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Full Length Research Paper

Organizational and institutional environment in wheat production chain in Mozambique

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Wheat's production chain is one of the sectors that have received a lot of attention not only by the Mozambican government, but also by its national and international partners alike. This is due to the interest of the government and its partners to raise production levels and as such, lower the need of importing these goods in the coming years. Due to efforts from Mozambican government to elevate production levels of wheat, the objectives of this research are to analyze the organizational and institutional effects on the development of Mozambican wheat production chain. The foundation of this project consists mainly of a new institutional economy as this institution recognizes the economic development of certain institutions. The primary and secondary data have been collected through interviews conducted with wheat producers and members of research institutes in the agrarian field in Mozambique. Some of the data have also been collected using the internet. Through the data collected and compiled, it was discovered that Mozambique in fact does not have specific policies concerned with the production of wheat, but rather information related to this exact matter are found in a greater policy which concerns itself with the promotion of agriculture itself. Therefore, the data indicates that concerning the production of wheat, there have been certain failures in the process of commercializing it, such as the inexistence of formal contracts, as well as failure in compliance with the few informal contracts which are in place. There has also been poor negotiation of pricing by the producers themselves, thus the need for an intervention in the matter by the Mozambican government.

Key words: Mozambique, agricultural policies, wheat production in Mozambique.

INTRODUCTION

Wheat has been in production since approximately 10,000 BC. The consumption of wheat has become popular in a number of countries; today wheat is the second most produced cereal crop worldwide, after maize (Awika, 2011). Wheat not only contributes to the economy of the countries that produce and export it, but is also considered one of the main sources of energy to a great number of the human population. Wheat is also greatly used in the food industry, in the making of pasta, biscuits and breakfast cereals.

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Table 1. Projection and wheat production in Mozambique.

Item	Evolution's Projection		Amount produced	
Year	2008/2009	2009/2010	2010/2011	2013
Projected area (ha)	11.350	22.875	45.000	12.300
Estimated wheat production (ton.)	21.300	46.313	96.750	22.000

The demand for wheat is rising rapidly even though during the harvest of 2012/2013, the worldwide wheat's production was at approximately 658 million tons, compared to the 697 million tons during the 2011/2012 harvest, which was considered the highest yet recorded production of wheat in world history (Food and Agricultural Organization (FAO), 2012). At the forefront of wheat production, there is the European Union, China, India, Russia, the United States of America and Brazil (Brazil, 2013).

Egypt and Morocco occupy the fourteenth and fifteenth spots, respectively when referring to wheat production, they are considered the front runners in Africa (Brazil, 2014). Even though Africa has a low level of production when it comes to wheat, the International Maize and Wheat Improvement Center (CIMMYT, 2014) hope to make Africa the highest importers of this product. Africa could guarantee its food security through wheat production as there is the potential to be self-sufficient.

In Mozambique, the triticale area is a sector with great difficulties in the production chain. In the last couple of years, there have been great effort made by the Mozambican government to promote wheat production and increase its productivity, yet producers have not been meeting the effort made by the government, therefore the goals set by the ministry of agriculture in Mozambique are rarely met. One of the examples of the failure to meet the goals is the ratio between the quantity of wheat in the production forecast by Action Plan for Food Production (PAPA) and the quantity of wheat that has been produced so far, as seen in Table 1.

According to the program for the production of wheat represented by PAPA (Mozambique, 2008), the estimated wheat production of 2010/2011 was about 96.750 tons, which would reduce the current deficit in 387.9 thousand tons; this corresponds to 80% of the forecasted consumption. During 2013, the amount of wheat produced in Mozambique did not correspond with the goals set in 2008. Therefore, specific problems have been discovered in each sector of the productive chain of wheat production in Mozambique. The aim of this research is to analyze which factors on an institutional and organizational level affect the development of wheat production chain in Mozambique.

Wheat production in Manica is used as the data for the study; this is one of the regions with a relatively high number of wheat producers, and is also the location of one of the main organizations when it comes to studies in the agrarian field (Institute of Agricultural Research of Mozambique (IIAM)).

Other than that, there are some universities and other educational institutions located in these regions that are dedicated to research in the agrarian field. As a baseline, a New Institutional Economy (NIE) was used as it was seen as the key role some institution play in the economic development and incorporating a concept often discussed in NIE (Economy of Transaction Costs (ETC)).

According to North (1990), NIE concentrate its effort in studying institutions or formal and informal rules of engagement that shapes social, economic and political interaction and its role in coordinating human actions. According to Azevedo (2000), NIE can be seen from two points:

(1) In an institutional view (formed by macro institutions) or
(2) The economy of transaction costs - ETC (this is formed in micro-institutions, that are responsible for regulating specific transactions).

Even though the study done by NIE is about the economic view of things, NIE also uses other resources to explain the nature and evolution of a variety of institutes. One of its main objectives is to study the economic functionality and efficiency of various types of institutional systems (laws, contracts and organizational methods), not to mention the influence that economic motivation has, and the kind of institutional changes that come with it.

Therefore, the results acquired through theories developed by NIE provide an important instrument that can be used to better comprehend the different interactions between economic systems, legal and juristic institutions that condition economic activity and transactions (Pondé, 2007).

Through the use of its main theory (ETC), NIE signals the importance of organizational environment to be the contingency plan for organizations. The organizational environment is set up by informal rules (sanctions, taboos, traditions and codes of conduct), including well formal rules (constitutional, laws and rights of property).

For this reason, NIE is used by many researchers as an argument which is more efficient than traditional economic theories due to its inclusion of facts that are often neglected, especially when it comes to the behavior of individuals or agents.

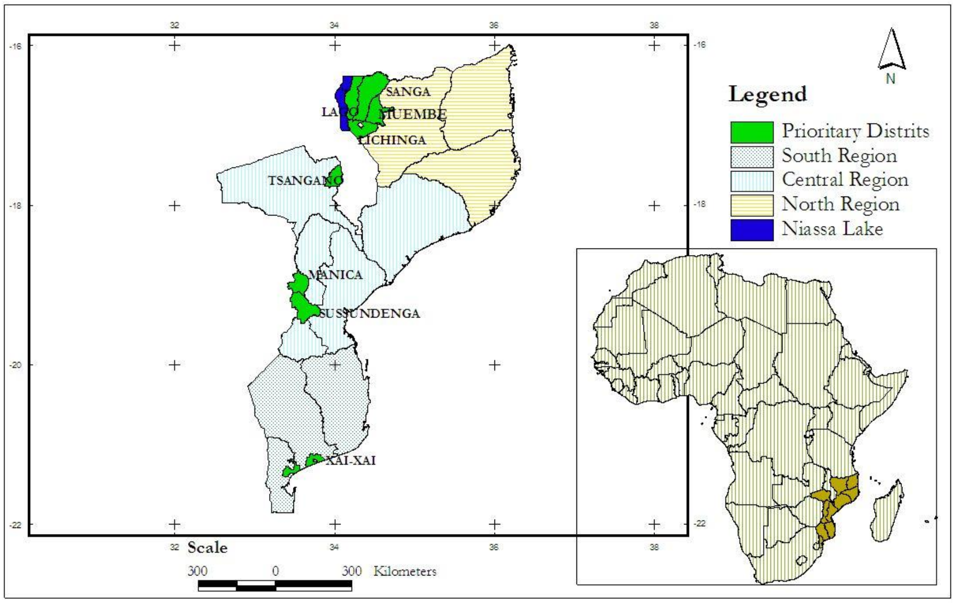

Figure 1. Location of key areas for wheat production in Mozambique according to PAPA (Mozambique, 2008).
Source: Elmer de Matos, GEOLAB/UEM.

One of the main reasons why NIE became a respected theory by various escolars and schools is due to its assumptions on the limited rationality by agents (Breitenbach and Silva, 2010). According to Williamson (1996), NIE preoccupies itself with the relation between institutions and efficiency, using:

(1) Organizational environment and
(2) Modes of governance.

The organizational environment studies the effects and changes the environment has on economic results, therefore this part is mainly dedicated with the rules of the game. The area of modes of governances concentrates on the transaction with a focus on governance structures that rule the economic agents (in this case, the general rules in society are also considered). In the study of modes of governance there is also the identification of how different governance structures deal with the transaction costs.

Wheat production in Mozambique

Other than the aspects concerned with agrarian affairs in Mozambique, brief demonstration of the wheat production chain was discussed, especially aspects that came from supplies and equipment, wheat production, and agroindustry with respect to the distribution and consumption of wheat.

By taking the climate, soil and crop management variables into consideration (PAPA (Mozambique, 2008)) regions with the right potential for wheat production were chosen, which are Manhica (in the Maputo province), Xai Xai (in the Gaza province), Sussundenga and Manica (in the Manica province), Tsangano (in the Tete province) as well as Lichinga, Muembe, Lago and Sanga (in the Niassa Province), as represented in Figure 1. All efforts were made to fortify the promotion of studies and production of certified seed, the import of seeds and fertilizers as well as the allocation of bonified loans.

The National Institute of Statistics (INE) has forecasted that the Mozambican population until 2015 will rise to about 25.7 million inhabitants, and 70% of this number represent inhabitants of rural areas (Arndt et al., 2010). Since the formation of the constitution of the Peoples Republic of Mozambique in 1975, land has been defined as something owned by the state, therefore it cannot be sold in any way, and it also defines agriculture as the basis of developing the country.

The agricultural system in Mozambique is mainly made up of small-holders farms, which in average are about 1.4 hectares large. In 2014 the agriculture sector contributed about 23% to the national Gross Domestic Product (GDP) per capita, and it also employed about 80% of the economically active population. Through strategic measures, the green revolution was introduced in 2008, it was primarily discussed in politics in 2007. With this program the Mozambican government is interested in modernizing agriculture by introducing mechanized agriculture, as well as the use of improved seeds, the promotion of the use of irrigation systems, and a higher use of fertilizers and pesticides.

The green revolution has though been faced by a

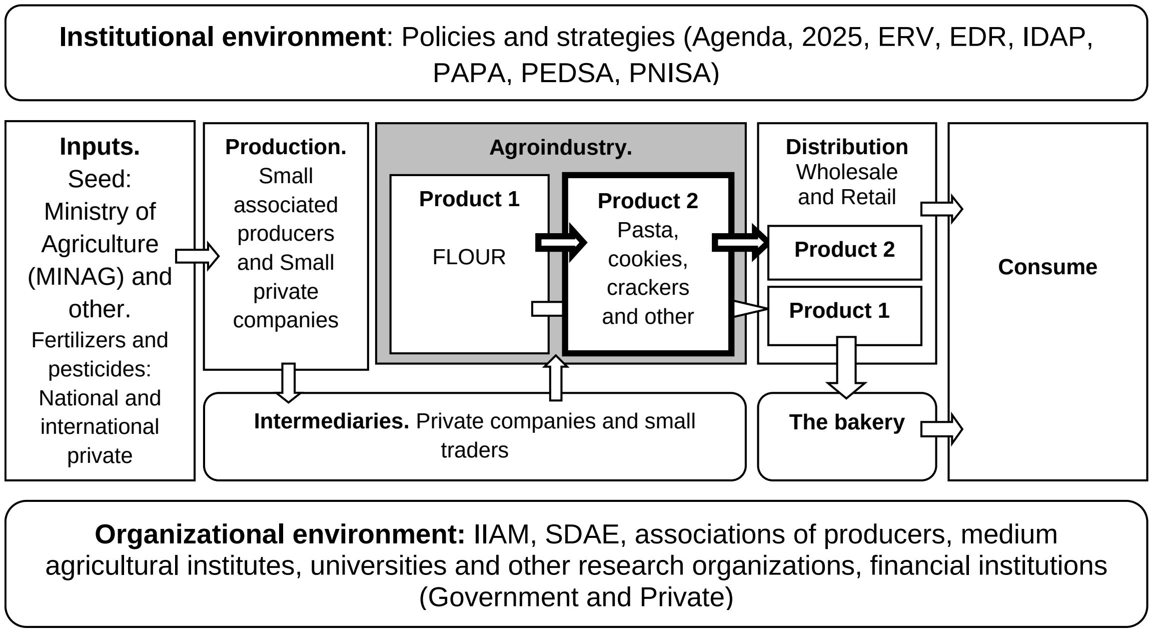

Figure 2. Representation of wheat productive chain in Mozambique.

number of obstacles, such as the fact that most producers in Mozambique practice agriculture of auto-consumption (food crops), while many farmers and farms are in areas that are difficult to access, and a very small number of people contribute to the Mozambican agriculture, and therefore it is mainly done for subsistence.

Just like other agriculture crops, the production of wheat in Mozambique is mainly done by self-sustenance farmers and small producers. Location of key areas for wheat production in Mozambique (Mozambique, 2008) form part of the associations of producers that are registered (name of association, objectives, members of management and other information) by the District Services for Economic Activities (SDAE). Other than the production of wheat, self-sustenance farmers also produce other crops such as maize, cassava, beans, sorghum, rice, soya and cashew nuts. According to the farmers that were interviewed, wheat production is maintained even with the problems encountered. Family members of the farmers are involved in the production of wheat (and other products); during the time of soil preparation and time of harvest, members of the community and the association do help with the activities needed on the farms

Figure 2 shows the representation of the productive chain of wheat in Mozambique. One of the aspects that need to be commented on in this production chain is that the Mozambican government through the ministry of Agriculture is the biggest supplier and importer of wheat seeds. Even though there are private companies (both national and international) that are input suppliers, these companies are more focused on the sales of fertilizers, pesticides and other agricultural products used in different regions of the country.

According to the findings after the acquisition of seeds and fertilizers, the farmers produce wheat under close supervision by personnel of SDAE. The area for each farm consists of areas up to two hectares. After the harvest, the wheat is stored until the intermediaries between farmers and agro industries oversee a sale. The sale is one of the most critical parts in wheat production chains, as there are no pre-established contracts when it comes to the sales between the intermediaries and the farmers, therefore, intermediaries use this to their advantage.

With the farmers not having sundry alternatives, they end up selling their products at a price established by the intermediaries, which is dissatisfying to them resulting to a decline in wheat production. Some farmers that were interviewed in Manica affirmed that the only reason they have not given up on wheat production is because it is a part of their culture (Figure 2).

The agroindustry section of the productive chain of wheat in Mozambique is composed of big companies (such as Matola Industrial Company, Beira milling and Industrial Company of Nacala), these companies buy wheat from farmers through intermediaries, and then transform it into flour. The agroindustries in Mozambique work in two lines:

(1) Production of flour presented in Figure 2 is represented by product 1; and
(2) The production of pastas, biscuits and other foodstuffs

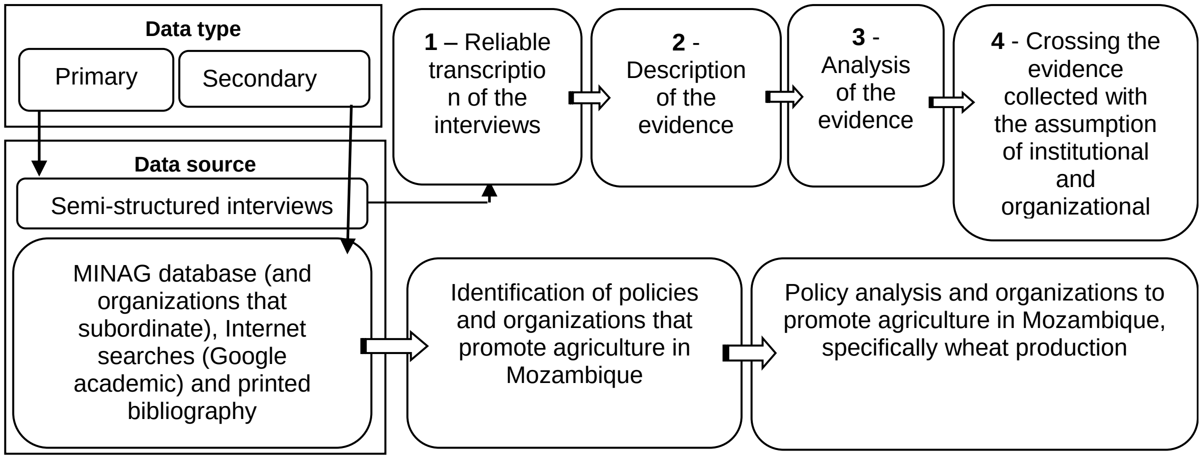

Figure 3. Data analysis work flow.

presented in Figure 2 is represented by product 2.

