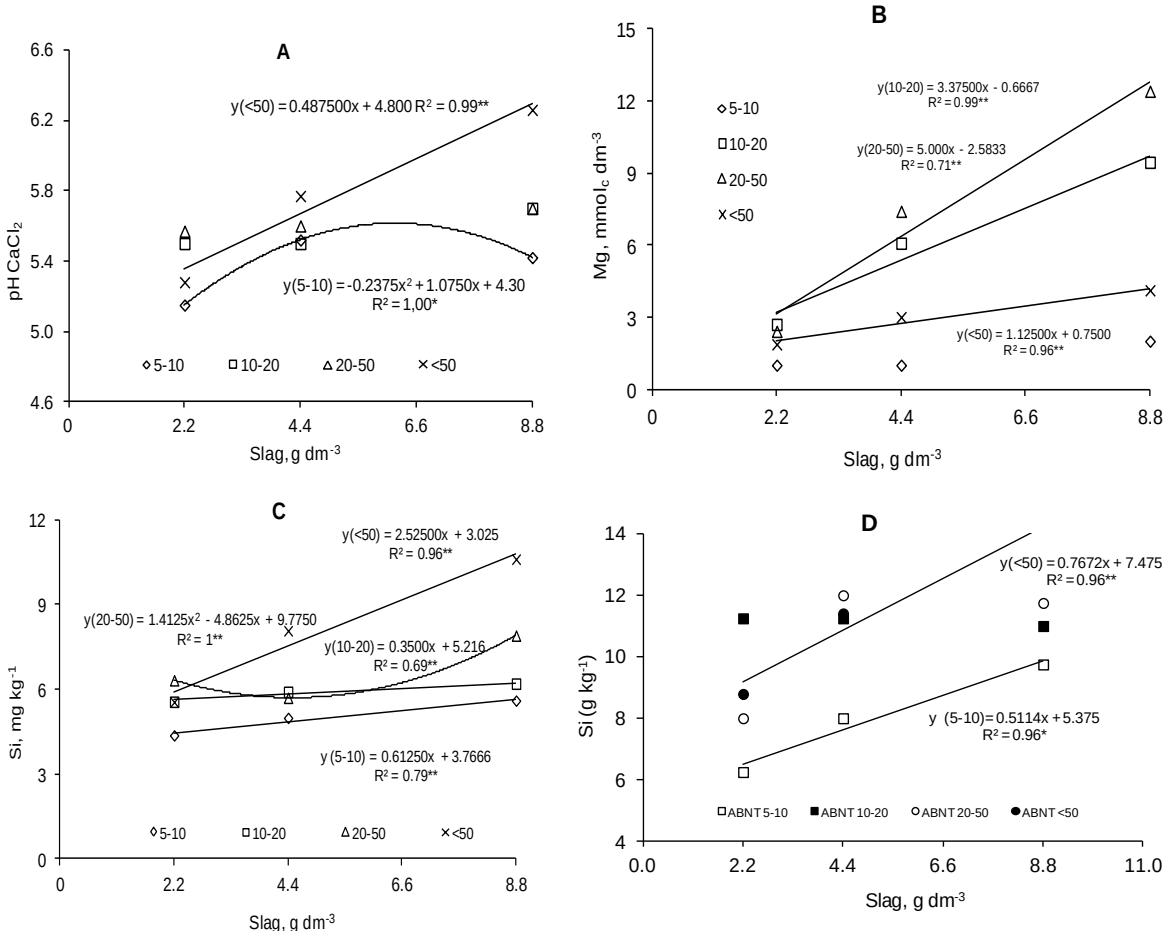

Figure 6. Effect of the slag doses and particle size fractions on values of pH $CaCl_2$ (A), magnesium (B) and available silicon (C) for a dystrophic Red Latosol with medium texture, and silicon (D) content in the plant shoots – 2nd cutting.

The slag doses influenced the pH $CaCl_2$, Mg^{+2} and V% of the soil, as well as the availability of Si in the soil and the plant (Table 4). Unlike clayey soil, the greater availability of Si in the soil provided by the slag doses also favored the higher content of this element in the plant. Table 4 shows the behavior of particle size after six months of *B. brizantha* cultivation in a soil of medium texture on the variables studied. The finer particle size (ABNT <50) resulted in the highest dry matter yield as well as the highest values of pH $CaCl_2$, Ca^{+2}, Mg^{+2}, V% and Si in the soil and the plant (Figure 6a, b, c, d).

Evaluating the interactions of the factors studied

(Figure 6a), only the coarsest (ABNT 5-10) and finest particle sizes (ABNT <50) influenced pH $CaCl_2$ in function of the slag doses, indicating that these fractions, even after 90 days of incubation with the soil and another 60 days of brachiaria cultivation, continued reacting and solubilizing. However, for the coarser particle sizes, with application of the highest dose (8.8 g dm^{-3}) there was a tendency to reduce its effect on pH. For magnesium (Figure 6b), only the coarsest particle size did not show a mathematical fit for the availability of this nutrient in the soil as a result of slag doses, favoring larger nutrient quantities in the soil.

All particle sizes in function of slag levels influenced the availability of silicon to the soil (Figure 6c). It is important to highlight that the greater the sieve mesh size, the greater the availability of Si to the soil, even with the increasing doses applied. On the other hand, only for the particle sizes ABNT 5-10 and <50 was a mathematical adjustment obtained which represented Si uptake by the plants as a function of slag levels (Figure 6d).

Conclusion

Blast furnace slag, in its different particle size fractions, differently influenced the pH, Ca and Mg of medium texture soil, where the fraction that passed through the ABNT 50 sieve had the greatest effect on the chemical attributes evaluated. The corrective materials, blast furnace slag and limestone, act similarly on pH, Ca, Mg and V%. For greater liberation of silicon to the soil and absorption by plants it is necessary to use smaller particle sizes (<0.3 mm) in soil with average texture and intermediate sizes (0.85 to 1.41) in soil with clayey texture.

Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(38), pp. 3718-3725, 17 September, 2015
DOI: 10.5897/AJAR2015.9903
Article Number: 8EDD79455560
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Dynamics in nutritional qualities of tef and wheat straws as affected by storage method and storage duration in the central highlands of Ethiopia

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Received 12 May, 2015; Accepted 18 June, 2015

This study assessed the effects of storage method and storage duration on the dynamics in nutritional qualities of tef (Eragrostis tef-cereal indigenous to Ethiopia) and wheat straws in Ejere woreda, central highlands of Ethiopia. The trial was designed with a factorial combination of two storage methods (shelter shade, open-air) and four storage durations (zero, two, four and six months). A total of 12 farmers (six conserving tef straw and the rest six conserving wheat straw) were selected for sampling and evaluation of the crop residues. Among the six farmers conserving each of the crop residues, three of them stored the straws in open-air while the other three used shelter shade. All the measured parameters (DM, ash, CP, IVOMD, ME, NDF, ADF and lignin contents) were significantly ($p<0.05$) affected by storage method and storage durations. The CP, IVOMD and ME contents showed consistently decreasing trends with prolonged storage durations, with higher nutrient losses in straws stored in open air than those stored under shelter. The estimated losses in CP contents during the six months storage period, respectively when stored under shelter and in open air were 30.2 and 41% in tef straw; and 22.3 and 46.9% in wheat straw. Similarly, IVOMD was reduced by 35.8 and 41.1% in tef straw and by 33.3 and 42.6% in wheat straw when stored under shelter and in open air, respectively during the six months storage period. On the other hand, the fiber fractions showed increasing trends with prolonged storage durations, with higher rates of increase in straws stored in open air than those stored under shelter. During the six months storage period, NDF content was increased by 8.5 and 13.6% in tef straw and by 8.9 and 12.9% in wheat straw, respectively when stored under shelter and in open air. The ADF content was increased by 8.4 and 12.2% in tef straw and by 14.9 and 19.3% in wheat straw when stored under shelter and in open air condition, respectively. Lignin content was also increased by 14.2 and 53.1% in tef straw and by 37.7 and 32.2% in wheat straw when stored under shelter and in open air, respectively. The decrease in CP and IVOMD, and the increase in fiber fractions with prolonged storage durations in the crop residues could be attributed to the loss of readily soluble nutrients and the higher concentration of the fibrous materials in the feed DM mainly when stored in open air. The result revealed that quality of crop residues which is inherently low would be substantially reduced further during storage especially when stored in open air. Therefore, supplementation schemes should consider the storage method, storage duration and the associated dynamics in nutritional quality in crop residue-based feeding system of dairy cattle.

Key words: Crop residues, nutritional quality, storage method, storage duration, tef and wheat straws.

INTRODUCTION

Poor animal nutrition and productivity arising from inadequate supply and low quality feed are among the major constraints facing livestock production in developing countries. The fibrous agricultural residues represent a considerable feed resource in the smallholder mixed farming system of the tropics where most of the land is primarily devoted to human food production (Nordbloom, 1988). Crop residues constitute an important source of ruminant feed during the long dry season in mixed crop-livestock farming systems of Ethiopia. According to Zinash and Seyoum (1991), about 70% of crop residues are used as animal feed while other uses and field losses associated with harvesting, collection, transportation and storage account for the remaining 30% in the highlands of Ethiopia. Ethiopian smallholder farmers grow diversified crops and usually produce a mixture of crop residues including the cereal straws like tef, wheat, barley, oats, maize, and sorghum; and different grain legume haulms. There is no exact figure on the quantity of crop residues produced in the country. But, from a total of 12 million ha of land covered by different crops (CSA, 2012), an estimated 40 million tones of crop residues could be produced considering an average grain yield of 1.7 tone/ha and average straw to grain ratio of 2:1 suggested by Daniel (1988). Nevertheless, the actual figure could be likely to be more as various high yielding crop varieties have been cultivated by large number of farmers. As more and more land is put under crop cultivation, grazing lands as sources of feed become scarce and crop residues particularly cereal straws remain the important sources of basal feed for dairy cattle. According to De Leeuw (1997), the potential availability of crop residues for livestock feed increases with an increase in the area of land put under crop production. In areas where the proportion of cropped land is relatively low, the contribution of crop residues to the total feed will be minimal. For instance, Varvikko (1991) reported that in Selale district of Northern Shoa, Ethiopia, where only 40% of the land is cultivated, 40% of livestock feed consisted of stored hay, while only 12% was contributed by crop residues. On the other hand, Gryseels (1988) reported that in the highlands of Ethiopia where grazing lands are being converted to crop land, crop residues and post-harvest stubble grazing accounted for about 90% of all feeds.