Product 1 of agroindustry which consists of flour is distributed to different bakeries all around the country, being used as the primary material in the making of bread and other producers. A major part of the products is acquired by the consumer through bakeries. Product 2 which consists of pastas and biscuits are acquired by the consumer through informal sellers and stores.

The organizational environment of the production chain of wheat flour in Mozambique is characterized by the lack of specific politics to promote the increase in productivity and production. The main policies and strategies to motivate the increase in production of wheat in Mozambique are mainly part of the bigger general policies about the production of food and development of agriculture in Mozambique, for example Agenda 2025, strategies concerned with the green revolution, strategies for rural development, Program to Support the Intensification and Diversification of Agriculture and Livestock in Mozambique (IDAP), Action Plan for Food Production (PAPA), Strategic Plan for the Development of the Agrarian Sector (PEDSA) and National Agrarian Sector Investment Plan (PNISA), these policies are shown in this study.

The organizational environment of the productive chain of wheat in Mozambique is characterized by the existence of organizations of studies, or rather academic organizations and loan organizations. In recognizing the limitation of some of these organizations, it is important to mention the main characteristics of the organizational environment and the lack of dialogue between producers, research organization and the loan organizations.

MATERIALS AND METHODS

The research was conducted using primary and secondary data. The primary data consisted mostly of interviews that were conducted between May and July, 2013 with wheat producers in the Sussundenga district in the Manica Province in Mozambique. It was also conducted using available data and information (nominal relation of farmers, products produced, local and ease of access as well as the size of property) which have been provided by the Manica Provincial Department of Agriculture, picking out groups of producers with a great variety of products. The people were specifically picked with the help of SDAE personnel, an organization under the Ministry of Agriculture.

The interviews were conducted in the properties of the interviewees, and afterwards in the company of SDAE personnel; a visit to other producers of wheat allowed the study to come to a conclusion. For the interview, routine questionnaires with semi structured questions were used, which would be announced by the researcher; the answers were recorded. Due to consent by the interviewees, names of the farmers will not be revealed (Figure 3).

A second encounter has been marked where the description of the data were collected (Miguel, 2007). According to Zanelli (2002), there is a necessity to join the data and the theoretic presumptions that guide the study in a way to compose a consistent view.

According to Yin (2001), the third phase of the process consists of the analysis of evidence collected and case studies. The fourth and ultimate phase is the process that is characterized by crossing collected data and the theoretic presumptions of the organizational environment which contributes in arriving to a conclusion about the role played by organizations and institutions in the production chain of wheat in Mozambique.

The secondary data and information is constituted by policies, plans and strategies, and some other document elaborated and or implemented by the government of Mozambique to promote agriculture and wheat production in Mozambique, which were obtained by the ministry of agriculture and other subordinate organizations. Some information was also obtained by using the worldwide web.

RESULTS

Aspects ranging from organizational environment to the organization of the wheat production chain in Mozambique, and how these influence the development of the triticale sector were discussed. In the first section, the organizational environment is discussed separately on how it affects the sector, after this the organizations that support the productive chain of wheat production in Mozambique will be discussed.

Organizational environment of the productive chain of wheat in Mozambique

According to Williamson (1996), the organizational environment is defined as the rule of the game, formal and informal alike; they contribute towards the promotion and development of economic activity, in this specific case, the development of the production chain of wheat.

In Mozambique, the organizational environment of triticale sector is composed of a number of policies, plans and strategies which all aim at the promotion of agriculture in one or other of the groups involved in food production in order to obtain national food security and to increase export of national produce.

No specific policy for the promotion of wheat production has been identified, the production of wheat is included in other documents that have the general goal of promoting agricultural activity in Mozambique, it is also incorporated in documents that have been set up to promote the group in the production chain that is represented by agroindustries.

According to Satolani et al. (2008) when the organizational environment is unstable in its political, social and economic systems, there will be uncertainty especially with the action of opportunists, and the instability of the politics, legal and social institutional environment may trigger the high transaction cost which might discourage investments.

PAPA in 2008, as well as PNISA in 2013, mentioned the strength of the production chain as a whole, but with more focus on only one of the elements of the production of wheat, in this case being the producers, but the rest of the chain remains fragile due to the opportunism of intermediaries, the high price of transaction which according to Satolani et al. (2008) could demotivate the investment into the sector.

According to the producers interviewed and the representative of IIAM, one of the major problems identified in the production chain of wheat in Mozambique is the lack of official contracts between the producers and the intermediaries or the agroindustry's, which on many occasions causes the disagreement between the two parties about the selling price. This is one of the main causes of the reluctance of farmers to continue planting wheat and their willingness to produce crops, in which formal and informal contracts are already in place. Between a productive chain's firms, transaction is assured by a governance structure defined by Fleury and Fleury (2003) and Williamson (2005), as a group of institutions and individuals directly involved in the transactions including sharing costs and profits derived from the process.

Most of the producers in Mozambique have organized themselves into associations of producers, and in the wheat production sector this is also the case. This kind of organization is an alternative to acquire some conditions required for production since some sort of governance capable of coordinating the relationships between the agents of the production chain is needed.

The main function of these governance structures is to reduce the cost of transactions by having organizational supplies which can lower costs through some organizational tools capable of lowering contractual costs, monitoring the performance, organization and adaptation of activities (Farina et al., 1997).

In the productive chain of wheat in Mozambique, there is inequality when it comes to the effort being made in promoting the wheat production chain, as most of the promotion is being done on the level of production itself, the rest of the production is relatively neglected which keeps their incentive low. High number of faults within the market could negatively affect the few contracts that are in place, and are being subjected to opportunistic agents.

According to the interviewed, given the dissatisfaction about the price of wheat in Mozambique, some producers from Manica opted to join the barley production project disseminated by Beers from Mozambique (CDM) in 2012 campaign. Here, seeds were distributed and technical support was given to the producers throughout the production and at the end CDM bought all harvested barley. Different from wheat's productive chain, barley has had an efficient governance structure with good incentive to the producers and the contracts were kept intact with no rooms for opportunists.

Reports state that producers only regrets was that the CDM project did not continue since they could not generate incomes, and had the will to keep producing it. The disconnection between wheat producers and the market can annul every effort made by the government to boost wheat production in Mozambique because the decision made by producers to produce wheat depends on the existence of low transaction cost.

Organizational environment of the production chain of wheat in Mozambique

Satolani et al. (2008) constitutes organizations as a group of individuals that come together to reach a common goal and some of their coordinated actions can have a political and economic outcome. In Mozambique, the organizational environment that is in charge of the productive chain of wheat is characterized by the existence of public research organizations, universities and institutions of secondary education working in agrarian sciences, in association with farmers and loan organizations.

Out of the public entities, the Ministry Of Agriculture is the one responsible for promoting agriculture in

Mozambique. Though several other entities (National Directions, Provincial Offices, District Economic Services, Mozambique Agronomic Research Institute, Center for the Promotion of Agriculture (CEPAGRI) among others) have been made to promote agriculture in general or a specific production chain.

According to Satolani et al. (2008), organizations can be characterized by having a political or economic goal, in the case of associations of wheat farmers in Mozambique, they mostly have economic gain in mind, according to the farmers interviewed, their main aim of joining an organization is to obtain economic gain.

Saes (1999) sees the market as a mechanism of coordinated action of individuals, in this mechanism, each individual act independently in making decisions about their actions. The power of the market is that through it, different goals can be pursued yet no one can impose its own goal above everyone.

According to Williamson (1996), there is an incentive and control mechanism for organizations to achieve their goal. In Mozambique, wheat productive chain is an attempt to lower transaction cost, though opportunism has always been the main problem between producers and the middle men generating dissatisfaction among producers.

Even though wheat producer's associations in Mozambique are filled with individuals who make their living from agriculture, they have their own goals and families and they are very attached to cultural beliefs. An example is the affiliation of a single producer to two or more associations with different goals in terms of production. Saes (2000) states that organizations can only achieve their goals if there are coordination of their member's action. In this productive chain, there are some mistakes identified in the process of obtaining seeds. The data reveal that due to logistic issues producers are unable to get seeds to sow as at when due. With this uncertainty, producers occupy wheat destined areas with other crops in order to feed their families.

Conclusion

Wheat productive chain in Mozambique is one that faces many difficulties to boost its production and productivity. Considering that governance structure is one of the mechanisms and control used by organizations to reach their goals, the productive chain has a hierarchical governance structure where:

(1) The incentives to the producers are weak,
(2) There are mistakes in the commercialization of wheat,
(3) Lack of formal contracts and the few existent informal contracts are violated,
(4) Producers have no authority to negotiate the price, and
(5) There is a need for intervention by Mozambican government through Ministry of Agriculture and other organization ruled by it.

In the development and introduction of policies and strategies aiming at the promotion and increase of production, Mozambican government can and could ponder on social and economic aspects of wheat producers, and the focus should be related to:

(1) For how long have they been producing wheat in that region?
(2) During this period, was there an increase of production area?
(3) Before MINAG (Ministry of Agriculture, the Mozambican institution responsible for agriculture.) stepped in as seed supplier, where did they get the seeds?
(4) What have been the objectives of the production?
(5) Is there any possibility of an area increase by these producers?

These and other questions may help to figure out the possibility of these producers to boost the country's wheat production and productivity or if there is a need to persuade more producers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Yields and forage nutritive quality of high-yielding dual purpose cowpea (*Vigna unguiculata* L. Walp.) varieties in the Sahelian low-input cropping system

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Cowpea is a major food legume crop in the Sahel with tolerance to drought and to the nutrients-leached acid sandy soils of this region. However, the existing cowpea varieties grown by farmers are low yielding and pest sensitive which make them unsuitable to satisfy farmer's needs. The objective of this study was to identify high-yielding cowpea varieties which are well adapted to the Sahelian ecosystem. Eight dual-purpose cowpea varieties from various sources were tested with and without insects control in Niger during two cropping seasons (2005 and 2007). In 2005, a relatively wet year, KVX 745-11-P and four other varieties (ISV 20, ISV 40, ISV 128 and IT98D-1399) gave highest grain yields ranging from 1220 to 1521 kg ha^{-1}. In the dry year (2007), the highest grain yield was recorded with ISV 128. There were also significant differences in forage yield between varieties in both the wet and dry year. Application of insecticide increased cowpea grain yields significantly. Cowpea produced without insect control (spray) resulted in high grain yields losses and increased cowpea fodder yields in both years. KVX 745-11-P was the most sensitive variety to insects whereas IT98D 1399 seemed to be relatively the most insect tolerant variety. There were no significant differences between varieties in most forage quality parameters. These results provide the possibility of a potential extension of dual-cowpea varieties for improved food security in the Sahel.

Keywords: Dual purpose cowpea, grain yield, fodder quality, sahel

INTRODUCTION

Cowpea is a major pulse crop in the Sahel and contributes to the nutrition and livelihoods of millions of people living in this region. It provides protein rich grains for human consumption and quality forage for animal feed making it a dual-purpose crop (Dube and Fanadzo, 2013). The dual-purpose character of cowpea makes it a very attractive crop where land is becoming scarce (Singh et al., 2003). It helps smallholder farmers who

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have little land to achieve food security and feed their animals from the same area. Furthermore the dual purpose cowpea varieties have the potential of bringing nitrogen (N) into the farming system through biological fixation and thereby enhancing fertility status of the soils (Anele et al., 2010).

Cowpea is well adapted to Sahelian ecosystems and it is relatively tolerant to drought and can grow in the poor sandy soils (Belko et al., 2014). Unfortunately the existing varieties grown by farmers are low yielding and pest sensitive which make them less suitable to satisfy farmers' needs.

According to Calzadilla et al. (2013), the population in Sub-Saharan Africa could double by 2050 increasing agricultural consumption by 2.8% annually until 2030, and by 2.0% annually from 2030 to 2050. There is, therefore a need to develop and make available to the farmers, high-yielding cowpea varieties in order to ensure food security. In order to achieve this objective, the International Institute of Tropical Agriculture (IITA) conducted intensive breeding of cowpeas varieties with emphasis on high yield potential for grain as well as fodder with tolerance to major biotic and abiotic stresses (Singh et al., 2003). Today many of the varieties used in West Africa originated from IITA. The breeding work by IITA was conducted mostly in the region of Kano in North Nigeria where average annual rainfall is around 900 mm. This is much higher than the average rainfall (350 to 500 mm per year) in the Sahelian regions where cowpeas are produced. Thus cowpea varieties selected in Kano might not be tolerant to the drier conditions as those selected in Niger. There is a need of identifying cowpea varieties more adapted to the Sahelian zones.

On the other hand, annual cowpea grain yield in farmers' fields, was less than 500 kg ha^{-1} (Sambo et al., 2013) while in research stations potential yields are more than 1,500 kg ha^{-1} of grain and 2,500 kg ha^{-1} of fodder could be recorded (Singh et al., 2003). Low yields in farmers' fields are caused by a multitude of reasons including low soil fertility and low yielding varieties. However, insect attack is a major reason for these low yields. In order to increase cowpea yields and ensure food security in the Sahel, this study was carried out to identify high-yielding dual-purpose cowpea varieties that might fit to the Sahelian conditions.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Sadoré Research Station of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Niger. Sadoré is situated at 13° 15'N and 2° 18'E and 240 m above sea level. The climate is characterized by a rainy season that occurs between June and September, and a dry season that prevail during the rest of the year. The mean annual rainfall at Sadoré is 560 mm (Sivakumar and Salaam, 1999). The average temperature is 29°C (ICRISAT climate database). The soil is classified as a sandy silicious isohyperthemic Psammentic Paleustalf. The chemical characteristics of the composite soil samples taken from 0 to 20 cm depth of the experimental site in 2005 indicate that the soil is typically low in organic C (0.2%), total N (151 mg/kg) and in available phosphorus was 13.7 mg/kg with a pH-H_2O value of 5.1.

Experimental design and data collection

The experiment was conducted during the rainy season in 2005 and 2007. A randomized complete block design arranged in a split plot with five replications was used. The main plot treatment factor was the insecticide spray (*Lamda- cyhalothrine* 25 EC) at two levels (with and without insecticide spray) and the subplots consisted of eight dual purpose cowpea varieties. Each subplot measured 8 m x 8 m (32 m^2). In 2005, cowpeas were planted in a site that was left fallow for five consecutive years. In 2007 it was planted near the 2005 field in a site that was left fallow for six years. The cowpea varieties were dibbled at spacing of 1 x 0.5 m with three seeds per hole. The subplots were separated from each other by 2 m wide borders to reduce spray drift between plots.

Sowing was done at the onset of the rains on June 27^{th} and July 13^{rd} in 2005 and 2007, respectively. The cowpea varieties used for the test came from various sources. Two varieties from IITA (IT98D-1399 and IT98K-131-2), one variety (KVX745-11-P) from Institut National de l'Environnement et de Recherches Agricoles (INERA) breeders in Burkina Faso, four varieties bred and selected at ICRISAT-Niger (ISV 128, ISV 20, ISV 28 and ISV 40) and one variety introduced from Mexico (Ejetero V11). For each experimental year, the field received 30 kg N ha^{-1}, 13.1 kg P ha^{-1} and 24.9 kg K ha^{-1} as NPK 15-15-15. Fertilizer was broadcasted and incorporated into the soil by a disk plough. Spraying started with the appearance of the first flower buds. Four consecutive spraying were done at seven days interval between sprays.

Daily rainfall was recorded with a rain gauge located in the experimental field. Days to flowering and maturity were determined for each variety. Harvesting was done in September to October. To determine grain yield and fodder yield, cowpea was harvested from an area of 6 x 6 m within each subplot. The pods were harvested and threshed and all the haulm collected. The seeds were sun-dried thereafter weighed and expressed in kg ha^{-1}.

Plant sampling and analysis

Plants samples were taken from each treatment at harvest and analyzed for feed value. The oven-dried cowpea haulms were milled and pass through a 1 mm sieve then analyzed for lignin content according the procedures of Van Soest and Robertson (1985). Hemi-cellulose and cellulose were calculated as the differences NDF − ADF and ADF − lignin, respectively (Hossain et al., 2013). Organic matter digestibility (OMD) was determined by the *in vitro* gas production technique calibrated with standards obtained *in vivo* (Menke et al., 1979). The total nitrogen content in the different cowpea plant parts was determined using the Kjeldahl digestion procedure (Houba et al., 1995) and the percent protein content was estimated from the Kjeldahl (crude protein % = Total N % x 6.25).

Data analysis

Prior to analysis of variance, the data were checked for normality using residual plots in GENSTAT v.9 (Lawes Agricultural, 2007). Thereafter, the data collected were subjected to analysis of variance in GENSTAT v.9 using a split plot treatment structure. Model of ANOVA included year, cowpea varieties, spray treatment

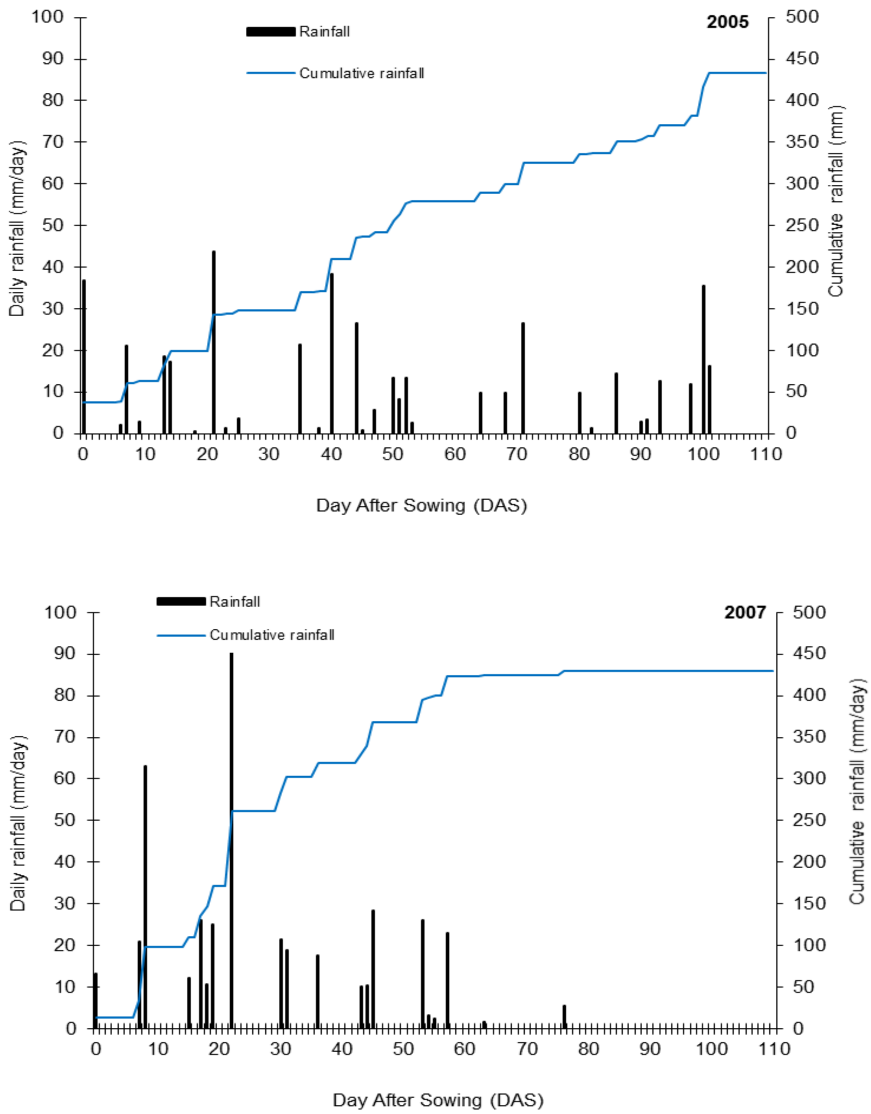

Figure 1. Cumulative rainfall and rainfall distribution during 2005 and 2007 cowpea production season.
Source:

and their interactions.

RESULTS AND DISCUSSION

Rainfall distribution

In 2005, rain was evenly distributed during the production period (wet year) but in 2007 (dry year) rain stopped being regular from 58 days after sowing (Figure 1). The rainfall recorded during the cropping seasons 2005 and 2007 were 433 mm and 430 mm, respectively (Figure 1). These quantities of rainfall were below the long-term rainfall average (560 mm) recorded in the study area (Ibrahim et al., 2015a). Even though, the cumulative rainfall recorded was almost equal in both years, there were large differences in rainfall distribution between the two rainy seasons. In 2005, rains were evenly distributed throughout the cropping period whereas in 2007 the last effective rain occurred 58 days after planting.

Cowpea varieties developmental stages

Number of days to flowering and days to maturity for cowpea varieties are presented in Table 1. Days to flowering varied from 45 to 48 days after sowing among the eight varieties. There were no statistical differences

Table 1. Number of days to flowering and days to maturity for eight dual purpose cowpeas varieties in 2005.

Varieties	Days to flowering	Days to maturity
Ejetero V11	47 ± 2	65 ± 1
ISV128	45 ± 2	65 ± 1
ISV20	45 ± 2	72 ± 1
ISV28	47 ± 2	72 ± 1
ISV40	45 ± 2	69 ± 1
IT98D-1399	45 ± 2	66 ± 1
IT98K-131-2	48 ± 1	70 ± 1
KVX745-11-P	48 ± 2	68 ± 1
Probability values (5%)	0.078	< 0.001

± Standard error.

among the cowpea varieties in terms of number of days to flowering. However, the number of days to maturity varied significantly ($P < 0.001$) among the cowpea varieties. Varieties ISV 128 and Ejetero were the earliest cowpea varieties (65 days after sowing) compared to other varieties used in the current study. Early maturity is an important parameter to be considered in the selection of cowpea varieties particularly in the Sahelian zones characterized by unpredictable rainfall pattern. The cowpea varieties tested in the current study appear to be earlier in maturity compared to the cowpea varieties recommended and cultivated by farmers in Niger with days to maturity varying from 80 to 89 days (Dugje et al., 2009).

Cowpea grain and forage yields

Grains and forage yields during the two experimental years are given in Table 2. There was a significant ($P < 0.001$) year-effect on cowpea grain yield. In 2005, grains yield ranged among varieties from 841 to 1522 kg ha^{-1}. In 2007, grain yields were much lower and ranged from 405 to 990 kg/ha. The higher grain yield recorded in 2005 could be attributed to better rainfall distribution in this year as compared with 2007 (Figure 1). Several studies have reported seasonal yields differences particularly in the Sahel due to inter-annual rainfall distribution (Anele et al., 2011; Ibrahim et al., 2015b). In 2005, sprayed KVX 745-11-P gave the highest grain yield (1522 kg ha^{-1}) that did not differ significantly from the yields of IT 98D-1399, ISV 40 and ISV 128. In 2007, which was relatively a drier year, sprayed ISV 128 (990 kg ha^{-1}) and IT 98D-1399 recorded the highest grain yields than all other varieties. An explanation for the relatively drought tolerance of ISV 128 and to a lesser extent of IT98D-1399 could be a result of deeper roots that exploit water in the soil more than drought sensitive varieties as was demonstrated for a drought tolerant cowpea variety by Matsui and Singh (2003). In both years, grains yield was significantly higher in sprayed plots than in non-sprayed plots. Cowpea produced without spray resulted in high grains yield losses from 93% in 2005 to 63% in 2007. The findings of this study are consistent with those of Ajeigde et al. (2005) who reported a huge cowpea yield losses in the absence of insect control. Generally, all varieties tested were sensitive to insects, some more than others. Insects' damage was relatively severe in KVX 745-11-P plots where the grain yield of non-sprayed plants represented only 1.2 and 8% of the yield of sprayed plants in 2005 and 2007, respectively. Although potential grain yield of this variety is high, it can only be expressed if treated with insecticides. The variety IT98D-1399 was found to show promising tolerance to flower insects particularly thrips and recorded a relatively high yield in the absence of insecticide application. This study did not provide the opportunity for better understanding of the mechanism underlying the behavior of IT98D-1399 in thrips tolerance. Further study aiming at determining the mechanisms of tolerance operating in IT 98D-1399 is therefore needed.

There was significant ($P < 0.001$) variability between varieties in forage yields. In both years forage yields of the untreated plants were higher than the yields of sprayed plants. In the absence of insect control, cowpea fodder yields have increased by 31% and 23% in 2005 and 2007, respectively. The lower fodder yields recorded with sprayed plots could be attributed to the leaves defoliation as a result of the longer duration for pods to be matured. Diversion of photosynthates to seed production may partly affect foliage production. In 2005, the plots of ISV 20 sprayed with insecticide gave the highest forage yield (2666 kg ha^{-1}) that was not statistically different from forage yields of ISV 40, ISV 128 and KVX 745-11-P. There was a significant year-effect on cowpea forage yields. Cowpea fodder yield in wet season (2005) was approximately 58% greater than in drier season (2007). The seasonal yield variability could be attributed to the good rainfall distribution observed throughout the growing period in 2005 (Figure 1) which

Table 2. Grain and forage yields of sprayed and non-sprayed cowpeas varieties during two growing seasons.

Cowpea variety	Spray	Grain yield (kg/ha)		Fodder yield (kg/ha)	
		2005	2007	2005	2007
Ejetero V11	Yes	841±78	405±26	1333±190	557±64
	No	14±5	99±9	1740±259	910±60
ISV 128	Yes	1341±169	990±156	3264±337	1115±244
	No	129±96	397±89	2930±196	1536±169
ISV 20	Yes	1220±141	538±35	2666±254	1755±109
	No	16±3	86±6	3708±566	2130±180
ISV28	Yes	972±74	432±66	1334±187	1364±120
	No	29±13	55±19	3187±100	1555±153
ISV 40	Yes	1369±267	712±56	2594±202	1533±157
	No	128±69	203±24	3625±196	1593±115
IT 98D-1399	Yes	1488±103	753±75	1542±157	875±95
	No	239±71	309±19	2719±146	1298±212
IT98K-131-2	Yes	755±41	638±35	1570±180	1125±145
	No	82±22	198±32	3104±393	1722±172
KVX 745-11-P	Yes	1521±122	672±90	2240±256	1277±146
	No	18±3	54±19	2864±279	1677±147
Probability values					
Variety (V)		<0.001		<0.001	
Insecticide (I)		<0.001		<0.001	
V × I		0.003		0.006	
Year (Y)		<0.001		<0.001	
Y × V		0.001		0.048	
Y × I		<0.001		0.001	
Y × V × I		0.055		0.037	
CV (%)		26.8		24.2	

CV, Coefficient of variation; ± Standard error.

ultimately favoured better plant growth and biomass production.

Cowpea fodder quality

Fodder quality parameters are given in Table 3. Varieties and the insecticide had no significant effect on cowpea fodder quality. *In vitro* OMD ranged from 600 to 643 g/kg in sprayed and non-sprayed plots with the highest value of *in vitro* OMD being obtained with the ISV 128 variety. Crude protein (CP) content varied from 108 to 138 g/kg and from 114 to 126 g/kg between the sprayed and unsprayed plots. All the cowpea varieties had CP concentrations greater than 80 g/kg DM, the level below which voluntary intake of tropical forages is reduced (Minson, 1981). Kaasschieter et al. (1998) reported CP values for cowpea ranging from 78 to 217 g kg^{-1} DM. Cowpea haulms of the varieties used in this study had higher CP content than those used by Savadogo et al. (2000). Such variation in quality of cowpea haulms may be due to factors such as genetic characteristics, environment (soil characteristics, rainfall) and crop management (Singh, 1995). There were no significant differences between varieties and insecticide treatment and their interaction in relation to lignin and hemi- cellulose.

Table 3. Fodder quality parameters.

Varieties	Spray	*In vitro* OMD (g/kg)	Crude protein (g/kg)	Lignin (g/kg)	Cellulose (g/kg)	Hemi cellulose (g/kg)
Ejetero V11	Yes	600±3	138±1	68±0	257±2	166±3
	No	599±2	122±3	73±1	243±1	149±2
ISV 128	Yes	643±5	108±1	56±2	190±1	128±1
	No	643±1	114±1	65±1	175±1	110±1
ISV 20	Yes	643±3	120±4	67±1	249±3	134±1
	No	640±3	125±2	65±3	252±2	96±1
ISV28	Yes	615±1	119±1	67±1	282±2	89±2
	No	614±4	139±2	66±1	257±1	83±1
ISV 40	Yes	607±5	120±3	66±1	283±2	100±2
	No	609±3	119±1	58±2	245±1	117±3
IT 98D-1399	Yes	598±1	114±2	65±1	264±1	132±1
	No	599±3	126±2	69±3	226±1	130±1
IT98K-131-2	Yes	601±1	116±1	62±2	280±2	92±2
	No	605±1	119±1	54±1	238±3	104±2
KVx 745-11-P	Yes	607±4	114±4	55±0	261±1	110±2
	No	610±5	126±2	60±1	219±1	104±1
Probability values						
Variety (V)		0.676	0.46	0.552	0.087	0.087
Insecticide (I)		0.496	0.136	0.783	0.057	0.081
(V x I)		0.943	0.302	0.766	0.291	0.067
CV (%)		7.8	5.3	5.1	6.4	4.1

CV, Coefficient of variation; ± Standard error.

Cellulose concentration was significantly higher in plants sprayed with insecticides.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Comparison of five different methods in estimating reference evapotranspiration in Cape Coast, Ghana

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A number of methods have been developed to estimate reference crop evapotranspiration (ETo), but most of the reliable methods are complex and parameter rich models and therefore difficult to apply in data scarce regions. This study was conducted to determine suitable simple ETo methods in Cape Coast by comparing estimated ETo values of three indirect-measurement methods: Hamon, Hargreaves, Blaney Criddle; and two direct-measurement methods: Class A pan and Piche evaporimeter with the Food and Agriculture Organization (FAO) Penman-Monteith equation (FAO56-PM) estimated ETo values. All the methods underestimated ETo values obtained by the FAO56-PM method. However, the estimated ETo values by the Hamon, Hargreaves, and Blaney-Criddle are strongly correlated (R = 0.89, 0.87 and 0.81 respectively), while the Class A pan and Piche evaporimeter methods are weakly correlated (R= 0.37 and 0.31, respectively) with the FAO56-PM method. All but the Piche evaporimeter methods appeared suitable for estimating ETo in the study area. The Class A pan, though weakly correlated with the FAO56-PM method, was also suitable because it had the least mean absolute error (MAE; 0.26 mm day^{-1}) and mean absolute percentage error (MAPE; 6.5%) among the other methods and its ETo curve was closer to the FAO56-PM's.

Key words: Reference crop evapotranspiration, Cape Coast, Food and Agriculture Organization (FAO) Penman-Monteith equation, direct-measurement method.

INTRODUCTION

Efficient consumption of water as agricultural irrigation, drinking water and industrial use is an important issue in the coastal savanna region of Ghana especially during the dry season months. With the growing scarcity of fresh water globally due to climate change, it is increasingly important to maximize efficiency of water usage. This implies proper management of available water to effectively apply water according to the crop water needs.