Crop residues are generally characterized by high content of fiber (usually above 40%), low nitrogen (0.3 to 1.0%) and low content of essential minerals such Na, P and Ca (Adegbola, 1998; Smith, 1993). Cell wall estimated by neutral detergent fiber (NDF) accounts for at least 72% of the dry matter and represents a large source of potential energy for ruminants (Umunna and Iji, 1993). The ability of rumen microorganisms to digest cell polysaccharides, consisting mainly of cellulose and hemicellulose is limited by lignin. As fiber is often used as a negative index of nutritive value in predicting the total digestible nutrient (TDN) and net energy (Van Soest, 1988), the available energy from crop residues is likely to be low in relation to crop residue yield. The consequences in ruminant animals are low feed intake (about 1.2 kg DM/100 kg live weight) and low performance (Adegbola, 1998). According to Chenost and Sansoucy (1989), feeding value of crop residues is limited by their low voluntary intake, low digestibility and low nitrogen, mineral and vitamin contents. Generally, the quality of a straw or its feeding value is influenced by its chemical composition, level of voluntary intake, digestibility and efficiency of metabolism at the tissue or cell level (Doyle et al., 1986).

The nutritional quality of crop residues which is inherently low is subjected to variations depending up on a number of factors *viz*., species and variety of the crops, stage of harvest, leaf:stem ration, soil fertility, fertilizer application, plant diseases, handling and storage conditions (Preston and Leng, 1986). Particularly crop residue management practices (harvesting, handling, collection and storage) have effects on both the quantity and quality of the residues. Owen and Aboud (1988) stated that harvesting, handling and storage systems should minimize the loss of leaf and leaf sheath (the more nutritious parts) of straws. They further emphasized that delayed harvesting of the crop would be expected to cause greater loss of leaf and leaf sheath, with a consequent reduction in nutritive values. In Ethiopia, since crop residues are produced only once in a year after crop harvest following the main rainy season, their quality and contribution for the annual feed supply depends on proper collection, conservation and utilization. Different studies (Tesfaye and Chairatanayuth, 2007; Funte et al., 2010; Zewdie, 2010) have shown that collection and storage of crop residues is one of the important copping strategies to mitigate dry season feed shortage in different parts of the country. According to Fekede (2013), crop residues are used as sources of roughage feed by dairy cattle on average for about six depending on their level of awareness, resource capacity and intended time of using the stored feed. Despite the anticipation that qualities of crop residues could undergo further reduction during storage, there is no documented information on the dynamics in nutritional qualities of crop

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Table 1. Crop residues (tef and wheat straws) sampling dates for laboratory evaluations.

S/N	Sampling date	Description
1	26 January 2012	At threshing (just prior to storage)
2	26 March 2012	2 months after storage under shade and in open air
3	26 May 2012	4 months after storage under shade and in open air
4	26 July 2012	6 months after storage under shade and in open air

months per year as stored feeds in selected milk shed areas of the central highlands. Some farmers store crop residues in open air while others use shelter shades residues in the process of production, conservation and utilization under Ethiopian condition. Such information will help to design appropriate conservation and management strategies, and also to provide evidence to extensionists, advisors and farmers about proper management and utilization of crop residues, including the supplementation scheme in crop residue based livestock feeding systems.

This study was therefore conducted to assess the effects of storage methods and storage durations on the dynamics in nutritional qualities of tef and wheat straws in the central highlands of Ethiopia.

MATERIALS AND METHODS

Study area and sampling procedures

The study was conducted in Ejere woreda, located about 40km west of Addis Ababa in West Shewa Zone of the Oromia Regional State. The woreda is one of the milk shed areas and well linked to fluid milk market. Moreover, various crops are grown in the area from which different crop residues are produced and conserved for use as feed during periods of feed shortage. The area is closer to Holetta Agricultural Research Center and easily accessible for monitoring and sampling of crop residues for laboratory analysis. The effect of storage method and storage duration on nutritional qualities of crop residues was studied using tef (*Eragrostis tef*) and wheat (*Triticum aestivum*) straws which were the dominantly produced crop residues in the study area. A total of 12 accessible farmers (6 conserving tef straw and 6 conserving wheat straw) were selected based on their willingness to cooperate for monitoring and sampling of crop residues for laboratory analysis. Among the six farmers conserving each of the aforementioned crop residues, three of them stored the crop residues in open air, while the other three used shelter shade for storing the crop residues. Sampling of the crop residues for laboratory analysis began during the time of threshing and continued at two months interval for the subsequent 6 months storage period (Table 1). During each stage of sampling, three samples were collected for each crop residue under the two storage methods. The samples were properly composited, divided into two equal halves and subjected to laboratory analysis in two replications.

Laboratory analysis

After oven drying (65°C, 72h), all the samples collected during the different sampling stages were chopped into shorter fiber lengths and milled through 1-mm sieve size for chemical analysis. The samples were analyzed for dry matter (DM) (oven-dried at 105°C overnight) and total ash using method 924.05 of AOAC (1990). The Kjeldahl wet digestion procedure (AOAC, 1999; method 954.01) was used to determine the total N content. The crude protein (CP) content was then estimated by multiplying the Kjeldahl N by 6.25. The *in-vitro* organic matter digestibility (IVOMD) was determined according to the two-stage rumen fluid technique described by Tilley and Terry (1963). Rumen fluid was obtained from three rumen-cannulated Zebu x Holstein crossbred steers fed on a basal diet of native grass hay and supplemented with 2 kg concentrate per day. The same natural pasture used in this study was the source of the hay fed to the donor animals. Metabolizable energy (ME) content was estimated from IVOMD according to MAFF (1984): ME (MJ/kg DM) = 0.015*IVOMD (g/kg DM). The neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin were determined following the standard procedures (NDF: Mertens (2002), analyzed with heat stable amylase and expressed without residual ash; ADF: AOAC, 1995, no. 973.18, expressed without residual ash after incineration at 500°C for 1 h; lignin: Robertson and Van Soest (1981), determined by solubilization of cellulose with sulphuric acid).

Data analysis

Data was analyzed using Statistical Analysis System (SAS, 2002) and the significance of mean differences was tested using the least significance difference (LSD) method. Differences were considered significant when $P<0.05$.

The following statistical model was used for analysis for each of tef and wheat straws:

$$Y_{ijkl} = \mu + r_i + s_j + d_k + (s*d)_{jk} + e_{ijkl,}$$

where, Y = the measured parameter, μ = the overall mean, ri = effect of i^{th} replication, s_j = effect of j^{th} storage method, d_k = effect of k^{th} storage duration, $(s*d)_{jk}$ = the interaction effects of storage method and storage duration and e_{ijkl} = the random error.

RESULTS AND DISCUSSION

The interaction of storage method and storage duration had no significant effect ($p>0.05$) on all measured nutritional parameters in both crop residues. The dynamics in DM, ash, CP, IVOMD and ME contents of tef and wheat straws stored under shelter shade and in open air for different durations after threshing are presented in Tables 2 and 3, respectively. Both storage method and storage duration had significant effects ($p<0.05$) on DM,

Table 2. Dry matter, total Ash, CP, IVOMD and ME contents of tef straw stored under shelter and in open air conditions for different durations.

Storage method	Parameter	Storage duration (months)				Mean±SE
		Zero (at threshing)	Two	Four	Six	
Shelter shade	DM	924.0^{b}*	918.1^{c}	928.1^{a}	894.7^{d}*	916.2±7.5
	Ash	63.2^{c}*	64.9^{a}*	63.7^{b}*	57.8^{d}*	62.4±1.6
	CP	47.1^{a}*	43.9^{b}*	37.6^{c}*	32.9^{d}*	40.4±3.2
	IVOMD	522.3^{a}*	492.3^{b}*	429.4^{c}*	335.6^{d}*	444.9±41.3
	ME	7.9^{a}	7.4^{b}	6.5^{c}*	5.1^{d}*	6.7±0.6
Open air	DM	929.5^{a}*	917.8^{b}	927.9^{a}	855.8^{c}*	907.8±17.5
	Ash	62.8^{b}*	66.1^{a}*	60.2^{c}*	49.9^{d}*	59.8±3.5
	CP	50.3^{a}*	37.9^{b}*	33.2^{c}*	29.7^{d}*	37.8±4.5
	IVOMD	514.8^{a}*	476.6^{b}*	385.4^{c}*	303.3^{d}*	420.0±47.4
	ME	7.7^{a}	7.1^{b}	5.8^{c}*	4.6^{d}*	6.3±0.7

$^{a-d}$Parameter values with different superscripts within a storage method in a row differ significantly ($p<0.05$); *values for the same parameter differ significantly between the two storage methods within a column ($p<0.05$); DM (g/kg); ash, CP and IVOMD measured in g/kg DM; ME (MJ/kg DM).

Table 3. Dry matter, total Ash, CP, IVOMD and ME contents of wheat straw stored under shelter shade and in open air conditions for different durations.

Storage method	Parameter	Storage duration (months)				Mean±SE
		Zero (at threshing)	Two	Four	Six	
Shelter shade	DM	929.8^{b}*	924.0^{b}*	937.0^{a}*	855.0^{c}*	911.5±19.0
	Ash	99.3^{c}*	105.9^{a}	104.1^{b}*	91.6^{d}*	100.2±3.2*
	CP	40.9^{a}*	36.5^{b}*	32.7^{c}*	31.8^{d}*	35.5±2.1
	IVOMD	470.6^{a}*	451.0^{b}*	411.4^{c}*	313.7^{d}*	411.7±34.9
	ME	7.1^{a}	6.8^{b}	6.2^{c}*	4.7^{d}*	6.2±0.5
Open air	DM	934.8^{a}*	919.4^{b}*	935.9^{a}*	863.8^{c}*	913.5±17.0
	Ash	92.0^{b}*	105.7^{a}	85.8^{c}*	78.8^{d}*	90.6±5.7*
	CP	41.6^{a}*	32.2^{b}*	26.3^{c}*	22.1^{d}*	30.6±4.2
	IVOMD	466.3^{a}*	419.8^{b}*	355.4^{c}*	267.9^{d}*	377.4±43.0
	ME	7.0^{a}	6.3^{b}	5.3^{c}*	4.1^{d}*	5.7±0.6

$^{a-d}$ Parameter values with different superscripts within a storage method in a row differ significantly ($p<0.05$); *values for the same parameter differ significantly between the two storage methods within a column ($p<0.05$); DM (g/kg), ash, CP and IVOMD measured in g/kg DM; ME (MJ/kg DM).

ash, CP, IVOMD and ME contents of both the crop residues. The DM content of both the straws showed inconsistent trends along the different durations of storage, but lower values were recorded six months after storage than the earlier storage durations in both storage methods. The DM content of both the straws tended to be higher during forth month after storage (sample taken during the month of May) under both storage methods. This may be attributed to the high loss of moisture from the stored crop residues as a result of higher temperature associated with the long dry season. Similarly, the ash content did not show consistent trends with storage durations, but lower values were recorded six months after storage in both crop residues under both the two storage methods. Wheat straw generally had higher ash content than tef straw which agrees with the reports of

various authors under the Ethiopian condition (Kabaija and Little, 1988; Yitaye, 2008; Zewdie, 2010; Firew and Getnet, 2010). In storage, the physical and chemical properties of straws generally deteriorate due to loss of nutrient and water in respiration process. Temperature is one factor that affects respiration rate and preservation of postharvest life in storage. Subsequent to grain harvest, the conditions under which the straw is stored may affect its quality. The degree of protection from the environment appears to determine the extent of storage associated losses in quality. Following the initial and rapid losses of loosely-bound nutrients, rate of loss decreases for nutrients held more tightly in the internal and external structures of the residues (Schreiber and McDowell, 1985).

The CP, IVOMD and ME contents of the two crop residues showed consistently decreasing trend with prolonged storage durations under both storage methods (Tables 2 and 3). However, comparatively higher nutrient losses were recorded in open air storage than under shelter shade storage method. The estimated losses in CP content of tef straw during the six months storage period were 30.2 and 41%, respectively when stored under shelter shade and in open air. Likewise, CP content of wheat straw was reduced by 22.3 and 46.9% when stored under shelter shade and in open air, respectively during the six months storage period. The higher loss in CP content recorded for wheat straw than tef straw under the open air storage method may be attributed to the fact that tef has a fine stemmed straw which can be firmly stacked in such a way to minimize percolations of rain water and exposures to other inclement weather conditions. Devendra (1982) reported a preliminary investigation of the effects of storage conditions on the chemical composition of the straws. The three conditions investigated in his study represent fully exposed straw, partially exposed straw and straw kept under shelter. Exposure to the weather decreases crude protein content from 5.6 to 3.4%, Ca from 0.31 to 0.21% and P from 0.11 to 0.02%. To optimize the feeding value of cereal straws it is preferable to store them under cover and keep them in a dry condition. Since residues have no ability to acquire replacement of nutrients once separated, detached organs lose a larger percentage of their initial concentrations when exposed to leaching (Marschner and Marschner, 2012). The extent of protection of straw during storage varies widely. Under good storage conditions the general experience is that little deterioration in nutritive value occurs. However, deleterious effects have been recorded when effective protection has not been provided. The major causes of nutrient loss during storage as described by Tripathi et al. (1995) include shattering loss of leaves, leaching of soluble nutrients by rain, potentially large losses due to mold damage and bleaching by exposure to sunshine.

The reductions in IVOMD of tef straw during the six months storage period are estimated to be 35.8 and 41.1% under shelter shade and in open air storage methods, respectively. Similarly in wheat straw, IVOMD was reduced by 33.3 and 42.6%, respectively when stored under shelter shade and in open air during the six months storage period. The ME content is also reduced by 35.4 and 40.3% in tef straw and by 33.8 and 41.4% in wheat straw, respectively under shelter shade and in open air storage methods during the six months of storage duration. The result clearly depicted that storage in open air resulted in higher nutrient losses in tef and wheat straws. This calls for the need to examine our feeding strategies (especially supplementation schemes) accordingly when feeding dairy cows using crop residues as basal diets. The research result indicated that heavy rain may leach out the cell contents resulting in low digestibility (Pearce et al., 1979). Similar effects would be expected under conditions of inadequate protection from moisture when cut straw is stored. In addition, moldiness may reduce the acceptability of the material to animals.

Pearce et al. (1979) reported that rain damaged cereal straw has lower quality than undamaged straw. The *in-vitro* organic matter digestibility of the straws which have suffered by rain damage ranged from 25 to 34% compared with 30 to 49% for the undamaged straw. It is likely that leaching of water soluble carbohydrates was the major effect of the rain damage but under prolonged shower conditions, microbial and fungal actions may also depress the concentration of fermentable constituents. Rainfall intensity plays a major role in crop residue nutrient loss. As with standing plants, residues leach larger volumes of nutrients in conditions of prolonged low rainfall intensities than in short periods of heavy rainfall as a result of the slower saturation rate, time to runoff and prolonged straw-water contact (Schreiber and McDowell, 1985). Variation in rate of nutrient loss depends on individual nutrient leachability (Schreiber and McDowell, 1985). Nutrient leaching in both corn and wheat residues follow a hyperbolic pattern and nutrient loss in wheat straw is very rapid. One study demonstrated that the most nutrient loss from wetted straw occurred in the first few minutes of a 60 min rainfall period (Schreiber, 1985). Corn stover follows a similar leaching pattern (Schreiber, 1985; Schreiber, 1999); after 212 days of exposure to simulated rainfall events, losses of P, N (NO3-N plus NH4-N) and C were measured to be 0.92, 2.04 and 43 kg ha^{-1}, or 6, 1.3 and 1% of total corn residue nutrient content, respectively. However, 76, 62, and 77% of P, N and C, respectively were lost in the first 90 days of the experiment (Schreiber, 1999). All these evidences indicate that postharvest handling and storage of straws can have significant effects on final straw quality.

Tables 4 and 5 indicate the dynamics in contents of the fiber fractions (NDF, ADF and lignin) in tef and wheat straws, respectively as affected by storage method and

Table 4. NDF, ADF and lignin contents of tef straw stored under shelter shade and in open air conditions for different durations.

Storage method	Parameter (g/kg DM)	Storage duration (months)				Mean±SE
		Zero (at threshing)	Two	Four	Six	
Shelter shade	NDF	720.6^{d*}	739.4^{c*}	765.3^{b*}	781.8^{a*}	751.8±13.6
	ADF	458.9^{d*}	466.6^{c*}	483.1^{b*}	497.3^{a*}	476.5±8.6
	Lignin	75.3^{c*}	72.9^{d*}	79.8^{b*}	86.0^{a*}	78.5±2.9*
Open air	NDF	723.5^{d*}	764.3^{c*}	795.4^{b*}	822.2^{a*}	776.4±21.2
	ADF	464.6^{d*}	493.0^{c*}	502.6^{b*}	521.1^{a*}	495.3±11.8
	Lignin	81.0^{d*}	96.3^{c*}	98.9^{b*}	124.0^{a*}	100.1±8.9*

$^{a-d}$Parameter values with different superscripts within a storage method in a row differ significantly ($p<0.05$); *values for the same parameter differ significantly between the two storage methods within a column ($p<0.05$).

Table 5. NDF, ADF and lignin contents of wheat straw stored under shelter shade and in open air conditions for different durations.

Storage method	Parameter (g/kg DM)	Storage duration (months)				Mean±SE
		Zero (at threshing)	Two	Four	Six	
Shelter shade	NDF	730.8^{d*}	754.9^{c*}	776.1^{b*}	795.9^{a*}	764.4±14.0
	ADF	502.9^{d*}	513.4^{c*}	545.7^{b*}	578.0^{a*}	535.0±17.0
	Lignin	70.8^{d*}	78.4^{c*}	88.0^{b*}	97.5^{a*}	83.7±5.8
Open air	NDF	734.9^{d*}	772.1^{c*}	797.3^{b*}	829.5^{a*}	783.5±20.0
	ADF	505.4^{d*}	532.9^{c*}	579.2^{b*}	603.2^{a*}	555.2± 22.1
	Lignin	77.4^{d*}	91.5^{c*}	97.6^{b*}	102.3^{a*}	92.2±5.4

$^{a-d}$Parameter values with different superscripts within a storage method in a row differ significantly ($p<0.05$); *values for the same parameter differ significantly between the two storage methods within a column ($p<0.05$).

storage duration. Both storage method and storage duration had significant effects ($p<0.05$) on the fiber contents of both the crop residues. In contrary to CP, IVOMD and ME contents shown in Tables 2 and 3, the fiber fractions showed increasing trends with prolonged storage durations under the two storage methods in both the crop residues except for the lower lignin content recorded two months after storage than the figure recorded at threshing in the case of tef straw. The increase in NDF content of tef straw during the six months storage period are estimated to be 8.5 and 13.6%, respectively when stored under shade and in open air conditions. Similarly, NDF content of wheat straw is increased by 8.9 and 12.9% when stored under shelter shade and in open air conditions, respectively during the six month storage period. The estimated increases in ADF content of tef straw during the six months storage period are 8.4 and 12.2% when stored under shelter shade and in open air conditions, respectively.

In wheat straw, ADF content was increased by 14.9 and 19.3%, respectively when stored under shelter shade and in open air conditions during the six months storage period. The lignin content was also increased by 14.2 and 53.1% in tef straw and by 32.2 and 37.7% in wheat straw, respectively when stored under shade and in open air conditions during the six months storage period. It was generally noted that storage under open air condition resulted in higher concentrations of the fiber fractions in crop residues (tef and wheat straws in this case). The increasing trend in contents of the fiber fractions in the straws with prolonged storage durations could be attributed to the loss of readily soluble nutrients and the consequent higher concentration of the fibrous materials in the feed DM mainly when stored in open air condition. Concentrations of the fiber fractions were comparatively higher in wheat straw than in tef straw. This was in agreement with the reports of different authors in the country (Kabaija and Little, 1988; Yitaye, 2008; Zewdie, 2010; Firew and Getnet, 2010). The higher contents of the fiber fractions in wheat straw than in tef straw may be attributed to the relatively thick stem with higher

concentrations of cell wall materials in the former crop residue than the latter.