Evapotranspiration (ETo) is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surfaces and transpiration from plants (Allen et al., 1998). Evapotranspiration is one of the major hydrological components of water budget and an indispensable component in water use in crop

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production. Accurate quantification of ET is crucial in water allocation, irrigation management, and development of best management practices to protect surface and ground water quantity and quality (Irmak and Irmak, 2008). Therefore, a reliable and consistent estimate of evapotranspiration is of great importance for the efficient management of water resources.

In a given agricultural field, the ET process is impacted by many different soil, plant and management factors. However, ET is primarily driven by climatic conditions, such as air temperature, solar radiation, relative humidity of air, and wind speed. Familiar practices for estimating ET are to first estimate reference ETo and then relate it to a corresponding crop coefficient. According to Allen et al. (1998), reference ETo is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground. Quantification of ETo expresses the evaporative power of the atmosphere at a specific location and time of the year, and therefore ETo is necessary in crop production, management of water resources, scheduling of irrigation, evaluation of the effects of changing land use on water yields and environmental assessment.

In Cape Coast and the surrounding communities, almost all crop farming activities come to a halt in December, January and February. This is because apart from being within the driest months, it is during these months that the coastal savanna experiences harmattan dry northeasterly trade winds from the Sahara Desert. The harmattan is characterized by cold, dry, dusty-laden winds and also wide fluctuations in the temperatures of day and night. During the harmattan season, temperature can be low all day but sometimes in the afternoon the temperature can soar to as high as 30°C, while the relative humidity drops to a low level (Emiko and Javier, 2012). Therefore, insufficient water availability to meet crop water requirement especially during these months coupled with a strong competition from other water users are limiting for all year-round crop production to meet the demand of the high population growth in Cape Coast and the surrounding towns which are fast expanding. It is anticipated that this water demand causes the reduction in irrigation water availability for vegetable production which abound in the area. It is in this regard that reliable and consistent estimates of reference evapotranspiration have to be determined for water managers responsible for planning and distribution of water in the metropolis to understand the spatial and temporal fluctuations of the processes of evapotranspiration for all-year-round crop production realization.

A number of methods have been developed to estimate reference ETo but unfortunately most of the reliable ETo methods are parameter rich models and therefore difficult to apply in data scarce regions. Again most these methods are developed from different climatic variables and adaptation are often subject to rigorous local calibration and prove to have limited validity for different locations. Testing the accuracy of the methods under different conditions normally is laborious, time-consuming and costly.

Although many approaches have been developed and adopted for various applications based on available input data, there is still a remarkable range of uncertainty related to which method is to be adopted in the estimation of ETo in Cape Coast of Ghana. The FAO Penman-Monteith equation (FAO56-PM) which is recommended as the sole standard for estimating ETo is relatively high data demanding and sensitive to data that are difficult to measure (Allen et al., 1998; Chen et al., 2005). The lack of instruments, remote access, computer control and automation, and measurement tools in many meteorological stations in and around Cape Coast presents a serious problem to data collection and data use in evapotranspiration research and practices. In this study, the FAO56-PM estimates of ETo were used as a standard to evaluate the performance of other methods in estimating the ETo.

The objective of this study was to determine reference evapotranspiration methods that closely approximate ETo in the study area during the dry season of the year based on the available climatic data by comparing five different methods of estimating ETo with FAO56-PM approach. This can help establish a common method for the estimation of ETo in Cape Coast, and in turn help the local farmers in the area to adopt a simple method for practical use in determining crop water requirement during the dry season. This also can help the University of Cape Coast in particular to adopt less costly and easy applicable method for ETo research and practice.

MATERIALS AND METHODS

Study area

The study was conducted in 2013 and repeated in 2014 and 2015 at the agro-meteorological station at University of Cape Coast. According to Asamoah (1973), the study area falls within the coastal savanna ecological zone and has two rainfall regimes separated by a dry period. The major rainy season starts from March to July with the peak in June, while the minor season is from September to November with the peak in October. The dry period is from December to February, characterized by hot days, cool nights and low relative humidity coupled with relatively high ETo during which farming activities come to a halt. The annual rainfall ranges from 800 to 900 mm. Temperature is relatively uniform throughout the year with the mean annual minimum temperature of 25°C and maximum of 32°C (Asamoah, 1973).

Agro-meteorological station and data collection

An agro-meteorological station number 0501/044/23 was used for the study. The station was situated on latitude 5.1°N and longitude 1.4°W at altitude of 31.1 m above sea level. It was fenced up to 1.2 m in height with a dimension of 10 m × 10 m and within a field of 50 m × 50 m. This station provided meteorological information on rainfall, relative humidity, temperature, wind speed, sunshine duration, radiation and evaporation relevant to agricultural production within the university and the entire Cape Coast metropolis. The data collected covered December, January, and February because apart from being the driest months in the year, it was during these months that the study area experienced the harmattan dry winds, resulting to a halt of crop farming especially vegetables farming activities. Most of the readings were recorded twice each day (0900 and 1500 h GMT) over the three months for three consecutive years (2013, 2014 and 2015) and the mean daily values of 8-day periods of the parameters were used for the study.

ETo methods used

Five simple methods, namely, Class A evaporation pan, Piche evaporimeter or atmometer, Blaney-Criddle, Hargreaves and Hamon were selected to estimate the ETo of the study area. These methods were grouped into two categories, viz, direct-measurement method (Class A evaporation pan and Piche evaporimeter) and indirect-measurement method (Blaney-Criddle, Hargreaves and Hamon methods). The performances of these methods were measured by comparing their ETo estimates with the FAO56-PM method's ETo estimates (ETo-PM).

Class A evaporation pan

Class A evaporation pans are the most widely used type of devices to perform measurements of evaporation and subsequently reference evapotranspiration (McVicar et al., 2012). The standard Class A pan, developed by the US Weather Bureau was used for the study. The pan was a spherical tank of galvanized iron, with a diameter around 120 cm and was 25 cm deep, and mounted on a wooden platform (Sanchez-Lorenzo et al., 2014). The pan was filled with water to about 5 cm below the rim and the daily fall of the water level was manually measured every morning at 0900 h, refilling the water level if needed or reducing the content of water if rain had caused the tank to overflow (WMO, 2008). The pan evaporation was then related to the reference evapotranspiration by a pan coefficient as (Allen et al., 1998):

$$ET_0 - AP = K_p E_{pan} \quad (1)$$

where ET_o-AP is the reference evapotranspiration (mmd^{-1}), K_p is the pan coefficient = 0.7 (based on the prevailing climatic and environmental conditions at the study area), E_{pan} is the pan evaporation (mm day^{-1}).

Piche evaporimeter (atmometer)

The Piche evaporimeter used for the study consisted of a 3 cm diameter disc of filter paper held by a metal clip to the bottom of an inverted graduated cylindrical tube of 1.5 cm in diameter, which supplied deionized water to the disc as outlined by Sanchez-Lorenzo et al. (2014). The water thus evaporated from the surface of the filter paper. The volume of water remaining in the graduated tube was measured daily and the amount of water lost by evaporation in millimeters was determined by the difference between water levels on consecutive days (Diop et al., 2015). The Piche evaporimeter was placed inside a meteorological (Stevenson) screen together with other meteorological instruments (WMO, 2008). The ETo was calculated using the recorded evaporation readings, Epi, multiplied by two coefficients as Casanova et al. (2008):

$$ET_o - P_i = \propto E_{pi}\rho(\sigma) \quad (2)$$

where ETo-P*i* is the Piche evaporimeter estimated reference evapotranspiration (mm day^{-1}); $\propto$ is a factor that considers the semi-protection of the Piche evaporimeter from the solar radiation = 0.27; E_{pi} is the evaporation reading by the Piche evaporimeter (mm day^{-1}); $\rho(\sigma)$ is a prevailing temperature dependent factor = 2.41 (Casanova et al., 2008).

Penman-Monteith equation

The United Nations Food and Agriculture Organization (FAO) in paper 56 recommended the use of Penman-Monteith (PM) equation (FAO56-PM) as the standard method for estimating reference ETo, and for appraisal of other methods (Allen et al., 1998). The FAO56-PM method is ranked as the best method for estimating daily and monthly ETo in all climates (Galvilan et al., 2006; Trajkovic and Kolakovi, 2009). In the FAO56-PM method, ETo is computed as (Allen et al., 1998):

$$ET_o - PM = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (3)$$

where ET_o-PM is the FAO56-PM estimated reference evapotranspiration (mmd^{-1}); Δ is the slope vapour pressure curve (kPa °C^{-1}); Rn is the net radiation (MJm^{-2}d^{-1}); G is the soil heat flux density (MJm^{-2}d^{-1}); γ is the psychometric constant (kPa°C^{-1}); T is the mean daily air temperature (°C); U_2 is the wind speed at 2 m height (ms^{-1}); and (e_s–e_a) is the vapour pressure deficit (kPa).
The FAO56-PM is a physically based approach and required the following input (Subburayan et al., 2011): air temperature (°C), relative humidity (%), wind speed (ms^{-1}), solar radiation (MJm^{-2}day^{-1}), and number of daylight hours (h).

A software, CROPWAT 8.0 (FAO, 2015), was used to compute the reference evapotranspiration values using the FAO Penman Monteith equation.

Blaney-Criddle method

The Blaney-Criddle equation is simple and a temperature-based method (Shahidian et al., 2012) that is used to estimate reference evapotranspiration. The Blanney-Criddle reference evapotranspiration, ET_o-BC, (mm day^{-1}) is thus determined as (FAO, 1986):

$$ET_o - BC = p(0.46T_{mean} + 8) \quad (4)$$

where T_{mean} is the mean daily temperature (°C); p is mean daily percentage of annual daytime hours.
The Blanney-Criddle method used the following measurements: mean daily temperatures, T_m (°C) and mean daily percentage of day light hours.

Hargreaves method

The Hargreaves method is also a temperature-based method that is

Table 1. Mean daily climatic condition of the study area.

Period	Mean values of meteorological data for 5-day period intervals						
	Maximum Temperature (ºC)	Minimum Temperature (ºC)	Mean Temperature (ºC)	Solar radiation (MJm^{-2} day^{-1})	Relative Humidity (%)	Wind speed (km day^{-1})	Sunshine (h day^{-1})
1	31.7	24.8	28.2	19.1	81.8	27.3	6.74
2	30.9	23.8	27.3	17.5	84.4	25.4	5.25
3	32.1	24.1	28.1	22.3	82.2	24.5	8.50
4	31.6	24.3	27.9	18.9	84.8	23.9	6.70
5	32.0	24.0	28.0	20.5	84.4	24.7	7.05
6	31.4	24.9	28.1	21.5	84.0	25.6	7.77
7	30.9	24.0	27.4	18.5	89.0	17.7	6.60
8	31.8	25.3	28.5	18.2	84.2	19.4	6.70
9	31.6	24.3	27.9	19.6	84.0	20.3	7.06
10	32.0	24.5	28.2	18.0	85.0	25.3	6.92
11	31.5	20.5	26.0	17.8	80.2	28.1	6.50

usually used to determine reference evapotranspiration especially for areas that lack many meteorological data (Shahidian et al., 2012; Subburayan et al., 2011). The Hargreaves reference evapotranspiration (ETo-Hr), is thus determined as (Hargreaves, 1994):

$$ET_o - Hr = 0.0023 R_a (T_{max} - T_{min})^{0.5} \left(\frac{T_{max}+T_{min}}{2} + 17.8\right) \quad (5)$$

where R_a is the extraterrestrial radiation (mmday^{-1}); T_{max} is the mean daily maximum temperature (°C) and T_{min} is the mean daily minimum temperature (°C).

The Hargreaves method therefore required measurements of the following: Mean daily maximum air temperature, T_{max} (°C); Mean daily minimum air temperature, T_{min} (°C); and Ra is the extraterrestrial radiation (mm day^{-1}).

Hamon method

One of the simplest estimates of reference evapotranspiration is that of the Hamon equation. The Hamon reference evapotranspiration, ETo-Ha, is given as (Haith and Shoemaker, 1987):

$$ET_o - Ha = \frac{2.1 {H_t}^2 e_s}{(T_t + 273.2)} \quad (6)$$

where Ht is the average number of daylight hours per day during the period in which day t falls; e_s is the saturated vapour pressure at temperature, T, (kPa); and T_t is the daily average temperature at day t (°C) and

$$e_s = 0.6108 exp \frac{17.2 T_t}{T_t + 237.3} \quad (7)$$

Therefore, the Hamon method used the following measurements: (1) Average number of day light hours per day and (2) Daily mean air temperature (°C).

Data analysis

The data obtained from the climatic variables were analyzed by finding their means over 8-day periods. The means of the 8-day periods were used to compute ETo values for the tested methods. The ETo values were aggregated into eleven periods with each period representing 8-day interval. The performance of the methods were analyzed by computing the mean absolute error (MAE), the mean absolute percentage error (MAPE) and the correlation co-efficient of the 8-day period estimate of ETo with those of FAO56-PM (ETo-PM) as the dependent variable using Microsoft excel.

RESULTS AND DISCUSSION

Prevailing climatic condition at the study area during the periods

The mean daily values of climatic parameters obtained for 8-day periods in the driest months (December, January and February) of the year at the study area are presented in Table 1. Period 3 recorded the highest maximum temperature (32.1°C), while periods 2 and 7 recorded the lowest maximum temperatures (30.9°C). The highest minimum temperature (24.9°C) and lowest (20.5°C) were recorded in periods 6 and 11, respectively. Period 8 had the highest mean temperature (28.5°C), whereas period 11 had the lowest mean temperature (26.0°C). Relative humidity was the highest (89%) in the period 7 and lowest (80%) in the period 11. Wind speed was lower (17.7 km day^{-1}) in the period 7 and higher (28.1 km day^{-1}) in the period 11. Period 6 had long hours of sunshine (7.77 h), while period 2 had short hours of sunshine (5.25 h). The solar radiation followed similar trend as the number of sunshine hours. The highest solar radiation (22.3 MJm^{-2} day^{-1}) was in Period 3 and the least (17.5 MJm^{-2} day^{-1}) was recorded in Period 2 with the corresponding least number of sunshine hours.

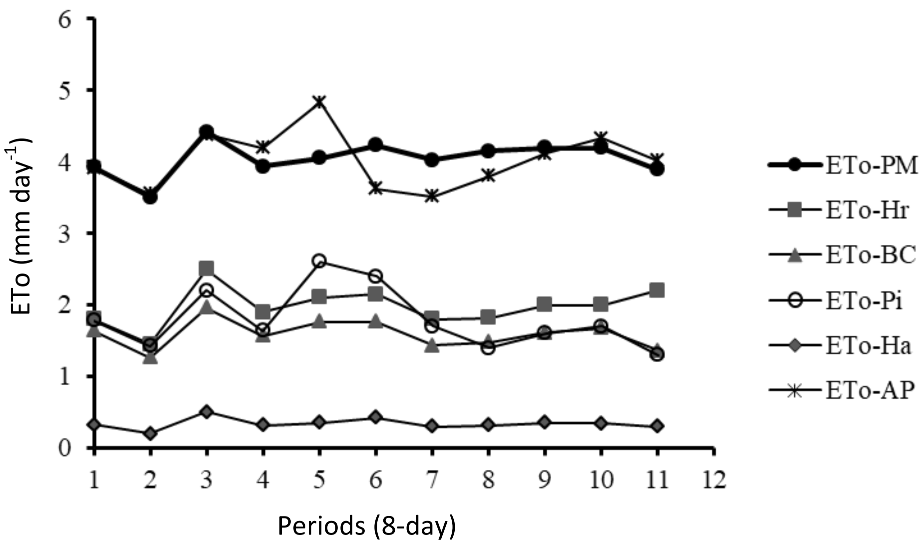

Figure 1. Comparison of mean daily ETo obtained by Penman-Monteith (ETo-PM) with Blaney-Criddle (ETo-BC), Piche Evaporimeter (ETo-Pi), Hargreaves (ETo-Hr), Class A pan (ETo-AP), and Hamon (ETo-Ha) for the periods under study.