Conclusion

Both storage method and storage duration had considerable effects on nutritional qualities of tef and wheat straws. The CP, IVOMD and ME contents of both the crop residues showed consistently decreasing, while the fiber fractions showed consistently increasing trends with prolonged storage durations under both storage methods. However, the dynamics in nutritional qualities (the rates of decline in CP, IVOMD and ME, an increase in the fiber fractions) were higher when the crop residues were stored in open air than under shelter shade. Generally, the nutritional quality of tef and wheat straws which is inherently marginal to livestock/dairy cattle nutrition is liable to further substantial reductions during storage, mainly under open air storage conditions. Therefore, supplementation schemes should consider the storage method, storage duration and the associated dynamics in nutritional quality in feeding systems where tef and wheat straws are used as sources of roughage feed by dairy cattle and other livestock species.

Conflict of Interest

The author(s) have not declared any conflict interest.

ACKNOWLEDEGMENT

The study was funded by Ethiopian Institute of Agricultural Research and laboratory analytical service was provided by Animal Nutrition Research Program of Holetta Research Center.

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Vol. 10(38), pp. 3726-3730, 17 September, 2015
DOI: 10.5897/AJAR12.539
Article Number: 5BFC42555562
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Prediction of leaf N in centipedegrass by a chlorophyll meter

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Received 24 February, 2012; Accepted 25 August, 2015

The persistence of color response to fertilizer treatments is an important criterion of turfgrass performance. Centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.) is widely used throughout sub-tropical region, and was selectedas the subject of this study. Four N treatments were applied, with NH_4NO_3monthly atan application rate of 0, 2.5(1.4), 5.0(2.8), and 10.0(5.6) g-N/m^2 (oz). A slow-release fertilizer applied as Osmocote at an application rate of 7.5g-N/m^2 was added to each treatment. The trial was conducted in the greenhouse for 12 weeks. Chlorophyll content, N content, leaf area, plant biomass measurement, and growth characteristics were used to determine turfgrass growth qualities. From the results we found that highest average plant height, leaf length, leaf width, shoot dry weight (DW), and root DW were obtained with all fertilizer products application than without N fertilizer input. Regardless ofN fertilizer concentrations, the first leaf, and third leaf CMR increased with N treatments compared to the control in this study. Centipedegrass CMR closely corresponded to N application concentration. The experimental results revealed that average sufficiency index (142) showed an adequate amount of tissue N supplied at this stage of centipedegrass growth. Linear regression of leaf chlorophyll content and CMR values was found in this study (r^2=0.9436, P<0.01). This research suggested that the chlorophyll meter could be useful to directly understand the tissue N in centipedegrass. The linear regression of dry weight-based or area-based N concentration on leaf CMR values was highly significant (P<0.01). The results also illustrated that CMR values correlated with N_{dw} (r^2=0.9034) (N content/dry weight) better than with N_a (r^2=0.7611) (N content/leaf area), indicating that CMR estimated N_{dw} better than N_a. Thus, this investigation suggested that N_{dw} is the major contributor to variation in SPDA-502 chlorophyll meter readings. Chlorophyll meter measurement can offer an alternative to the tissue test, and can aid in determining fertilizer N recommendations for centipedegrass was demonstrated in this study.

Key words: Centipedegrass, chlorophyll meter readings, N content, dry weight.

INTRODUCTION

Centipedegrass is a native turfgrass of Taiwan and is one of the most popular turfgrass species widely used in other subtropical regions (Turgeon, 1991). Efficient use of N fertilizer is important to economical and environmental

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Abbreviations: CMR, chlorophyll meter reading; **N**, nitrogen; **SLW**,specific leaf weight.

turfgrass production, and to ground and surface water quality (Emmons, 1995; Stevenson, 1986). Assessment of fertilizer product performance under controlled conditions is a potentially useful method for prescreening turfgrass response to fertilizer treatment before conducting actual field trials (Horst et al., 1994; Miller and Thomas, 2003; Kuo et al., 2005). While the field performance of various N sources is difficult to forecast future performance given unknown climate (Takebe, 1990). In field, the turfgrass quality after treated with N fertilizer is still determined largely through visual assessment.

However, visual assessment is generally imprecise, not definitive, and dependent on evaluator prejudice (Ichie et al., 2002). Turfgrass quality cannot be measured in the same way as that of other agricultural crops (Morris, 2001). More efficient, low-cost, and non-destructive methods of pre-screening turfgrass growth are required to help tackle the problem of excessive fertilizer use in intensively cultivated areas (Bell et al., 2004). However, the traditional method of extraction and quantifying plant N content is both times consuming and destructive. Recently, reflectance measurements are popular using in prediction fertilizer status in crops (Trenholm and Unruh, 2005). In addition, more promising method of chlorophyll meters enable quick and easy measurement of leaf blade greenness, which is an indicator of shoot N and chlorophyll content (Rodriguez et al., 2000; Takebe et al., 1990; Turner and Jund, 1991; Wood et al., 1992a). Chlorophyll meters also display promise as a tool for improving N management (Peterson et al., 1996; Stevens and Hefner, 1999). Numerous researchers have proved the positively linear relationship between tissue N status and chlorophyll meter readings of some crops (Fox et al., 1994; Kantety et al., 1996; Minotti et al., 1994; Wood et al., 1992b).

Moreover, conditions for the use of chlorophyll meters (Minolta SPAD-502) recently have been clarified for wheat (Denuit et al., 2002), woody plants (Ichie et al., 2002), rice (Ramesh et al., 2002), peanut (Nageswara Rao et al., 2001), and barley (Giunta et al., 2002). However, the application of chlorophyll meters to more economically valuable and popular warm-season species, such as centipedegrass has not been explored. Turfgrass response to different fertilizer products has been evaluated in a numbers of different species but hardly found in centipedegrass. The present experiment comprised two parts. First, centipedegrass response to fertilizer rates and sources was screened; second, the relationship between Minolta SPAD-502 chlorophyll meter readings and plant biomass, plant growth characteristics, leaf area, and N status in leaf was investigated.

MATERIALS AND METHODS

Seeds of centipedegrass (from the Rose Extension Center, Taipei, Taiwan) were grown in a 15 cm diameter X 20 cm deep plastic pot containing loam, peat moss and vermiculite (2:2:1 = v:v:v) medium. The greenhouse study was conducted in the environmental controlled greenhouse (22/20°C day/night, 3.64·MJ $m^{-2}·d^{-1}$) (Model LX-102 potable light meter, Alfa Electronics inc., NJ.) located in the campus of Taiwan University, Taipei. Pots were watered twice weekly. Different sources and rates of N were applied every 4 weeks as Ammonium Nitrate (NH_4NO_3; Tai-Fertilizer Company, Taipei, Taiwan) at an application rate of 0, 2.5(1.4), 5.0(2.8), and 10.0(5.6) g-N/m^2 (oz) after seeds germination. A slow-release fertilizer applied as Osmocote (14N: 6.2P: 11.6K; Tai-Ho Company, Taipei, Taiwan), a resin-coated fertilizer, at an application rate of 7.5(4.2) g-N/m^2 (oz) was included in each treatment for once only at the first time treatment.

Additionally, a modified N free full-strength Johnson's nutrient solution was applied weekly to prevent deficiency of the other essential elements (Table 1). Potable water was used as a control. The first and third fully expanded leaves (those with collars surrounding the stem) from the apex of the plant were randomly sampled from each pot for CMR measurement (Model Minolta SPAD-502, Minolta Co. Ltd., Japan). Twenty-five randomly selected samples from each portion of leaves were measured, thus there were totally 50 samples recorded for CMR and chlorophyll content measurement (Mode U-01 UV/Visible Spectrophotometer, Hitachi Ltd. Japan) to study the correlation between them. The N sufficiency index (defined as the SPAD value of a plant receiving fertilizer divided by the SPAD value of a plant not receiving fertilizer times 100) was calculated. The CMR measurement was based on the difference between light attenuation at 430 nm and 750 nm, with no transmittance. Moreover, the length and width of the third fully expanded leaf was measured before harvested. The SLW of the third fully expanded leaf was calculated as the ratio of leaf weight to area. Leaf area was measured using LI-COR area meter, (Model Li-3000, Alfa Electronics inc., New Jersey, USA). Leaf N content was analyzed by semi-micro Kjeldahl digestion and distillation (Kuo et al., 1999). Leaf N content was expressed based on both the dry weight (N_{dw}) (N content/dry weight) and leaf area (N_a) (N content/leaf area) to compare which one is more promising as indicator for presenting leaf N status when compare to CMR. Harvested sample seedlings of centipedegrass were divided into root and shoot components and oven dried at 70°C for 48 h after CMR measured. The root and shoot dry weight (DW) was recorded. The experiments were repeated once lasting for 12 weeks. The sample pots of both experiments in the greenhouse bench were completely randomized designed. Mean separation was evaluated at the 0.05 probability level using Duncan's multiple range tests (Statistix 8, Analytical Software, Orlando, Florida, USA). Since the result of two experiments were similar, so only one experimental result was shown in this study.

RESULTS AND DISCUSSION

Highest average plant height, leaf length, leaf width, shoot DW, and root DW were obtained with all fertilizer products application than without N fertilizer input (Table 2). Treatments receiving the higher rate of N only had significantly higher plant height but not significantly responded to their leaf length, leaf width, shoot DW, and root DW than slow-release N treatment only, in spite of the higher rate of fast-release fertilizer applications. These results revealed that fast-release fertilizer treatment is shorter-term performance and do not contributed to root biomass of centipedegrass. Slow-release fertilizer alone provides longer-term release of N, less potential for leaching if misapplied, and less danger of turfgrass burn than do fast-release fertilizer sources.

Table 1. Composition of modified N-free Johnson's solution.

Chemical composition	Full strength	Element	Concentration of element(ppm)
		Macro nutrient (m)	
$Ca(H_2PO_4)_2 \cdot H_2O$	0.0125	P	62
		Ca	80
K_2SO_4	0.5	K	235
		S	32
$MgSO_4 \cdot 7H_2O$	1.0	Mg	24
		S	32
		Micro nutrient (Mm)	
KCl	50.0	Cl	1.77
H_3BO_3	25.0	B	0.27
$MnSO_4 \cdot 7H_2O$	2.0	Mn	0.11
$ZnSO_4 \cdot 5H_2O$	2.0	Zn	0.13
$CuSO_4 \cdot 5H_2O$	0.5	Cu	0.03
H_2MoO_4（85%）	0.5	Mo	0.05
Fe-EDTA	20.0	Fe	1.12

Table 2. Effect of N applications on plant height, leaf length, leaf width, shoot DWand root DW of centipedegrass.