Comparison of ETo estimates of the Penman-Monteith method and the other methods

Figure 1 shows the comparison of daily ETo estimated by Hargreaves, Blaney-Criddle, Hamon, Piche evaporimeter and Class A pan methods with FAO56-PM method for Cape Coast, a hot and humid tropical coastal savanna town of Ghana. The ETo values estimated by the FAO56-PM method ranged between 3.5 and 4.42 mm day^{-1}. The range of values were within the range obtained in a similar hot and humid coastal location in India by Subburayan et al. (2011) which had a wider range. The narrow range obtained could be attributed to relatively lower mean wind speed in the study area (<2 ms^{-1}) as compared to Subburayan et al. (2011) mean wind speed of 7.7ms^{-1}.

The ETo values estimated by the indirect measurement methods (Blaney-Criddle, Hargreaves and the Hamon methods) followed similar trend as the Penman-Method except that the Hargreaves slightly deviated at Period 11. This suggested that the estimation of ETo by these methods were greatly influenced by their corresponding input climatic data since all had their ETo values peaked at Period 3 where both the maximum temperature, sunshine hours and solar radiation were the highest with relatively low humidity (Table 1). The ETo values estimated by the two direct measurement methods (Class A pan and the Piche evaporimeter) followed similar trend as ETo-PM from Periods 1 to 3, but deviated from the other Periods. However, the distribution trend of estimated ETo values by Class A pan and Piche evapoerimeter were relatively similar, only that Class A pan had higher magnitude whilst Piche evaporimeter had low magnitude of values and both methods had their highest estimated ETo value at Period 5. This suggested that same climatic variables affected these two direct measurement methods. Nevertheless, the estimated ETo values by the Class A pan were higher at all the periods than that of the Piche evaporimeter. The difference could be due to the fact that the Piche Evaporimeter was shielded from solar radiation by the screensaver and its measurement could not be directly affected by the radiative parameters controlling the ETo (Sanchez-Lorenzo et al., 2014).

All the methods except Class A pan (which was subject to the drudgeries of all the climatic parameters) mostly underestimated ETo values obtained by the FAO56-PM method. The Class A pan, however, overestimated the ETo-PM values in Periods 4, 5, 10 and 11, underestimated ETo-PM in Periods 6, 7, 8 and 9, and estimated equally in Periods 1, 2 and 3 (Figure 1). The maximum overestimation and the maximum underestimation were 19 and 14%, respectively. The overestimation in Periods 4, 5 and 10 could be attributed to relatively high maximum temperature during those periods, while the Period 11 could be attributed to relatively high wind speed and low relative humidity. Relatively low maximum temperature coupled with low wind speed and high relative humidity could also be the cause of the underestimation. In comparison with the other methods, the ETo-AP curve was closer to the ETo-PM curve (Figure 1). This suggested that the Class A pan was better than the other methods in estimating the ETo. The Class A pan was therefore worth considering in estimating ETo in the study area when weather data are not sufficient.

The Piche evaporimeter method underestimated ETo-PM values at all periods. The underestimation partly could be due to lack of sufficient wind in the Stevenson's screen that was shielding the evaporimeter Sanchez-Lorenzo et al. (2014). These underestimations of the ETo results were similar to those of Diop et al. (2015), but different from those of Knox et al. (2011) who observed overestimation of ETo relative to FAO56-PM. The underestimation was in the range of 35 to 60%. The ETo-Pi increased in Periods 5 when the temperature and the number of sunshine hours were high (Table 1). The higher ETo-Pi in Period 5 could be as a result of the peak of the harmattan season in the study area. The ETo-Pi gradually reduced from Period 6 to 8 and slightly increased again at Period 9 and then started decreasing up to Period 11. Apart from Periods 9 to 11 where the decrease ETo-Pi followed the trend of decreasing the number of sunshine hours and invariably decreasing solar radiation, the ETo-Pi did not follow the trend of any specific determined climatic factor. This suggested that the use of Piche evaporimeter method in estimating ETo was not greatly influenced by a specific climatic factor but a combination of climatic factors.

The distribution pattern of the Hargreaves estimated ETo curve was deviated at Period 11 relative to the ETo-PM curve. Across the periods, the ETo-Hr increased with increase in its input parameters (temperature and solar radiation). The Hargreaves method underestimated ETo values as compared to the FAO56-PM method estimates and the underestimation ranged between 40 and 50%. This is comparable to similar underestimation for humid location reported by Subburayan et al. (2011), but was contrary to overestimation for humid location by Temesgen et al. (2005) and Trajkovic (2007). The Hargreaves method was nearly accurate as FAO56-PM in ETo estimation (Hargreaves, 1994) as depicted by the closeness of the curve to the ETo-PM as compared to the other indirect measurement methods and the Piche evaporimeter. The higher values of the estimate ETo by the Hargreaves method could be based on the solar radiation as input variable as compared to the Blaney-Criddle and the Hamon methods which used sunshine hours as input variable. This suggested that the Hargreaves method could be used in the study area when the weather data were scanty.

From Figure 1, lower values of ETo-BC were observed at Periods 2, 7 and 11. This could be attributed to relatively low number of sunshine hours and the corresponding low temperature. This was not surprising because these parameters were the inputs for the Blaney-Criddle method and therefore, any variations to them were likely to affect the estimated ETo (Papadopoulou et al., 2013). The Blaney-Criddle method also underestimated ETo-PM with the maximum underestimation of over 50%. The Blaney-Criddle method had higher estimate ETo values and closer with the FAO56-PM method than the Hamon method which had the lowest estimate ETo values.

The Hamon method underestimation of ETo-PM was over 70%. Nonetheless, the Hamon method gave the least underestimation of ETo values relative to the FAO56-PM across the periods (Figure 1), when day light hours were more and the temperature was relatively high as depicted at Period 3. However, as depicted at other periods, when the day hours were short and the temperatures were relatively low, the Hamon gave the higher underestimation of ETo relative to the FAO56-PM. It can be seen across the periods that the Hamon ETo estimates increased with increasing number of sunshine hours and a corresponding increase in temperature. This was not surprising because the Hamon method directly depended on daylight hours and temperature.

Degree of agreement between ETo-PM and ETo estimated by the other methods

The ETo estimates by each method were compared with the estimation of the Penman-Monteith method (ETo-PM) to measure the accuracy and reliability of the ETo methods under study. The performance of the ETo methods were measured using the following parameters: (1) MAE which measured how close the estimates were to the ETo-PM; (2) MAPE which expressed accuracy as a percentage of the error; and (3) Correlation coefficient (R) which gave a measure of the strength of the correlation between the ETo estimates.

The correlations between FAO56-PM method and the other five methods and expressed in a linear regression form ($y = Ax + B$) are shown in Figure 2. The results showed higher correlation coefficient ($R > 0.8$) for the indirect measurement methods (Hargreaves, Blaney-Criddle and Hamon) compared with the direct measurement methods (Class A pan and Piché evaporimeter) ($R < 0.4$) (Table 2). This indicated that the indirect measurement methods had a strong correlation with the Penman-Monteith method and therefore can efficiently approximate the actual ETo pattern in Cape Coast. However, the direct measurement methods showed their capability to estimate ETo with relatively least MAE and MAPE (Table 2). This suggested that both the direct and indirect measurements have their own pros and cons in estimating ETo in the study area.

The strength of association between FAO56-PM and Hamon was the highest ($R = 0.89$) among the indirect measurement methods even though it had the highest MAE and MAPE (3.7 mm day^{-1} and 75%, respectively). The stronger correlation between Hamon and FAO56-PM could be attributed to the high temperature and long hours of sunshine prevailing in the study area. This corroborated with the observation by Irmak et al. (2003) that those methods which used average number of day light hours and temperature were as important as FAO56-PM in estimation of ETo in coastal areas. This

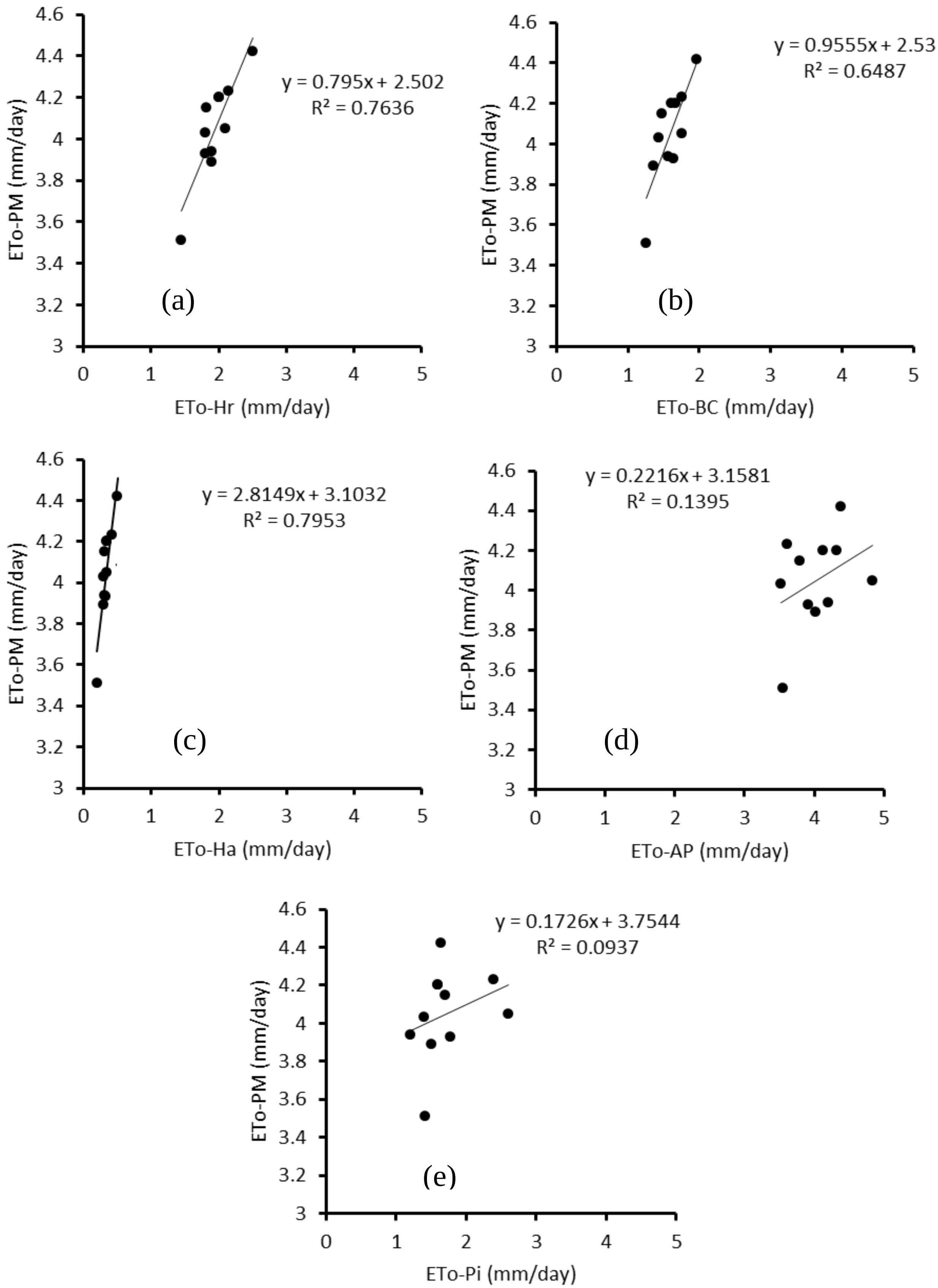

Figure 2. Regression analysis for the ETo estimates of FAO-56PM with (a) Hargreaves (b) Blaney-Criddle, (c) Hamon, (d) Class A pan, and (e) Piche evaporimeter.

Table 2. Errors and correlation between Penman-Monteith method and other ETo methods under study.

Reference evapotranspiration, ETo, method	Error		Correlation coefficient (R)
	MAE (mm day^{-1})	MAPE (%)	
Penman-Monteith	-	-	-
Class A Pan	0.26	6.50	0.37
Piche Evaporimeter	2.39	49.10	0.31
Hargreaves	2.10	42.10	0.87
Blaney-Criddle	2.45	50.00	0.81
Hamon	3.71	75.00	0.89

suggested that Hamon method can be considered as one of the simplest applicable methods to estimate ETo values in the study area, since it required only average number of day light hours per day and mean temperature (Haith and Shoemaker, 1987).

The Hargreaves and the Blaney-Criddle methods also showed higher correlation coefficients as compared to the direct measurement methods (Table 2). Even though the capabilities of the three indirect measurement methods were similar and they all needed a few number of parameters to estimate ETo, the estimation of ETo curve by the Hargreaves was closer to the estimation by the FAO56-PM as compared to the other two methods. Notwithstanding the comparatively closeness of the ET-Hr curve to the ETo-PM, there was also a strong correlation (R= 0.87) and relatively small MAE and MAPE (2.1 mm day^{-1} and 42%, respectively) established between the Hargreaves and the FAO56-PM. Hargreaves (1994) noted that Hargreaves method was as accurate as the FAO56-PM in ETo estimation. This suggested that Hargreaves method could be used in the study area when sufficient climatic data was lacking.

A high correlation coefficient (R = 0.81) established between Blaney-Criddle and FAO56-PM was an indication of a strong correlation between the two methods. This could be attributed to the prevalence of constantly high temperature (a major input) in the study area. Papadopoulou et al. (2003) observed that ETo values estimated by Blaney-Criddle method decreased as temperature dropped and even tended to cease when temperature dropped below 0°C. The Blaney-Criddle method could be used to estimate ETo as it was simple, required very few climatic data and the temperature which was a major input was always high in the study area.

Both the Class A pan and the Piche evaporimeter produced very low correlation coefficients (R). This showed that direct measurement methods had a weak relationship with the FAO56-PM. However, the Class A pan had the least MAE and MAPE (0.26 mm day^{-1} and 6.5% respectively) relative to the Piche evaporimeter and even among all the methods. The difference in their correlation coefficients and the errors could be due to the fact that the Piche evaporimeter was shielded from solar radiation and its measurement could not be directly affected by the radiative parameters controlling ETo which was not the case for the Class A pan which was in the open as intimated by Sanchez-Lorenzo et al. (2014).

The Class A pan gave R = 0.37 with FAO56-PM method and this was a weak correlation. This could be attributed to the absence of a ring at the circumference of the Class A pan at the Agro-meteorological station where the study took place which probably caused the pan to tilt when containing water. The characteristic behavior of the pan that could have enormous effect such as underestimation or overestimation of ETo as explained by Allen et al. (1998). On some occasions, frogs and birds were seen around the pan suggesting probable drinking of water by these animals. This was likely to cause a reduction in the water level and therefore changed the ETo estimation values of the pan. The fact that the Class A pan had the minimum errors though with weak correlation with the Penman-Monteith method showed that Class A pan was a good estimator of reference evapotranspiration when used in the study area.

Conclusion

ETo is one of the most important variables in the hydrological cycle. It plays an important role in the water and energy balance on earth's surface and it is of particular interest to agricultural and irrigation practices. Climate change could affect hydrological processes mainly through ET and assessing it in the context of climatic variability was therefore very important in crop production. Performance of five ETo methods were tested relative to standard Penman-Monteith with the aim to guide water practitioners, researchers and farmers in selecting appropriate method for estimating ET during the harmattan season in Cape Coast, Ghana.

Though the indirect measurement methods (Hamon, Hargreaves and Blaney-Criddle) had higher errors, the correlation between them and the Penman-Moteith method were very high and therefore can be concluded that the indirect measurement methods can efficiently approximate the actual ETo pattern in the study area. This suggested that the input parameters of these methods were significant for obtaining the proximate values in the ETo estimations. The high correlation of

Table 3. Correlation between the ETo estimates by the various ETo methods under study.