Treatment (g-N/m^2)	Plant height (cm)	Third fully expanded leaf		Shoot DW (g)	Root DW (g)
		Length (cm)	Width (cm)		
Control	5.19 ^{c*}	7.81 ^{b}	0.5 ^{b}	2.76 ^{c}	4.03 ^{ab}
Osmocote7.5	37.92 ^{b}	20.18 ^{a}	0.6 ^{a}	19.59 ^{ab}	4.43 ^{a}
NH4NO32.5 + Osmocote7.5	35.50 ^{b}	21.16 ^{a}	0.6 ^{a}	18.69 ^{ab}	3.44 ^{ab}
NH4NO35.0 + Osmocote7.5	36.46 ^{b}	20.98 ^{a}	0.6 ^{a}	17.32 ^{b}	3.06 ^{b}
NH4NO310.0+ Osmocote7.5	46.36 ^{a}	21.43 ^{a}	0.6 ^{a}	20.09 ^{a}	3.65 ^{ab}

*Values in a column followed by the same letter are not significantly different at 5% level, by Duncan's multiple range tests.

Table 3. Effect of N applications on average CMR value of first and third fully expanded leaf, sufficiency index, dry weight based N (Ndw), and leaf area based N (Na) of centipedegrass.

Treatment(g-N/m^2/month)	CMR value	Sufficiency index	N_{dw} (%)	N_a (g/m^2)
Control	30.3 ^{b}	100	1.22 ^{d}	0.47 ^{b}
Osmocote7.5	43.0 ^{a}	142	2.92 ^{c}	0.77 ^{a}
$NH_4NO_3$2.5+Osmocote7	42.9 ^{a}	142	3.07 ^{b}	0.79 ^{a}
$NH_4NO_3$5.0+ Osmocote7.5	44.9 ^{a}	148	3.17 ^{a}	0.77 ^{a}
$NH_4NO_3$10.0+Osmocote7.5	45.6 ^{a}	151	3.20 ^{a}	0.75 ^{a}

*Values in a column followed by the same letter are not significantly different at 5% level , by Duncan's multiple range test.

Regardless of N fertilizer concentrations, the first leaf, and third leaf of CMR increased with N treatments compared to the control in this study (Table 3). Centipedegrass CMR closely corresponded to N application concentration (Table 3). The relationship between adequately fertilized turf and N sufficiency index must be established in turfgrass research (Idso et al., 1996). Our experiment revealed that average sufficiency index (142) showed an adequate amount of tissue N supplied at this stage of centipedegrass growth (Table 3). However, a high level of N application did not significantly influence CMR values. The analysis of N content of different rate of fertilizer treatments found that significantly influenced both dry weight and leaf area

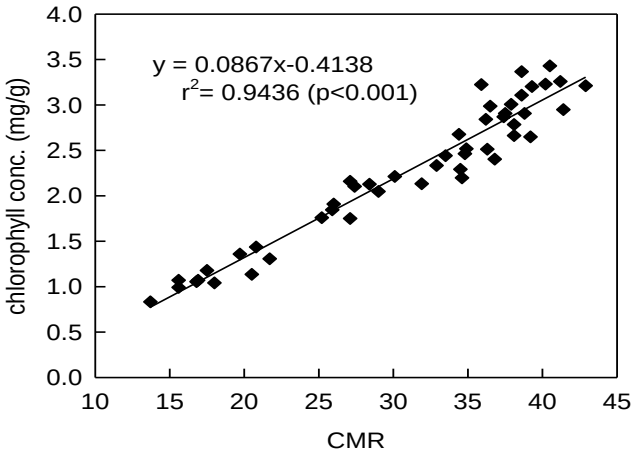

Figure 1. Linear regression between leaf chlorophyll content and chlorophyll meter readings in centipedegrass.

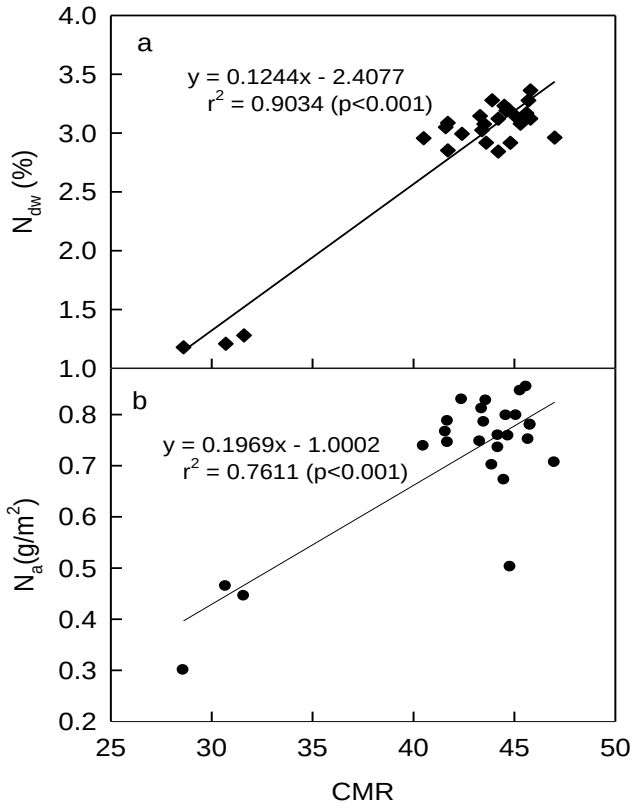

Figure 2. Linear regression of dry weight-based (Ndw) and leaf area-based (Na) leaf N content on chlorophyll meter readings in centipedegrass.

bases (Table 3). Figure 1 illustrates the linear regression of leaf chlorophyll content and CMR values (r^2=0.9436, P<0.01). From Figure 1, chlorophyll content was much responded to CMR and this finding agreed with that of Tunner and Jund (1991). Due to this relatively consistent degree of agreement between CMR values and plant chlorophyll content, it appears that the Minolta SPAD chlorophyll meter can be useful to directly understand the tissue N in centipedegrass. The linear regression of dry weight-based or area-based N concentration on leaf CMR values was highly significant (P<0.01). Figure 2 illustrated that CMR values correlated with N_{dw} (r^2=0.9034)

better than with N_a (r^2=0.7611), indicating that CMR estimated N_{dw} better than N_a. Thus, this investigation suggested that N_{dw} is the major contributor to variation in SPDA-502 chlorophyll meter readings. Thus, the CMR can accurately describe the N status of centipedegrass in the field, and thus determine whether N fertilizer application is required. Idso et al. (1996) also found a close relationship between leaf chlorophyll a, b, carotenoids, and xanthophylls and SPAD-502 chlorophyll meter readings in sour orange tree leaves. This relationship is confirmed by the fact that N is a key element in chlorophyll molecules, and N contributes to plant shoot dry weight. Chlorophyll meter measurement can offer an alternative to the tissue test, and can aid in determining fertilizer N recommendations for turfgrass. The present work demonstrated that using a chlorophyll meter to measure centipedegrass growth and development is both simple and effective. Future field experiments will determine various application intervals and different application rates for use in greenhouse studies of centipedegrass.

Conflict of Interest

The authors have not declared any conflict of interest.

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academicJournals

Vol. 10(38), pp. 3731-3739, 17 September, 2015
DOI: 10.5897/AJAR2015.10044
Article Number: 7F93A7955564
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Alluvial soil quality in agroforestry systems and native forest of the Brazilian semiarid region

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Received 17 June, 2015; Accepted 21 August, 2015

The agroforestry systems consist of techniques appropriate to local conditions, taking into account the coexistence with the semiarid in Brazil. The objective of the research was to evaluate the soil properties in agroforestry management units (SAFs), and native forest, in Bueno community, city of Irauçuba, CE. Treatments were: (1) Agroforestry management unit SAF 1 in the elevated portion of the landscape (interfluve); (2) Agroforestry management unit SAF 2 in the portion of slope (colluvium), and (3) Native forest. Soil samples were collected: 5 composite samples, derived from 15 sub-samples in areas of study in the layers 0.00-0.10; 0.10-0.20; 0.20-0.30 and 0.30-0.40 m. It was a completely randomized design, with 5 repetitions, treatments (SAF 1, SAF 2 and native forest) and the plots being repetitions. The analysis of variance was applied and means submitted to Tukey test at 5%. There were significant differences for properties analyzed, except to CE_{es}, indicating low concentration of soluble salts, without risks of salinity (0.25 a 0.34 dS m^{-1}). The exchangeable sodium (9.51 a 29.88 mg dm^{-3}), with normal values of PST (0.66 a 1.35%), in the SAF 2 differed from the others. The values of exchangeable sodium considered high are not characterized with restriction according to the normal EST. The units of SAF 1 and SAF 2 contributed to the maintenance of soil quality in top condition to MN, featuring high levels of calcium, magnesium and potassium, with restrictions to the exchangeable sodium SAF 1 and SAF 2 to a lesser extent to the native forest.

Key words: Irauçuba-CE, semiarid, caatinga, agroecology.

INTRODUCTION

Agroforestry is an integrated approach to land use that is characterized by deliberate maintenance of trees and other woody perennials in fields and pastures. This system is one of the best known traditional practices for livelihood, suitable land management and sustainable development (Kittur and Bargali 2013; Parihaar et al., 2014, 2015). These indigenous agroforestry systems not only support the livelihood through production of food, fodder and fuel wood, but also mitigate the impact of climate change through carbon sequestration (Arora et

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al., 2011; Singh et al., 2008; Bargali et al., 2009). These include strategies such as crop rotation, consortia, crops associations with animals, which are aimed at inputs obtainment and soil plant cover (Altieri, 1999).

Agricultural production intensification tendency to meet the global demand for food, the pressure on non-renewable natural resources and the need to produce with sustainability emphasizes the importance of understanding agricultural production factors, and especially understand the soil quality study (Gonzaga et al., 2013).

The Brazilian semiarid region is one of the most populous in the world and with rainfalls above the average of others, with spatial and temporal variability, favoring high evaporation rates. In this geographical space, shallow soils that are little weathered and with good chemical characteristics and physical limitations to agricultural cultivation dominate.