Method	ETo-PM	ETo-AP	ETo-Pi	ETo-Hr	ETo-BC	ETo-Ha
ETo-PM	-					
ETo-AP	0.37	-				
ETo-Pi	0.31	0.11	-			
ETo-Hr	0.87	0.33	0.16	-		
ETo-BC	0.81	0.35	0.27	0.82	-	
ETo-Ha	0.89	0.17	0.16	0.94	0.84	-

ETo by Hamon, followed by Hargreaves and Blaney-Criddle methods with FAO56-PM method reflected the importance of temperature, day light hours and solar radiation. This suggested the significance of sunshine duration and temperature in the study area when estimating ETo. The very strong correlation (R ranging from 0.82 to 0.94) (Table 3) among the indirect methods suggested that either of these methods could be used to estimate the reference evapotranspiration in the study area. However, the direct measurement methods (Class A pan and Piche evaporimeter) estimation of ETo were found to be weakly correlated with the FAO56-PM estimation. In spite of this, the Class A pan had the least MAE and MAPE value, and the ETo-AP curve was closer to the ETo-PM curve (Figure 1) compared with all the other methods suggesting that the Class A pan can be used in the study area. The very weak correlation (R = 0.11) between the Class A pan and the Piche evaporimeter indicated that it may not be advisable to substitute one method for the other in the study area in estimating the reference evapotranspiration. The Piche evaporimeter method was not useful in obtaining proximate values of ETo estimation in the study area owing to its very weak correlation coupled with relatively high errors with the Penman-Monteith method.

In conclusion, in data sparse region like the study area where only limited meteorological data is available and the FAO56-PM equation recommended as the standard for estimating ETo is not applicable due to the complexity of its input parameters, the use of Hamon, Hargreaves, Blaney-Criddle and Class A pan are considered as suitable methods for estimating ETo. The Class A pan was suggested as practical method for estimating ETo due to the closeness of its estimated ETo curve to that of the FAO56-PM estimated ETo curve and its low values of MAE and MAPE even though it correlated weakly with FAO56-PM. It is also recommended that the Hamon, Hargreaves, Blaney-Criddle and Class A pan should be considered for other places where the climatic conditions are similar to that of the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Production systems of village chickens in the Abu-Dhabi Emirate, UAE

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The study was undertaken to establish the village chicken (VC) production systems and to generate information on VC utilization, management practices, opportunities and challenges, using a survey. Only 20% of VC owners were females. The VC are raised mainly (80%) as dual purpose, eggs and meat. The average flock size is 457 layer hens, with 7:1 hens to cocks. Chickens houses were semi-closed cages (47%) partly shaded (20%), and shades with open range (32%). The hired labor was the sole person taking care of chickens and making the mating decisions in 85 and 68% of the properties, respectively. Selection is practiced by 37.5, 3, and 5% of large, medium and small flocks' owners, respectively. Cocks and hens replacements are from the same flock (97%). At least 61% of culling for hens and cocks is practiced for old age, 44% for low productivity and 5% for diseases. Thirteen VC breeds and crossbreds were found; the most available of which is the Emirati local breed which is found in 71% of the farms. Body weight was significantly (P<0.001) affected by the interaction between breed and region. Daily egg productivity was 32.4%, with average hatchability of 75.9%. The VC was reared mainly as a hobby and for home consumption, since most of the Emirati people prefer the taste of VC and to ensure that both their meat and eggs sources are additives free. The VC has poor productivity under the existed conditions.

Key words: Village chickens, production system, management practices, flock size.

INTRODUCTION

Many meanings are found from the term village chickens (VC) in literature, though it can be defined as those chickens kept under traditional system of raising for multiple purposes with no identified description (FAO, 2012; Aklilu et al., 2013; Liyanage et al., 2015). Raising VC has several purposes in many regions of the world which include; local consumption, extra income, pest control and manure production (Muchadeyi et al., 2004; Mtileni et al., 2009). In developing countries, 70% of the world's rural poor (2 billion people) depend on raising livestock as an important component of their livelihoods (Hoffmann and Scherf, 2005). VC is more adaptive to their climatic conditions, which is classified by small size and low egg production. In addition, Bondoc (1998) and

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Table 1. Distribution of gender of ownership property type and flock size by region.

Region	Overall	Abu-Dhabi	Al-Ain	Al-Dhafra	P-value
Total n	59	20	28	11	-
Gender ownership (%)	20.3	15.0	21.4	27.3	0.7051
Property type	-	-	-	-	0.0036
Registered animal farm (%)	22.0	30.0	25.0	0	-
Random animal farm (%)	13.6	0	28.6	0	-
Mixed farming (%)	64.4	70.0	46.4	100	-
Flock Size	-	-	-	-	0.1027
Small =< 100 layer (%)	32.2	35.0	21.4	54.6	-
Medium 101 - 500 layer (%)	54.2	45.0	71.4	27.3	-
Large > 500 layer (%)	13.6	20.0	7.1	18.2	-

Alshawabkeh and Tabbaa (2001) indicated that VC are used to utilize farm by-products and are mostly resistant to diseases and parasites.

Several production systems exist for chicken production, due to differences found in the environment and socio-economic situations of the traditional chicken growers in the world (Kitaly, 1996). Although most of the chickens' production systems are mainly based on free range (Dwinger et al., 2003), VC production in the United Arab Emirates (UAE) is mostly dependent on providing feed supplements. Housing of VC is variable under the UAE conditions (Unpublished data).

In general, even if VC breeds have low production rates, they are more adapted to their environment and may reserve essential and special genes or traits that may not be found in commercial breeds. No previous studies are available in the UAE regarding the production system of local breeds of chickens. Therefore, this study was undertaken to evaluate the VC production systems and to generate information on village based VC utilization, management practices, opportunities and challenges.

MATERIALS AND METHODS

The study area

The study was carried out in Abu-Dhabi Emirate which is located between 22°40" and 25°N and 51° and 56°E and was accomplished between March 2015 and June 2016, in 18 villages randomly selected from each municipality (Abu-Dhabi municipality (6), Al-Ain municipality (8) and Al-Dhafra municipality (4)). The Emirate is characterized with hot desert climate, low rainfall, and mostly clear skies all-year-round. Average maximum annual temperature is above 39°C with high humidity during the period from June to September, while cooler temperature (19°C) are experienced from November to March.

Sampling procedure

Households who raise more than 10 VC and willing to participate in the study within Abu-Dhabi Emirate were randomly selected. Keepers considered were those who keep VC under traditional system of raising, for multiple purposes with no identified description, regardless of the flock size.

A stratified random sample of 59 chicken keepers in the three municipal regions (Abu-Dhabi (20), Al-Ain (28) and Al-Dhafra (11)) were interviewed; based on expected number of chicken keeper in Abu-Dhabi Emirate (Table 1). This sample represents 10% of the expected size of chicken keepers' population.

Data collection

A survey was conducted to study the production systems of VC' populations of the Abu-Dhabi Emirate. A field questionnaire was developed with the list of attributes and levels, including socio-economic information and chicken productivity. Descriptive information was collected on common flock sizes and structures, as well as on the uses of animals (FAO, 2012).

Statistical analysis

Statistical analysis was performed on qualitative survey data using the Chi-square test PROC FREQ procedure (SAS Institute, 2009). Least squares analysis of variance was utilized to study, the effect of the region, geneder of VC keeper, sex, flock size and breed of chicken on quantitative data using GLM procedure (SAS Institute, 2009).

Flock size was classified as small if it was one hundred or less layer hens, medium with 101 to 500 layer hens and large flocks with more than 500 layer hens. This was based on previous study which shows that these sizes are related to utilization of VC production for home consumption, selling surpluss or commercialization of production (unpublished data). Gender of VC keeper was tested in the intitial analysis and found not significant on any of the studied criteria; therefore, it was removed from subsequent analyses. All possible interactions were also tested though only their two-way interactions were left in the final statistical model. Means for significant effects were compared at $P<0.05$ using t-test.

RESULTS AND DISCUSSION

Socioeconomic role

Due to high income of the Abu-Dhabi Emirate people only 20% of VC owners were females and this was not different throughout the regions (Table 1). At the same

Table 2. Distribution of goal and purpose of raising chicken by region, property type and flock size.

Variable	n	Goal of raising			Purpose of raising		
		Home consumption (%)	Selling (%)	Selling surplus (%)	Egg (%)	Meat (%)	Dual purpose (%)
Overall	59	59.3	5.1	35.6	11.9	8.5	79.7
Region P-value	-		0.2850			0.0234	
Abu-Dhabi	20	60.0	0	40.0	30.0	10.0	60.0
Al-Ain	28	67.9	7.1	25.0	3.6	10.7	85.7
Al-Dhafra	11	36.4	9.1	54.6	0	0	100
Property type P-value	-		0.3610			0.0781	
Registered animal farm	13	61.5	15.4	23.1	30.8	15.4	53.9
Random animal farm	8	62.5	0	37.5	0	0	100
Mixed farming	38	57.9	2.6	39.5	7.9	7.9	84.2
Flock size P-value	-		0.0765			0.5511	
Small =< 100 layer	19	68.4	0	31.6	21.1	5.3	73.7
Medium 101 - 500 layer	32	56.3	3.1	40.6	9.4	9.4	81.3
Large > 500 layer	8	50.0	25.0	25.0	0	12.5	87.5

time, gender of owner has no effect on any of the studied criteria. Though, VC are essential in countries with high poverty since they play a major role as a starter capital, economic buffers, source of animal protein as meat and eggs, standby cash and social activity enforcer (Dinka et al., 2010; Mtileni et al., 2013; Chrishanthan et al., 2014; Haoua et al., 2015). Therefore, the majority of VC ownership in the poor countries were women and children and were given the responsibility for management and production as an agribusiness activity for income generating (Dinka et al., 2010; Nduthu, 2015).

Also, VC in the UAE is not linked to the religious or socio-cultural practices as in most Muslim countries (Abdelqader et al., 2007). Though, in other parts of the world it is linked to religious functions (Gueye, 1998; Fotsa et al., 2007; Dinka et al., 2010; Nduthu, 2015). The visited properties in this study were registered as animal farms all owned by males, random animal farms 50% owned by females and mixed farms 21% owned by females. Gender was considered as a factor in the initial statistical analysis; however, it has no effect on any of the studied criteria.

The municipality registered animal farms are established as group by the municipalities and distributed among the local people, while the random animal farms are established in random places, may found in a group or single, and they are unregistered. Both registered and random animal farms are allowed to raise different species of animals but not to grow trees or crops, on the other hand, the mixed farms are registered farms and are allowed to grow trees, crops and vegetables besides raising animals.

In the overall, more than 64% of chicken keepers are under the mixed farming system, while under the Abu-Dhabi municipal 70% are under mixed farming and all in Al-Dhafra municipal are under mixed farming. In comparison with other countries such as Sri Lanka, only 25% of VC keepers are under the mixed farming system (Chrishanthan et al., 2014).

Goal and purpose of rearing

People in Abu-Dhabi Emirate rear VC mainly as a hobby and for home consumption, since they prefer the taste of VC and ensure that the source of their chicken meat and eggs are additive free. In this study, more than 59% of the surveyed owners are rearing the chickens for home consumption only, with another 35% rearing for home consumption and sell surplus product of eggs, chicks and chicken, while only 5% of the owners are rearing their chicken for selling (Table 2).

However, VC in other parts of the world plays a vital function in the nutritional, socio-culture and economy of the rural people, since VC are sold at higher prices than commercial chickens (Abdelqader et al., 2007; Mtileni et al., 2013; Alem et al., 2014). In many countries, the majority of farmers keep VC for selling or as gifts and presents for visitors, while few farmers keep chicken for home consumption (Haoua et al., 2015; Mutombo et al., 2015; Nduthu, 2015). In this study, region and property type were not affecting goal of VC rearing, though numerically, as flock size increases more VC keepers are specialized in selling their products or selling surpluses. In other countries, differences in goals of rearing among different regions were reported due to heterogeneity of flock population (Alem et al., 2014).

The VC in Abu-Dhabi Emirate is raised mainly (80%) as

Table 3. Some flock structure and productivity characteristics of sampled flocks and chickens.

Variable	n	Hen to Cock Ratio	Hens (%)	Cocks (%)	Chicks and growers (%)
Overall	59	7.0±0.83	53.0±3.58	11.2±1.09	34.0±3.99
Region P-value	-	0.2713	0.6269	0.7436	0.5598
Abu-Dhabi	20	7.0±1.69	64.1±7.39	12.2±2.40	22.9±8.67
Al-Ain	28	8.5±1.37	55.9±6.01	10.9±1.95	33.4±7.12
Al-Dhafra	11	11.1±2.47	63.0±10.79	9.6±3.51	22.7±12.21
Property type P-value	-	0.2040	0.1589	0.9766	0.3246
Registered animal farm	13	7.9±1.95	55.4±8.55	10.6±2.78	33.8±10.05
Random animal farm	8	11.8±2.56	75.2±11.19	10.8±3.64	12.9±13.23
Mixed farming	38	7.0±1.12	52.4±4.89	11.3±1.59	32.2±5.51
Flock size P-value	-	0.1323	0.0746	0.8891	0.4201
Small =< 100 layer	19	6.1±1.57	47.6±6.87	11.7±2.23	33.8±7.57
Medium 101 - 500 layer	32	8.9±1.56	60.3±6.85	10.4±2.23	29.2±8.06
Large > 500 layer	8	11.6±2.42	75.1±10.59	10.6±3.44	15.9±12.50

dual purpose for both eggs and meat, regardless of flock size (Table 2). Differences in VC rearing purposes were reported around the world. In Ethiopia for instance, Alem et al. (2014) found that the main purpose for chicken rearing was meat than egg production, while in Jordan and Kenya, the main purpose for chicken rearing was for eggs than meat production (Abdelqader et al., 2007; Mutombo et al., 2015). In the current study, significant differences ($P < 0.05$) in VC rearing purposes were found through regions. All Al-Dhafra keepers raise their chicken as dual purpose, while 60 and 85% of the keepers in Abu-Dhabi and Al-Ain regions, respectively, raise their chicken as dual purpose. Similarly, Alem et al. (2014) reported differences in rearing purposes between VC keepers living in different agro-ecological regions of Ethiopia, in addition to differences in rearing purposes due to gender of keepers.

Flock size and structure

Flock sizes of VC were ranging from small with one hundred or less layer hens (32%), medium with 101 to 500 layer hens (54%) and large flocks with more than 500 layer hens (14%) (Table1). The overall flock size average is about 457 layer hens and total of 1008 birds of all ages, with overall sample population total of 25,614 layer hens and 59,462 heads. It was observed that flock sizes for Abu-Dhabi and Al-Ain regions were medium, while more than 54% of the Al-Dhafra flocks were small size reared under mixed farming, although differences were not significant. Much smaller average flock sizes were reported by researchers in other countries (Abdelqader et al., 2007; Dinka et al., 2010; Mtileni et al., 2013; Chrishanthan et al., 2014; Nduthu, 2015). The average flock sizes reported were ranging from 5 to 50 heads. The main reason behind the very large average flock size in Abu-Dhabi Emirate comparing to other countries, maybe due to most owners, who prefer the flavour, texture and freshness of VC meat and eggs over the commercial.

Gender of owner in this study has no influence on flock size however, in South Africa Mtileni et al. (2013) reported that male VC keepers kept larger flocks than that of females. Results showed that on the basis of a property in Abu-Dhabi Emirate, the average hen to cock ratio is 7 to 1 with a range of 1.25 to 35 to one. This range is very large; the low represents the uneconomical and the high represents the infertile. However, many owners keep too many cocks to slaughter them as they need. The average hen to cock ratio in this study is similar to that reported by Abdelqader et al. (2007) and Mopate and Lony (1999). Although not significant ($P>0.1$), as flock size increases hen to cock ratio numerically also increase to become more economical (Table 3). While hens represents 53% and cocks represents only 11%, chicks and growers represent 34% of the flock (Table 3). Hens percentage tend ($P<0.1$) to increase as flock size increased. Different percentages for the distribution of chickens' categories were reported around the world (Abdelqader et al., 2007; Mtileni et al., 2013; Haoua et al., 2015).