In this region, human intervention in the agricultural environment has occurred in order to use natural resources for food obtainment and, with population expansion, in the pursuit of increased productivity and production. Soil intensive preparation for agricultural crops, deforestation and fires have caused several impacts on the agro-ecosystem, such as flora and fauna, water availability and agricultural soils quality reduction, changing the regional climate. Human action in a disorderly way, without observing land agricultural potential, change the physical, chemical and biological attributes, accelerating desertification.

This predominant agricultural production model in the Brazilian semiarid region does not favor its agro-ecosystem genetic and social heritage conservation and protection. This fact contributes to unveil threatening life form degradation scenarios on the planet, thus accelerating the desertification process.

Given the addressed problems, the semiarid region needs an interaction culture that considers the drought phenomenon, the available natural resources and the people who inhabit this plural and diverse geopolitical space. Thus, the development of technologies and research adapted to semiarid geoenvironmental conditions are necessary to achieve an agriculture based on rational water use and natural resources alternative sources.

Sustainable agriculture in the semiarid region can be achieved by means of agricultural production systems design using technologies and management practices that conserve or improve agro-ecosystem physical basis and sustaining capacity (Franco, 2000). Agroforestry systems are recognized by farmers and non-governmental organizations as a semi-arid interaction technology. These redesigns are integral parts of a larger system focusing on the family unit, with external inputs independence and agricultural crops diversity, ensuring food security sovereignty. Therefore, it is a recognized technology by farmers as a sustainable production method with the interaction and local features of the semiarid region.

Thus, it is essential to describe, assess the impacts and scientifically validate environmental and social improvement of this successful experience of interaction with the semi-arid, and thus build in a participatory manner a sustainable agricultural production alternative for family farmers.

In this context, the research aimed to evaluate soil chemical and physical properties in agroforestry management units (SAFs), with comparative reference to native forest in Bueno community, municipality of Irauçuba, CE.

MATERIALS AND METHODS

The research was conducted in Bueno community, municipality of Irauçuba, CE, and consisting of 37 families. Latitude: 03° 36 '24 27' S and longitude: 39° 51 '27 59 "W. Main activities are eminently of agricultural nature, where small livestock, beekeeping, rainfed crops of short cycle species such as beans, corn, sesame and sorghum, as well as production yards stand out. From experiences in the SAFs, they expanded their production systems with yards production around their homes.

The areas were defined and agroforestry management units (SAF) were implanted in July 2007. These followed local features criteria regarding landscape and degradation level, besides having a nearby water source for soil moisture use through groundwater upwelling (dam with valley). Therefore, two areas implanted with agroforestry management units (SAFs) were used, conducted with the same implantation criteria, with each one in different locations in the landscape (SAF 1), interfluve (higher land area) and (SAF 2) colluvium (lowland area), totaling 0.5 ha each SAF under study. The soil was classified as Eutrophic Fluvic Neosol (Santos et al., 2013).

The study consisted of the following treatments: (1) Agroforestry management unit, as defined in the previous SAFs design section, being located in the landscape higher portion (interfluve); (2) Agroforestry management unit, located on the lowland portion (colluvium) and 3) native forest as reference (Figure 1A to E).

Differences that distinguish SAF from units 1 and 2 were the position in the landscape, which influences the systems water dynamics. SAF 1 is constituted of good water drainage, with the environment remaining unsaturated, that is, soil pores partially filled with water and air throughout the year. In SAF 2, during the rainy season, is poor soil water drainage happens, providing a saturated environment, that is, all the pore space is filled with water. After the rainy season, soil moisture is higher compared to SAF 1, thus having more stored water in the soil, favoring managed agricultural crops development, a fact favored due to the superficial water table.

Area 3 refers to native forest (NF) and is considered as a reference, comprising a length of 3 ha, without human action for about thirty years. It is located on the opposite portion of SAFs 1 and 2 agroforestry management units, with a distance of approximately 600 m. This vegetation consists of hyperxerophilic caatinga, with predominance of the following main species: thrush, *Caesalpinia pyramidalis*, *Mimosa hostilis*, quince, Brazilian-walnut, *Combretum leprosum*, beach mororó and termite nests in the trees. The soil surface is covered with plant litter in different decomposition stages.

To perform the laboratory analyzes, samples with deformed structure were collected, with five composite samples, originated from 15 sub-samples in each study area in the layers of 0.00 to 0.10; 0.10-0.20; 0.20-0.30 and 0.30-0.40 m depth, using a Dutch

Table 1. Particle size distribution, textural classification and particles density in agroforestry management units (SAF 1 and SAF 1) and native forest, in the layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0.40 m.

Depth (m)	Sand			Silt	Clay	Silt/clay ratio	Textural classification	Particles density
	Coarse	Fine	Total					
	g kg^{-1}							kg dm^{-3}
Agroforestry management unit (SAF 1)								
0.00-0.10	359	244	603	274	123	2.23	Sandy loam	2.35
0.10-0.20	331	305	636	244	120	2.03	Sandy loam	2.40
0.20-0.30	336	281	617	241	142	1.70	Sandy loam	2.41
0.30-0.40	387	240	627	228	145	1.57	Sandy loam	2.41
Agroforestry management unit (SAF 2)								
0.00-0.10	507	205	712	235	53	4.43	Sandy loam	2.40
0.10-0.20	495	204	699	233	68	3.43	Sandy loam	2.43
0.20-0.30	480	198	678	244	78	3.13	Sandy loam	2.42
0.30-0.40	514	206	720	216	64	3.38	Sandy loam	2.46
Native forest (NF)								
0.00-0.10	481	177	658	251	91	2.76	Sandy loam	2.45
0.10-0.20	418	180	598	255	147	1.73	Sandy loam	2.42
0.20-0.30	414	156	570	228	202	1.13	Sandy loam	2.45
0.30-0.40	454	191	645	240	115	2.09	Sandy loam	2.43

type auger, put up in labeled plastic bags and taken to the Soil Analysis Laboratory. Samples were air dried, buffered and passed in sieves with mesh opening of 2.00 mm, thus obtaining the thin air-dried soil (TADS), which were subjected to physical, chemical and soil analysis.

For granulometric analysis, the pipette method was used, using the sodium hexametaphosphate chemical dispersant and distilled water in 20 g (TADS), with slow mechanical agitation in a shaker (Wagner 50 rpm) for 16 h. Sand (2.00 to 0.05 mm) was measured by sieving, clay (<0.002 mm) by sediment and silt (0.05 to 0.002 mm) by the difference between sand and clay fractions.

The particle density analysis (ρ_p) was performed through volumetric flask method, using greenhouse dried fine soil (GDFS) at 105°C and ethanol (Donagema et al., 2011).

$$\rho_p = \frac{m_s}{V_p}$$

Where: m_s = dry soil mass at 105°C (kg); and V_p = solids volume (m^3).

pH was obtained in water; Ca, Mg and P content through the Mehlich-1 extractor, and quantified by atomic absorption spectrophotometry (Ca and Mg) and flame photometry (P). Electrolytic conductivity (EC) and Na^+ were determined at 25°C in aqueous extract, at a 1:5 ratio; nitrogen (N) was digested in digester block with sulfuric acid, hydrogen peroxide and digesting mixture at 250°C for 30 min, and at 350°C for 2 h, and quantified by titration with NaOH 0.025 mol L^{-1} after distillation; exchangeable aluminum (Al^{3+}) by extraction with KCl 1 mol L^{-1} and titrated with NaOH 0.025 mol L^{-1}; potential acidity (H + Al) was measured by titration with NaOH 0.025 mol L^{-1} after extraction with calcium acetate 0.5 mol L^{-1}, at 7.0 pH; and soil organic matter (SOM), by titration with ferrous ammonium sulfate 0.005 M after heated in uniform plate with potassium dichromate 0.02 M. From the analyzes, the following indexes were obtained: sum of bases (SB); effective cation exchange capacity (t); cation exchange capacity at pH 7.0 (CEC); bases saturation (V%); exchangeable aluminum saturation (m%) and exchangeable sodium percentage (ESP), according to Donagema et al. (2011).

The design was completely randomized with five replications, with treatments (agroforestry systems and native forest) and plots considered as repetitions. The results were submitted to analysis of variance, and treatment means were submitted to Tukey's test at 5% probability, using the ASSISTAT 7.6 statistical program (Silva et al., 2002).

RESULTS AND DISCUSSION

Table 1 shows particle size distribution results (granulometry), their textural classification and particle density. The studied systems and their respective layers showed no textural range, and it was classified as sandy loam, since studied units had soil class (Fluvic Neosols). It is worth noting that granulometry is a soil physical characteristic of difficult modification, since it is inherent of the source material, not being modified by soil management practices and agricultural crops.

Silt fraction values (Table 1) were high, what is an indicative of young and little weathered soils, and according to the classification and standards adopted by the National Center for Soil Research – CNPS, EMBRAPA, 90% of the municipality area consists of shallow soils characterized by crystalline rocks, corroborating with Silva et al. (2014) and Rebouças et al. (2014). In SAF 2, there was clay decrease and sand increase, what can be explained by agroforestry management units topography (SAF 1 and 2), and SAF 1 is at the highest point in the landscape, thus being

Table 2. Mean squares for soil chemical attributes in agroforestry management units (SAF 1 and SAF 2) and native forest.

VS	DF	MS								
		pH	CE_{es}	N	SOM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}
SAF1, SAF2 and NF	2	7.962**	0.072^{ns}	0.990**	5214.613**	21.898*	39818.175**	3741.200**	72.223**	3.651**
CS Residue	24	0.021	0.025	0.003	30.137	4.314	112.846	2.719	0.037	0.048
Parcelas	26									
Profundidades (P)	3	0.475**	0.199**	0.236**	2314.944**	334.585**	114331.409**	58.638**	50.161**	7.391**
Interação CS x P	6	0.742**	0.274**	0.283**	1013.802**	21.464**	28008.642**	255.259**	4.934**	0.963**
Resíduo P	72	0.024	0.005	0.002	14.666	4.327	113.268	1.715	0.177	0.034
Total	107									
CV% - a		2.45	55.23	29.78	21.32	47.18	9.85	8.27	4.28	17.38
CV% - b		2.6	24.63	23.29	14.87	47.25	9.87	6.57	9.38	14.62

VS	DF	MS							
		Al^{3+}	(H+Al)	SB	t	T	V	m	PST
SAF1, SAF2 and NF	2	1.290**	859.527**	108.985**	120.685**	987.592**	4600.952**	260.823**	4.961**
CS Residue	24	0.015	1.584	0.063	0.124	11.859	407.273	10.529	0.11
Parcelas	26								
Profundidades (P)	3	0.184**	6.657*	110.366**	102.853**	228.978**	494.299*	41.716**	2.406**
Interação CS x P	6	0.179**	20.807**	12.128**	10.246**	53.458**	386.602*	53.939**	0.832**
Resíduo P	72	0.016	1.779	0.209	0.233	5.547	159.459	4.922	0.048
Total	107								
CV% - a		106.63	22.86	4.12	5.68	31.25	32.36	188.16	35.84
CV% - b		112.4	24.23	7.49	7.78	21.37	20.25	128.65	23.64

Agroforestry Management Units (SAF 1 and SAF 2); NF, native forest; VS, variation sources; DF, degrees of freedom; MS, mean squares; pH, hydrogenionic potential; CE_{es}, electrical conductivity in the saturation extract; N nitrogen; SOM, soil organic matter; P, phosphorus; K^+, potassium; Na^+, sodium; CS, cropping systems.

considered a sediment loss area. And SAF 2 is the more easily transported and deposited particles deposition area (clay, silt and organic matter), besides being also favorable for these sediments loss due to the surface groundwater saturation, thus forming a stream at a dam downstream. This is fueled by dam valley water and rainfall. It is worth noting that the decrease in clay has not influenced in the sandy loam textural classification.

Particles density, as well as granulometry, has not showed large amplitude variation in the values due to little texture variation, since particles diameter is closely related to its density, and they are, therefore, strongly correlated attributes. Values varied (2.35 to 2.46 kg dm^{-3}), what was characterized as mineral soil, conditioned by the source material and its mineralogical composition and silt/clay ratio (1.13 to 4.43).

In Table 2, SAFs 1 and 2 agroforestry management units and native forest soil chemical attributes mean squares are shown. Significant differences were found at 5% probability level for chemical attributes, except for phosphorus and electrical conductivity in the saturation extract.

Significant differences were found in the analyzed attributes, except for CE_{es}, indicating soluble salts low concentration, without salinity potential risks (0.25 to 0.34 dS m^{-1}) for SAF 1 and 2 agroforestry management units and native forest (Table 2). This fact can be explained by exchangeable sodium increase (from 9.51 to 29.88 mg dm^{-3}), and PST normal values (0.66 to

Table 3. Soil chemical attributes means in agroforestry management units (SAF 1 and SAF 2) and native forest.

Study unit	pH	CE_{es}	N	SOM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}
	(water)	dS m^{-1}	g kg^{-1}			mg dm^{-3}		$cmol_c$ dm^{-3}	
SAF 1	5.693[b]	0.254[a]	0.385[a]	39.014[a]	4.946[a]	130.379[a]	20.440[b]	5.258[a]	1.400[a]
SAF2	6.524[a]	0.273[a]	0.117[b]	22.708[b]	3.509[b]	69.630[c]	29.885[a]	5.342[a]	1.491[a]
NF	5.727[b]	0.339[a]	0.082[c]	15.527[c]	4.753[a]	123.464[b]	9.514[c]	2.848[b]	0.900[b]
	Al^{3+}	(H+Al)	SB	t	T	V	m	PST	
			cmolc dm^{-3}				%		
SAF 1	0.333[a]	11.034[a]	7.081[a]	7.372[a]	16.334[a]	49.431[b]	4.832[a]	0.665[b]	
SAF2	0.008[b]	3.719[b]	7.141[a]	7.150[b]	10.861[b]	67.278[a]	0.135[b]	1.351[a]	
NF	0.003[b]	1.765[c]	4.098[b]	4.096[c]	5.863[c]	70.376[a]	0.206[b]	0.762[b]	

Agroforestry management units (SAF 1 and SAF 2); NF, native forest; pH, hydrogenionic potential; CE_{es}, electrical conductivity in the saturation extract; N nitrogen; SOM, soil organic matter; P, phosphorus; K^+, potassium; Na^+, sodium. Ca^{2+}, Calcium; Mg^{2+}, magnesium; Al^{3+}, aluminum; (H+Al), potential acidity; SB, sum of bases; t, effective cation exchange capacity; T, cation exchange capacity at pH 7.0; V, base saturation; m, aluminum saturation; PST, exchangeable sodium percentage.

1.35%) differed from the other units under study at SAF 2. It is noteworthy that although exchangeable sodium values were considered high, they were not characterized with restrictions in function of the normal PST. Exchangeable sodium may be conditioned to characteristic soils formation source material consisting of crystalline rocks, relief conditions, soil and agricultural crops management. SAF 1 and SAF 2 study units had soil and caatinga degradation history in advanced stage due to deforestation, burning and overgrazing (Montenegro et al., 2004). Although high sodium values were found (Table 2), they are not characterized as solodic due to high CEC, with very good calcium, magnesium and potassium levels, according to recommendations for lime and fertilizer use by Minas Gerais Soil Fertility Commission (1999).

For studied systems, SAF2 pH average values differed from SAF1 and native forest (Table 3). It is noteworthy that pH values have no restrictions for crop development, although potential acidity differed between studied units, with an average value higher than others for SAF1 (11.03 $cmol_c$ dm^{-3}), with restrictions also to the high exchangeable calcium content, probably coming from the source material (crystalline rocks).

Calcium, magnesium, potassium and soil organic matter chemical attributes at SAF 1 and SAF 2 agroforestry management units were higher than native forest conditions. These results can be attributed to the constant organic compounds input in several decomposition stages derived from implanted plant species diversity in combination with caatinga (local biome) during seven years from its implementation. This indicates that plants management with crop residues thinning, pruning and raking shows SAFs potential in soil organic matter increase. These results corroborate with those found by Xavier et al. (2004), and is considered a good indicator of changes in soil organic matter as a function of soil management and agricultural crops.

It was found that nitrogen (N) and soil organic matter (SOM) values, followed the same tendency, with statistical difference between studied units, being higher in the SAF 1, followed by SAF 2 and NF, where N needs SOM mineralization According to Frazão et al. (2008), N levels are strongly correlated with those of organic matter.

SAFs agroforestry systems can be a viable alternative for agriculture development in the Brazilian semiarid to the extent that arable species introduction contributes to soil properties maintenance and improvement (Table 2). Other assessed attributes qualitatively contributed through observation and experience at SAF 1 and SAF 2 study units, such as bee pasture, thermal comfort, humidity control, residue inputs at several decomposition stages, food availability and diversity for permanent food and nutritional security. Studies evaluating agroforestry systems should take into account local conditions, such as weather pattern, sampling time, soil type and landscape position. Adopted methods for soil attributes assessment are dynamic and can be modified in time and space (Marchiori Junior et al., 2000). For phosphorus (P) content, there was SAF 2 statistical difference compared to the others, but with lower values.

For calcium (Ca^{2+}) and potassium (Mg^{2+}) ions, there were significant differences between studied units, with decreasing values in the following order: SAF2> SAF 1> native forest to (Ca^{2+}) (5.34, 5.25 and 2.85 $cmol_c$ dm^{-3}) and (Mg^{2+}) (1.49, 1.40 and 0.90 $cmol_c$ dm^{-3}), with relatively high values. Potassium (K^+) had significant differences between studied units, with decreasing values in the following order: SAF1> native forest> SAF 2 (130.35; 123.46 and 69.63 mg dm^{-3}). These high values reflect the sum of bases (SB), effective CEC (t) and base saturation (V>50%), being considered eutrophic in the studied units. When assessing studied units chemical quality, it is noteworthy to be careful with sodium, and subsequently PST, which had no limitations on studied

Table 4. Soil chemical attributes means in layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0.40 m.

Depth	pH	CE_{es}	N	MOS	P	K^+	Na^+	Ca^{2+}	Mg^{2+}
(m)	(water)	dS m^{-1}	g kg^{-1}			mg dm^{-3}		$cmol_c$ dm^{-3}	
0.00-0.10	6.070[a]	0.236[bc]	0.288[a]	37.082[a]	9.539[a]	201.022[a]	18.962[c]	6.513[a]	2.007[a]
0.10-0.20	6.074[a]	0.281[b]	0.106[b]	25.277[b]	2.117[c]	100.906[b]	20.646[b]	3.862[bc]	0.964[c]
0.20-0.30	5.990[a]	0.226[c]	0.122[b]	26.220[b]	2.110[c]	75.817[c]	21.673[a]	3.585[c]	0.841[c]
0.30-0.40	5.791[b]	0.413[a]	0.262[a]	14.421[c]	3.844[b]	53.553[d]	18.505[c]	3.970[b]	1.244[b]
	Al^{3+}	(H+Al)	SB	t	T	V	m	PST	
			$^c mol^c\ ^d m^{-3}$			%			
0.00-0.10	0.004[b]	5.989[a]	9.106[a]	9.105[a]	15.096[a]	64.210[ab]	0.275[b]	0.523[c]	
0.10-0.20	0.100[a]	5.845[ab]	5.174[b]	5.279[b]	11.019[b]	55.983[b]	1.515[b]	0.974[b]	
0.20-0.30	0.178[a]	4.932[b]	4.714[c]	4.890[c]	8.472[c]	64.097[ab]	3.301[a]	1.245[a]	
0.30-0.40	0.178[a]	5.259[ab]	5.432[b]	5.554[b]	9.490[bc]	65.156[a]	1.807[ab]	0.962[b]	

pH, hydrogenionic potential; CE_{es}, electrical conductivity in the saturation extract; N nitrogen; SOM, soil organic matter; P, phosphorus; K^+, potassium; Na^+, sodium. Ca^{2+}, Calcium; Mg^{2+}, magnesium; Al^{3+}, aluminum; (H+Al), potential acidity; SB, sum of bases; t, effective cation exchange capacity; T, cation exchange capacity at pH 7.0; V, base saturation; m, aluminum saturation; PST, exchangeable sodium percentage.

units, although sodium had masked the sum of base values, since sodium content were high in all units under study, SAF 1, SAF 2 and native forest (Table 3).