Housing and management system

Chicken in this study were raised in semi closed cages (47%), partly shaded (20%), and shades with open range (32%) regardless of region, property type or flock size (Table 4). Housing provides chickens with protection against predators, theft, extreme weather conditions and provides shelter for egg laying (Dinka et al., 2010). For

Table 4. Distribution of chicken housing types and some management measures by region, property type and flock size.

Variable	n	Semi close cages (%)	Partly shaded (%)	Shade and open range (%)	Owner share with chicken care (%)	Owner making mating decisions (%)	Presence of hatchery (%)
Overall	59	47.5	20.3	32.2	15.3	32.2	78.0
Region P-value	-		0.2607		0.7902	0.0216	0.2197
Abu-Dhabi	20	50.0	30.0	20.0	15.0	10.0	65.0
Al-Ain	28	53.6	14.3	32.1	17.9	39.3	85.7
Al-Dhafra	11	27.3	18.2	54.6	9.1	54.6	81.8
Property type P-value	-		0.2787		0.1360	0.2742	0.5589
Registered animal farm	13	69.2	15.4	15.4	30.8	46.2	84.6
Random animal farm	8	62.5	12.5	25.0	0	12.5	87.5
Mixed farming	38	36.8	23.7	39.5	13.2	31.6	73.7
Flock size P-value	-		0.7421		0.1037	0.3148	0.1951
Small =< 100 layer	19	52.6	10.5	36.8	5.3	21.1	68.4
Medium 101 - 500 layer	32	46.9	25.0	28.1	15.6	34.4	78.1
Large > 500 layer	8	37.5	25.0	37.5	37.5	50.0	100

the first two housing types, keepers must provide enough feeding to cover all nutritional needs, while the third type of housing provide the ability for the chickens to scavenge during daytime part of their requirements.

Similar to other countries, poor sanitary condition and insufficient protection were mostly provided for VC by most houses types (Abdelqader et al., 2007; Mtileni et al., 2013). No artificial light was provided in chicken houses, all VC keepers rely on the natural light. Some large flocks' owners were advised to provide artificial light to increase lighting period up to 16 to17 h, these owners produced 30% more eggs than the other owners, accompanied with an increase in feed intake by the layer chickens.

Keepers of VC in this study usually provide commercial feed rations available in the UAE market to their chickens according to age. Chicks and growers are provided with broiler rations while older hens and cocks are provided with layer rations. Hussein et al. (2014) provided nutrient composition to many broilers and layers feed rations available in the UAE market, which are also used to feed VC in Abu-Dhabi Emirate. However, VC in other countries was not provided with enough feeding. Most or all farmers allow chickens to scavenge the area around their places and offer some kind of supplement which might consist of kitchen leftover or household waste, cereal by-products and cereal grains resulting in low productivity of village chicken (Abdelqader et al., 2007; Dinka et al., 2010; Haoua et al., 2015). Scavenging might fulfil the nutritional requirements from energy, protein, vitamins and minerals depending on available area per bird, quality of scavenging feed resources, season, land fertility and physiological stage of the chicken. The birds scavenged whatever available on the ground such as worms, insects, crop residues, grasses and grains (Abdelqader et al., 2007). In some countries, chickens are only scavenging the range with no supplementary feed at all or provided with kitchen leftovers only (Nduthu, 2015; Olobatoke et al., 2015). In other countries, most chicken keepers do not provide feed additives however; commercial feed mix is also provided especially to chicks and growers (Mtileni et al., 2013; Chrishanthan et al., 2014). Abdelqader et al. (2007) results showed that VC under higher management levels outperformed those under lower management.

Most poor countries taking care of VC is the responsibility of families' labor, since VC production is based primarily on scavenging and does not require high managerial skills (Abdelqader et al., 2007; Dinka et al., 2010; Chrishanthan et al., 2014; Nduthu, 2015; Olobatoke et al., 2015). In these countries, housing, feeding and general management of VC are the obligation for women and children while selling or feed buying are the responsibility of men (Dinka et al., 2010; Chrishanthan et al., 2014;

Nduthu, 2015). Though, in this study, the hired labor is the sole person taking care of VC in 85% without interference and contribution from the flock owners, regardless of the region (Table 4). However, numerically more than 30% of the owners of registered animal farms share in taking care of VC and as flock size increase more owners interfere with decision taking of the VC care. Also, in 68% of the farms the labors alone are making the mating decisions without interference by the owners. Though, this is significantly different ($P<0.05$) according to region, more than 54% of the farm owners in the Al-Dhafra and 39% of the Al-Ain region are making mating decisions of VC and as flock size increase numerically more owners which are making mating decisions (Table 4).

Hatcheries are found in 78% of the farms regardless of regions, property type or flock size (Table 4). However, all large flocks have hatcheries and fewer hatcheries are found in the small flocks. In other countries, when the flock size is very small natural reproduction is the only tool for maintaining the flock besides brooding hens are responsible for hatching the eggs (Abdelqader et al., 2007; Nduthu, 2015). Farmers may provide brooding places and when chicks are hatched some extra care might be provided in family houses (Abdelqader et al., 2007).

Health management practices

Most of the VC owners in Jordan and Cameroon are not cleaning or disinfecting chicken houses or don't pay attention to health care (Abdelqader et al., 2007; Haoua et al., 2015). Similarly, keepers of VC in Abu-Dhabi do not use medicine except antibiotics if they have to and after the disease are wide spread in their flocks, in addition to vitamin supplements. In Kenya only 20% of the VC keepers are using the conventional disease control methods and 80% of the local traditional cure these methods (Mutombo et al., 2015). Only very few village keepers in many countries practice vaccination against Newcastle disease and infectious bronchitis (Abdelqader et al., 2007; Haoua et al., 2015).

Almost all VC keepers in Abu-Dhabi do not vaccinate their flocks. Farmers do these practices because they think this is more natural and organic production, since they mainly consume the production by themselves. Though, no immunization means increase the risk of chickens' exposure to diseases (Nduthu, 2015). However, rearing VC with minimum use of chemicals leads to organic eggs and meat which are on demand nowadays (Abdelqader et al., 2007; Mtileni et al., 2013).

Olobatoke et al. (2015) reported high disease prevalence among local chicken in Nigeria, this include Newcastle and Gumboro diseases. These diseases are also reported in other countries (Abdelqader et al., 2007; Haoua et al., 2015). It was noticed that the most prevalent clinical symptoms in Abu-Dhabi Emirate were respiratory manifestations as cough and nasal discharge, eye swelling, eye lesions, diarrhea and pox lesions. Some VC keepers also reported drop in egg production. Similarly, farmers do not practice record keeping on diseases and mortality of their stock (Chrishanthan et al., 2014).

Selection and culling

Selection is only practiced in 8% of the flocks, with no differences between regions or property types, however, 37.5% of large flock owners are practicing selection in comparison to only 5% of small and 3% of medium flocks owners (Table 5). The VC keepers usually select their productive hens mainly based on body size, then on pedigree (Dinka et al., 2010). Some keepers consider finger space between the pelvic bones (Dinka et al., 2010), however, in this study, keepers were ignorant about it. Though, both cocks and hens are raised from the same flock (97%), (Table 5). This practice is general in other countries, such as in Jordan, where most VC keepers select hatching eggs from the same flock (Abdelqader et al., 2007). This would raise the inbreeding coefficient very high, especially for small flocks, and cause deterioration of the flock productivity largely; especially that selection is not correctly practiced.

However, in Jordan, some keepers exchange eggs with other farmers to improve flock performance and few even exchange cocks (Abdelqader et al., 2007). Culling, on the other hand, is mainly practiced for old age hens and cocks (61%), however, it is significantly ($P<0.01$) different among regions, the most is in Al-Ain (82%), and among property types ($P<0.05$), the most in random animal farms (100%), (Table 5). Similarly, researchers in other countries reported culling for old age hens and cocks or surplus chicks which are sold or slaughtered (Abdelqader et al., 2007; Mtileni et al., 2013). Low productivity is the second cause of culling reason practiced by VC keepers (44%), as they claimed. Though, no production records were kept by the keepers and they were unable to differentiate between laying and non-laying hens. Record keeping and identification for breeding purposes are not practiced by VC keepers in other countries (Abdelqader et al., 2007; Mtileni et al., 2013; Chrishanthan et al., 2014). However, culling due to productivity is significantly different ($P<0.01$) among regions and the most is in Al-Ain (64%), it is also significant ($P<0.05$) due to different property types and flock sizes (Table 5). More than 5% of keepers also cull for diseases. Culling for home consumption, giving as gifts and selling of VC is practiced by more than 40, 8 and 3% of the keepers, respectively. However, more than 6% of the keepers do not practice culling; they leave birds until natural death.

Thirteen VC breeds in addition to crossbreds were found in this study (Table 6). The most available breed is

Table 5. Percente practicing selection, replacement within the same flock and different culling reasons of village chickens.

Variable	n	Selection (%)	Replacements within flock (%)	Culling reason						No culling (%)
				Age (%)	Productivity (%)	Diseases (%)	Eating (%)	Gifts (%)	Selling (%)	
Overall	59	8.5	96.61	61.0	44.1	5.1	40.7	8.5	3.4	6.8
Region P-value	-	0.9373	0.3275	0.0064	0.0099	0.6586	0.1734	0.5327	0.0109	0.5672
Abu-Dhabi	20	10.0	95.0	40.0	30.0	5.0	55.0	10.0	0	10.0
Al-Ain	28	7.1	100	82.1	64.3	7.1	28.6	10.7	0	7.1
Al-Dhafra	11	9.1	90.9	45.5	18.2	0	45.5	0	18.2	0
Property type P-value	-	0.6196	0.5821	0.0442	0.0326	0.1526	0.7113	0.0898	0.5644	0.7140
Registered animal farm	13	7.7	92.3	61.5	69.2	15.4	46.2	23.1	0	7.7
Random animal farm	8	0	100	100	62.5	0	50.0	0	0	0
Mixed farming	38	10.5	97.4	52.6	31.6	2.6	36.8	5.3	5.3	7.9
Flock size P-value	-	0.0063	0.1870	0.6799	0.0359	0.5578	0.2980	0.1946	0.1870	0.6090
Small =< 100 layer	19	5.3	94.7	57.9	26.3	5.3	26.3	5.3	5.3	5.3
Medium 101 - 500 layer	32	3.1	100	65.6	59.4	3.1	46.9	6.3	0	9.4
Large > 500 layer	8	37.5	87.5	50.0	25.0	12.5	50.0	25.0	12.5	0

the Emirati VC or what is locally called (Addar chicken) which is found in 71% of the properties. This breed comes with many shapes and colors and all has the same name. Although, indigenous genotypes are known as less productive, keepers prefer them, as they are more adapted to severe environmental conditions, have better maternal care, and produce leaner and tastier meat compared to exotic breeds (Mtileni et al., 2013). The second most available breed is Fancy or what is locally called French breed which is found in 36% of the farms. The breed is not similar to any of the known French breeds, however, because fancy is sound like French in Arabic, most keepers call this breed as French. The Fancy breed is of two colors one of which is very similar to New Hampshire Red and the second is very similar to Delaware breed. The third is the crossbred chicken (20%), which mainly with Fancy breed, secondly with Pakistani and then with other breeds. The fourth is the Omani (12%) and the fifth is the Pakistani (10%). Other breeds are found in less than 10% of the visited sample farms.

Body weight and some productivity measurements

Body weight was significantly (P<0.001) affected by the interaction between both breed and region and breed and sex (Table 6). However, the three-way interaction was not significant (P>0.1). Local breed was heaviest in the Al-Dhafra, while Fancy breed was heavier in both Abu-Dhabi and Al-Ain than that in Al-Dhafra. However, Brahman was the heaviest breed in Al-Ain and was very moderate in the Al-Dhafra. Males were always heavier than females, differences were not consistent among breeds; male-female differences in some breeds were not significant (P>0.05), (Table 6).

The overall daily egg production is around 76 eggs per property per day with a very low productivity rate of 32.4%, wide range of 1.43 to 69.63% while both ends of the range are low to be economical (Table 7). Although, low productivity was reported by Chrishanthan et al. (2014) for local chicken in Sri Lanka which is higher than that found under Abu-Dhabi conditions. Similar to reports from other countries, low productivity might be due to several management, environmental and genetic factors. Some of which are weak experience in poultry keeping, low feed quality, lighting program, bad management, no record keeping, diseases infection (clinical and subclinical), hot climate, low culling rate, no selection and genetic makeup of the breeds (Chrishanthan et al., 2014; Nduthu, 2015). Although, daily egg production was significantly different (P<0.001) among different flock sizes

Table 6. Body weight in grams of village chickens breeds as affected by the breed-region and breed-sex interactions of chicken.

Breed	Frequency	Breed*Region			Breed*Sex	
	%	Abu-Dhabi	Al-Ain	Al-Dhafra	Female	Male
P-value			<0.0001		0.0004	
Local	71.19	1357±28^{i}	1423±23^{i}	1722±50^{cdef}	1288±21^{f}	1575±31de
Fancy	35.59	2119±30^{b}	2106±40^{b}	1677±96^{efg}	1819±28^{bc}	2359±43^{a}
Crossbred	20.34	1551±54^{gh}	1706±49^{def}	1686±49^{defg}	1431±37de	1876±51^{b}
Omani	11.86	-	1388±44^{i}	-	1274±50^{f}	1502±78de
Pakistani	10.17	-	2210±280^{abcdef}	1935±101^{bce}	1596±112^{cde}	2320±174^{a}
Brahman	8.47	1960±144^{bcdef}	2547±186^{a}	1116±99^{j}	1528±86.83^{de}	1514.29±147^{def}
Kuwaiti	6.78	981±132^{j}	1173±77^{j}		1050±87^{g}	1200±112^{fg}
Fayomi	3.39	-	-	1635±101^{fg}	1500±123^{def}	1770±174^{bcd}
Karla	3.39	1783±154^{cdefg}	1305±117^{hij}	-	1344±129^{efg}	1614±147^{bcde}
Other breeds[1]	8.47	-	1676±65^{fg}	1718±73^{cdefg}	1514±58de	1874±89^{bc}

[1]Other breeds: uncommon breeds that are claimed to be Holland, Australia, Japan, Habhab and Abu-Dhabi. [a,b,c,d] Different superscripts within an interaction indicate significant differences (P<0.05).

Table 7. Some productivity characteristics of sampled flocks of village chickens.

Variable	n	Daily eggs production	Eggs productivity (%)	Hatchability (%)
Overall	59	75.6±9.68	32.4±2.50	75.9±1.77
Region P-value[1]	-	0.6145	0.2043	0.8836
Abu-Dhabi	20	99.2±15.61	27.5±4.73	71.6±3.25
Al-Ain	28	94.5±12.50	32.1±3.75	69.8±2.53
Al-Dhafra	11	74.4±24.45	18.2±7.36	70.5±4.74
Property type P-value[1]	-	0.5060	0.1424	0.0011
Registered animal farm	13	103.5±17.78	33.1±5.36	74.8±3.65^{a}
Random animal farm	8	73.8±23.65	17.6±7.10	58.4±4.84^{b}
Mixed farming	38	90.9±10.99	27.1±3.35	78.7±2.04^{a}
Flock size P-value[1]	-	<0.0001	0.0129	0.3703
Small =< 100 layer	19	21.2±15.54^{c}	37.5±4.78^{a}	67.9±3.48
Medium 101 - 500 layer	32	68.0±13.69^{b}	27.7±4.12^{a}	73.3±2.79
Large > 500 layer	8	178.9±23.61^{a}	12.7±7.11^{b}	70.8±4.09

and larger flocks have higher daily production, eggs productivity which was significantly (P<0.05) higher in smaller flocks. This could be due to more care taken for smaller flocks than that for larger ones. Keepers receive higher prices for eggs from VC than commercial eggs, since the demand on VC eggs is high due to preferences of flavour, dark yellow yolk, and the organic production of chicken (Abdelqader et al., 2007; Mtileni et al., 2013).