Mean values for soil chemical attributes in layers from 0.00 to 0.10; 0.10 to 0.20; 0.20 to 0.30 and 0.30 to 0.40 m are shown in Table 4. Significant differences were verified in the 0.30-0.40 layer, with higher value for CE_{es}, indicating soluble salts low concentration, without salinity potential risks (from 0.226 to 0.413 dS m^{-1}). This fact may have occurred due to increased exchangeable sodium in the 0.10-0.20 and 0.20-0.30 layers (20.65 to 21.67) mg dm^{-3}), differing from the other layers, with the same tendency for PST (0.97 to 1.25%). They were not characterized with restrictions.

The high sodium content in all layers (Table 4), were not characterized as solodic, with high CEC levels, statistically differing in the layers from 0.00 to 0.10 and from 0.10 to 0.20, with (15.10 to 11.02 $cmol_c$ dm^{-3}). Calcium differed statistically on 0.00 to 0.10 and 0.30 to 0.30 layers, (6.51 and 3.97 $cmol_c$ dm^{-3}), with magnesium having the same tendency (2.01 and 1.24 $cmol_c$ dm^{-3}), and potassium differing in all layers. These are considered high levels.

The pH varied in the 0.30-0.40 layer, with lower value (Table 4) without restrictions. Potential acidity has not differed between layers, and these were considered high values.

It was found that nitrogen (N) and soil organic matter (SOM) values in the layers follow the same tendency, except for soil matter at a depth of 0.30-0.40, with lower value than the others, with decrease in depth. The others, however, had lower values, which are considered low.

Soil chemical attributes interactions in agroforestry management units SAF 1, SAF 2 and native forest at layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0.40 m are shown in (Table 5).

The pH was statistically different in the native forest, which had lower value compared to SAF 1 and SAF 2, at the 0.00 to 0.10 layer (Table 5). Potential acidity and exchangeable aluminum differed between studied units, with higher average value (9.43 $cmol_c$ dm^{-3}) in the other studied units, besides not differing between layers. Assessing CE_{es}, SAF 1 differed statistically from other units under study in the layers of 0.20-0.30 and 0.30-0.40. Significant differences in pH value for natural forests replaced by plantations were also reported by Bargali et al (1993) and Joshi et al (1997).

SAF 1 PST differed from other studied units in all layers, with higher value. (PST = 0.57%), with normal values in the studied units and layers, being influenced by calcium, magnesium and potassium high levels. Because of these exchangeable cations high levels, it was not constituted as solodic.

Exchangeable sodium results were high, differing between studied units, with SAF 1 having higher value than others and the same tendency in layers, with restrictions on agricultural crops. CEC has not differed between studied units nor between layers, but the values were considered high, thereby giving cultivation good chemical characteristics. Calcium, magnesium and potassium chemical attributes were high and have not differed between studied units, except between layers with variations.

Organic matter in the native forest had lower value and differed from SAF 1 and SAF 2 agroforestry units, differing in 0.20-0.30 and 0.30-0.40 subsurface layers. SAF 1 Nitrogen (N) showed higher value and differed from SAF 2 and native forest, with no statistical differences between layers.

The sum of bases (SB), effective CEC (t) and base saturation have not differed between studied units, with statistical variation between layers. It is noteworthy that

Table 5. Chemical attributes interaction in Agroforestry Management Units (SAF 1 and SAF 2) and Native Forest in layers from 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30 and 0.30 to 0 40 m for pH, CE, PST, N, MOS, P, Al^{3+}, (H+Al), t, T, V, m, K^{+}, Na^{+}, ca^{2+}, Mg^{2+} and SB.

Cropping systems	Depth (m)			
	0.00-0.10	0.10-0.20	0.20-0.30	0.30-0.40
pH (água)				
SAF 1	6.157^{bA}	5.640^{cB}	5.530^{cBC}	5.447^{cC}
SAF2	6.683^{aA}	6.663^{aA}	6.563^{aA}	6.187^{aB}
NF	5.370^{cB}	5.920^{bA}	5.878^{bA}	5.740^{bA}
CE_{es} (dS m^{-1})				
SAF 1	0.077^{bC}	0.210^{bB}	0.220^{aB}	0.510^{aA}
SAF2	0.293^{aB}	0.107^{bC}	0.180^{aC}	0.513^{aA}
NF	0.339^{aB}	0.527^{aA}	0.277^{aBC}	0.214^{bC}
PST (%)				
SAF 1	0.577^{aB}	0.431^{bB}	0.963^{bA}	0.690^{bB}
SAF2	0.623^{aC}	1.848^{aA}	1.681^{aA}	1.251^{aB}
NF	0.369^{aC}	0.643^{bB}	1.090^{bA}	0.945^{bA}
N (g kg^{-1})				
SAF 1	0.723^{aA}	0.163^{aC}	0.117^{abC}	0.537^{aB}
SAF2	0.070^{bB}	0.070^{bB}	0.163^{aA}	0.163^{bA}
NF	0.070^{bB}	0.086^{bA}	0.087^{bA}	0.086^{cA}
MOS (g kg^{-1})				
SAF 1	56.663^{aA}	39.077^{aC}	45.833^{aB}	14.483^{abD}
SAF2	37.563^{bB}	24.747^{bB}	10.287^{cD}	18.237^{aC}
NF	17.020^{cC}	12.007^{cC}	22.539^{bA}	10.542^{bC}
P (mg dm^{-3})				
SAF 1	8.137^{bA}	2.132^{aB}	3.014^{aB}	6.501^{aA}
SAF2	9.127^{abA}	1.242^{aB}	1.608^{aB}	2.060^{bB}
NF	11.355^{aA}	2.978^{aB}	1.709^{aB}	2.971^{bB}
Al^{3+} ($cmol_c$ dm^{-3})				
SAF 1	0.000^{aC}	0.300^{aB}	0.533^{aA}	0.500^{aA}
SAF2	0.000^{aA}	0.000^{bA}	0.000^{bA}	0.033^{bA}
NF	0.011^{aA}	0.000^{bA}	0.000^{bA}	0.000^{bA}
(H+Al) ($cmol_c$ dm^{-3})				
SAF 1	9.433^{aB}	13.118^{aA}	10.533^{aB}	11.055^{aB}
SAF2	6.188^{bA}	2.640^{bB}	2.723^{bB}	3.328^{bB}
NF	2.348^{cA}	1.778^{bA}	1.540^{bA}	1.393^{cA}
t ($cmol_c$ dm^{-3})				
SAF 1	11.370^{aA}	6.553^{aB}	5.019^{bC}	6.548^{aB}
SAF2	10.580^{bA}	5.529^{bC}	6.167^{aB}	6.323^{aB}
NF	5.365^{cA}	3.739^{cB}	3.485^{cB}	3.792^{bB}
T ($cmol_c$ dm^{-3})				
SAF 1	20.802^{aA}	19.370^{aA}	11.498^{aB}	13.667^{aB}
SAF2	16.767^{bA}	8.169^{bB}	8.890^{aB}	9.617^{bB}
NF	7.718^{cA}	5.518^{bA}	5.030^{bA}	5.186^{cA}

Table 5. Contd.

V (%)				
SAF 1	54.657^{bA}	32.289^{bB}	53.460^{aA}	57.317^{aA}
SAF2	66.463^{abA}	67.782^{aA}	69.432^{aA}	65.434^{aA}
NF	71.511^{aA}	67.878^{aA}	69.398^{aA}	72.719^{aA}
m (%)				
SAF 1	0.000^{aC}	4.544^{aB}	9.902^{aA}	4.883^{aB}
SAF2	0.000^{aA}	0.000^{bA}	0.000^{bA}	0.539^{bA}
NF	0.826^{aA}	0.000^{bA}	0.000^{bA}	0.000^{bA}
K^+ (mg dm^{-3})				
SAF 1	319.194^{aA}	92.399^{bB}	67.560^{bC}	42.360^{bD}
SAF2	122.279^{cA}	69.720^{cB}	59.280^{bB}	27.241^{cC}
NF	161.592^{bA}	140.598^{aB}	100.610^{aC}	91.057^{aC}
Na^+ ((mg dm^{-3})				
SAF 1	27.611^{aA}	19.215^{bB}	18.166^{bBC}	16.767^{bC}
SAF2	23.063^{bC}	34.608^{aA}	34.258^{aA}	27.611^{aB}
NF	6.211^{cC}	8.115^{cB}	12.594^{cA}	11.138^{cA}
Ca^{2+} ($cmol_c$ dm^{-3})				
SAF 1	7.933^{aA}	4.833^{aB}	3.500^{bC}	4.767^{aB}
SAF2	7.767^{aA}	4.200^{bC}	4.800^{aB}	4.600^{aBC}
NF	3.838^{bA}	2.553^{cB}	2.456^{cB}	2.544^{bB}
Mg^{2+} ($cmol_c$ dm^{-3})				
SAF 1	2.500^{aA}	1.100^{aB}	0.733^{bC}	1.267^{bB}
SAF2	2.400^{aA}	1.000^{abC}	1.067^{aC}	1.500^{aB}
NF	1.120^{bA}	0.791^{bBC}	0.722^{bC}	0.967^{cAB}
SB ($cmol_c$ dm^{-3})				
SAF 1	11.370^{aA}	6.253^{aB}	4.485^{bC}	6.215^{aB}
SAF2	10.580^{bA}	5.529^{bC}	6.167^{aB}	6.290^{aB}
NF	5.370^{cA}	3.739^{cB}	3.490^{cB}	3.792^{bB}

Agroforestry Management Units (SAF 1 and SAF 2); NF: native forest; pH: hydrogenionic potential; CE_{es}: electrical conductivity in the saturation extract; PST: exchangeable sodium percentage; N nitrogen; SOM: soil organic matter; P: phosphorus; $Al3^+$: aluminum; (H+Al): potential acidity; t: effective cation exchange capacity; T: cation exchange capacity at pH 7.0; V: base saturation; m: aluminum saturation; potassium; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; SB: sum of bases. Lowercase letters refer to depths and capital letters to cropping systems.

(V>50%) was higher than 50% in studied units, and is considered eutrophic (Table 5).

Conclusions

SAF 1 and SAF 2 agroforestry management units contributed to soil quality maintenance in higher conditions than native forest. SAF 1 and SAF 2 agroforestry management units and native forest showed favorable chemical attributes to soil fertility concerning calcium, magnesium and potassium content, with restrictions regarding SAF 1 and SAF 2 exchangeable sodium levels, and in a lower extent to native forest. SAF 1 and SAF 2 agroforestry management units provided higher soil organic matter intakes compared to Forest.

Conflict of Interest

The authors have not declared any conflict of interest.

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