The overall hatchability rate using artificial hatcheries is (75.9%), far lower than that found in commercial hatcheries (Table 7). In other countries, using natural brooding and hatching practices for VC, keepers may obtain higher hatchability with an extremely lower number of hatched chicks (Abdelqader et al., 2007; Mtileni et al., 2013; Chrishanthan et al., 2014). Significantly (P<0.01) lower hatchability was found in random animal farms in comparison with registered farms or mixed farming. High hatchability may be obtained due to a shorter period of egg storage before incubation, and selecting the best eggs in terms of weight and health status and performance of hens (Abdelqader et al., 2007). Differences in hatchability were reported for different breeds of VC (Chrishanthan et al., 2014).

Conclusion

The VC in Abu-Dhabi are reared mainly as a hobby and for home consumption, since the Emirati people regard the taste of VC and to ensure that sources for both their meat and eggs are free from additives. The studied production measurements revealed poor productivity under the existed rearing conditions of Abu-Dhabi Emirate. Several factors might have affected their productivity under the existed conditions and should be controlled, including feed quality, lighting program, management, health status, climate conditions, culling rate and selection, in addition to genetic makeup of chicken breeds.

The current study confirms the need for extra efforts in the execution of effective extension programs to owners and labours, to improve management and health conditions and apply certain level of genetic improvement in order to improve productivity of VC. Genetic evaluation of VC breeds of Abu Dhabi Emirate is needed to test for the purity of these breeds. There is an urgent need for executing and implementing a national research program to collect, conserve and improve the VC in order to enhance the traditional poultry production in the country.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of 'Tifton 85' during hay production using different nitrogen fertilization rates and dehydration methods

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The objective of this study was to evaluate *Cynodon* species 'Tifton 85' at different hay production phases (harvest, baling, and storage) and different (N) rates. Dehydration of the first crop was carried out in the field, while the second crop was in the shed. Dry matter and protein content increased linearly with the N rates. Dehydration in the shed was not effective for hay production, since dry matter did not reach the desired level of 850 g kg^{-1}. During the hay production period (harvest, baling, and storage), the content of acid detergent fiber of the first crop and the second crop increased by 25.32 and 7.38%, respectively, and that of lignin increased by 21.33 and 32.27%, respectively. Forage digestibility decreased by 4.55%, when dehydration occurred in the field, whereas it decreased by 14.68% when dehydration occurred in the shed, a difference higher than 300% due to the loss of soluble carbohydrates. Overall, the findings of this study indicate that forage dehydration for hay production needs to be carried out in the field under appropriate environmental conditions to prevent nutritional losses. Additionally, dry matter of Tifton 85 increased by 20.40% and protein content increased by 18.65%, which equals 514.27 kg of soybean meal at 100 kg ha^{-1} of N.

Key words: Fertilization rates, hay production, nutrient quality of forage, pasture.

INTRODUCTION

The management of hay production is used to preserve forage through the partial dehydration of plant material. Physical, biological, and chemical processes during harvest and storage cause dry matter (DM) and nutrient losses (Rotz and Shinners, 2007). Thus, the main objective in hay production is to maintain the DM and nutrient content of forage, which is usually stored for at least one year.

Dehydration removes the water that enhances the action of deleterious microorganisms and prevents the

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long preservation of hay (Mufatto et al., 2016). Thus, hay is a forage resource that can cover any seasonal quantitative and qualitative deficiencies and thus, it is important to obtain fodder of high nutritional value (Cavalcanti et al., 2016).

Hay quality is related to its nutritional value, suitable characteristics of forage plants, climatic factors, and management (Gomes et al., 2015; Mufatto et al., 2016). Adverse climatic factors often increase the dehydration time, extending the respiration until the moisture concentration in the forage reaches 400 g kg^{-1} DM and lead to significant losses in carbohydrates and hexoses that are easily digestible (Collins and Clobentz, 2007).

Fertilization is an important factor in hay production management, since grasses require relatively high amounts of nitrogen (N) for their growth (Sanches et al., 2017). In tropical areas, *Cynodon* species is recognized as a valuable forage resource with great versatility that responds to the continuous increase in N applied to the soil, increasing the production of DM per hectare and the percentage of crude protein (CP) (Sohm et al., 2014).

N fertilization and harvest time also influence the concentration of neutral detergent fiber (NDF) and acid detergent fiber (ADF). Both NDF and ADF usually decrease with increasing N rate, but increase during the summer because of the relatively high temperature that promotes cellular aging, and thus, the formation of fibrous tissues (Sohm et al., 2014; Sanches et al., 2017). The nutritional potential of forage is determined by ADF that is composed of lignin (LIG) and modifies the DM digestibility as well as by the nutritional value. N usually increases the CP of forage, since it increases the participation of leaves in the total DM (Ames et al., 2014); thus, it is positively associated with DM digestibility.

This study aimed to evaluate the DM, canopy height, and number of tillers of *Cynodon* spp. 'Tifton 85' prior to harvest as well as the DM, mineral matter (MM), NDF, ADF, neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP), CP, LIG, cellulose (CEL), hemicellulose (HEM), and *in vitro* dry matter digestibility (IVDMD) at harvest, baling, and storage using five different N fertilization rates and two different dehydration methods.

MATERIALS AND METHODS

The study was carried out at the Experimental Farm of Antonio Carlos Santos Pessoa, Marechal Cândido Rondon campus, Western Paraná State University (24°31′53.0″S, 54°01′03.0″W, 420 m above sea level). According to Koppen, the weather of this area is classified as subtropical Cfa; rainfalls are well distributed throughout the year and summers are hot. The temperature of the coldest quarter ranges from 17 to 18°C, the hottest quarter from 28 to 29°C, and the annual temperature from 22°C to 23°C. The precipitation of the wettest quarter ranges from 400 to 500 mm, the driest quarter from 250 to 350 mm, and the annual precipitation from 1,600 to 1,800 mm (Caviglione et al., 2000).

The soil of the experimental area is classified as Red Eutrophic Latosol (LVe) (EMBRAPA, 2013) with the following chemical characteristics: 8.15 mg dm^{-3} P (Mehlich Puller), 23.92 g dm^{-3} Mo, 0.01 mol L^{-1} $CaCl_2$, 4.30 cmol$_c$ dm^{-3} H + Al, 0.05 cmol$_c$ dm^{-3} Al^{3+} (1 mol L^{-1} KCl), 0.23 cmol$_c$ dm^{-3} K (Mehlich Puller), 3.62 cmol$_c$ dm^{-3} Ca^{2+} (1 mol L^{-1} KCl), 1.69 cmol$_c$ dm^{-3} Mg^{2+} (1 mol L^{-1} KCl), 5.54 cmol$_c$ dm^{-3} Sb, 9.84 cmol$_c$ dm^{-3} CTC, 56.30% V, 0.89% Al, 6.30 mg dm^{-3} Cu (Mehlich extractor), 1.4 mg dm^{-3} Mn (Mehlich extractor), 63.00 mg dm^{-3} Zn (Mehlich extractor, 25.10 mg dm^{-3} Fe (Mehlich extractor)), and 650 g kg^{-1} clay.

The study was carried out in a hay production field, established in 2004. The grass *Cynodon* spp. 'Tifton 85' (*Cynodon dactylon* × *Cynodon nlemfuensis*) was cropped in a randomized complete block design (RCBD) with four blocks and five plots (5 m × 3 m) per block (a total of 20 experimental plots sub-divided by time). The weather conditions throughout the study period are as shown in Figure 1. Harvest for standardizing the forage was conducted on October 30, 2010. Dehydration of the first crop was carried out in the field, whereas that of the second crop in a shed (Table 1).

DM, canopy height and number of tillers per square meter were studied for five N rates (0, 25, 50, 75, and 100 kg ha^{-1} of N) and two harvests, whereas chemical composition and IVDMD were studied for five N rates and two hay production periods (harvest, baling, and storage) (Banzatto and Kronka, 2006).

The DM per hectare was estimated using a 0.25 m^2-metallic frame that placed 5 cm above the ground level (Salman et al., 2006) to harvest the fodder in each experimental unit. Three samplings were performed at each harvest per experimental unit. Samples were labeled, packed in paper bags, weighed, and then dried in a forced ventilation oven at 55°C for 72 h to estimate the DM per hectare. The average plant canopy height (average of three points) was measured prior to harvest using a millimeter ruler. The tiller number per square meter was calculated by multiplying the DM of each 0.25 m^2 area by four and dividing it by the average tiller weight of the same area.

Revolving and turning during forage dehydration were performed daily between 10:00 and 15:00 h. At baling and storage, samples were ground using a Willey mill, passed through a 30-mesh sieve, and stored in plastic bags. Then, they were used for evaluating DM, MM, NDF, ADF, NDIP, ADIP, CP, LIG, CEL, and HEM (Silva and Queiroz, 2009). IVDMD was determined as described by Tilley and Terry (1963) and DM digestibility was analyzed as described by the Association of Official Analytical Chemists (AOAC, 1990). Analysis of variance (ANOVA) in conjunction with Tukey's test was performed to study the effect of dehydration conditions and hay production phases (harvest, baling, and storage) on the variables. The effect of N rate was obtained by regression analysis; the model was selected based on the highest coefficients of determination (R^2), and the partial regression coefficients were calculated with Student's *t*-test (Pimentel-Gomes, 2009). Significance was set at $p < 0.05$. All analyses were performed using Sisvar 5.3 (Ferreira, 2011).

RESULTS AND DISCUSSION

DM increased with increasing N rate (Figure 2); however, no interaction was identified among N rate and DM at the first or second crop. DM increased with increasing N rate as follows: Y (DM ha^{-1}) = 4,308.28 + 8.79X (N rate), showing that at kg ha^{-1} of N, DM was 4,308.28 kg per hectare and that DM increased by 8.79 kg per hectare for each kg of N. These results could be attributed to the higher precipitation after the first harvest (Figure 1) that enhanced the utilization of residual N in the soil. It is known that N stimulates vegetative growth as well as water absorption for cell elongation in the meristem

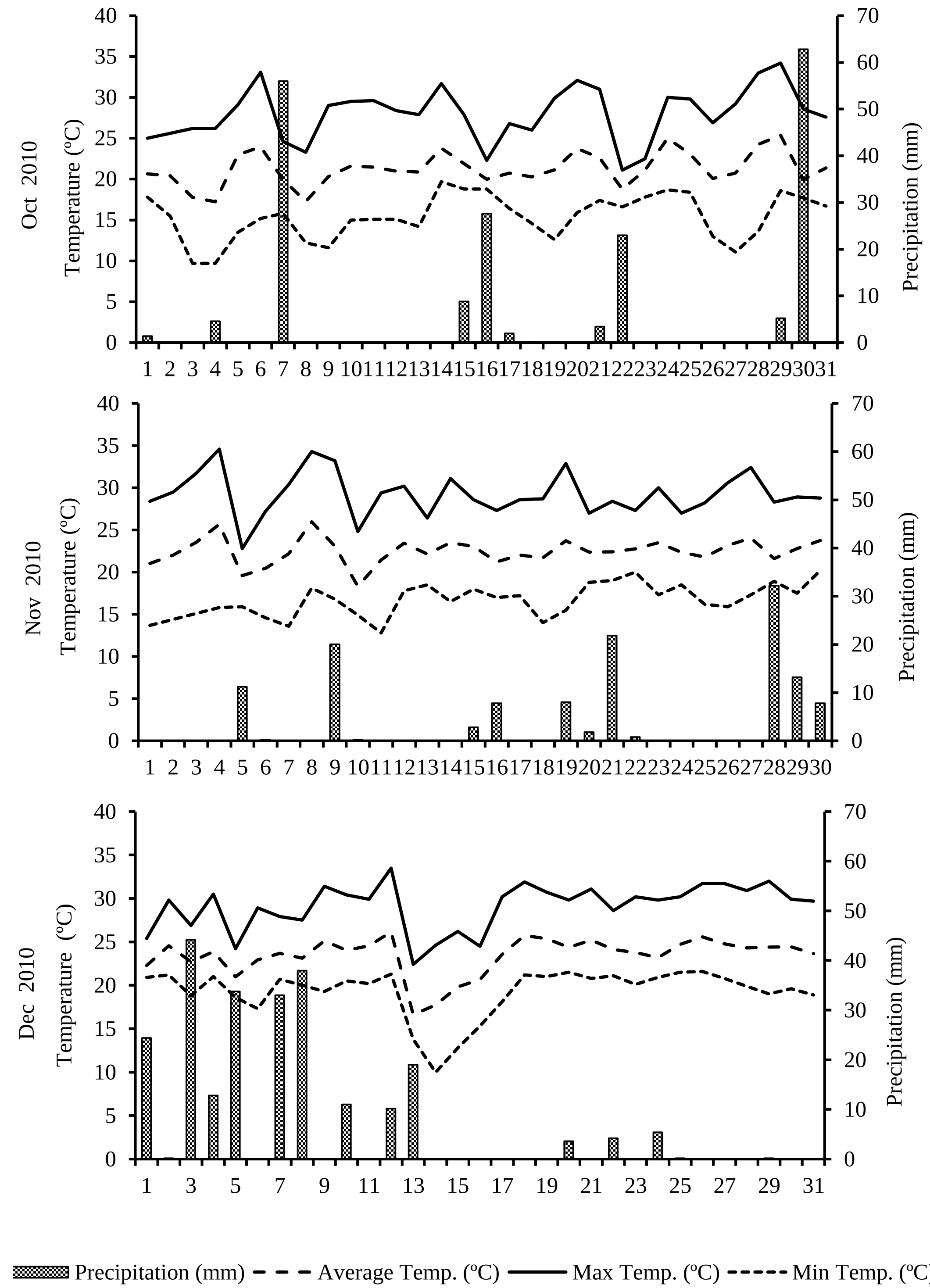


Figure 1. Climatic data throughout the study period (October 1 to December 31, 2010). Source: Agro-meteorological Station of Western Paraná, State University.

(Colussi et al., 2014). Additionally, N increases the photosynthetic efficiency of the leaf because it stimulates the synthesis of the Rubisco (Pereira et al., 2012).

In the present study, the average DM of the first crop was 3,905 kg ha^{-1} and of the second crop was 5,591 kg ha^{-1}. Sanches et al. (2017) observed an average DM of 3,037 kg ha^{-1} at a N rate of 84 kg ha^{-1} N, whereas Colussi et al. (2014) reported an average DM of 3,042 kg ha^{-1}

Table 1. Climatic data during dehydration of the first and second crops of 'Tifton 85' for hay production.

Date	Air temperature (°C)			Relative humidity (%)			Dew point temperature (°C)			Wind speed (m s^{-1})	Radiation (KJ m^{-2})	Precipitation (mm)
	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.			
1st harvest-dehydration in the field												
11/26/2010	23.2	30.6	15.9	67.8	93.0	35.0	16.3	18.7	13.1	1.9	31,016.78	0.0
11/27/2010	24.0	32.4	17.3	64.9	90.0	30.0	16.3	19.5	11.6	1.6	15,867.96	0.0
2nd harvest-dehydration in the shed												
12/24/2010	23.2	29.8	20.9	89.9	97.0	64.0	21.3	24.0	19.8	2.9	15,243.59	5.4
12/25/2010	24.7	30.2	21.5	85.8	97.0	64.0	22.0	24.3	20.7	2.6	23,364.96	0.2
12/26/2010	25.6	31.7	21.6	82.8	97.0	59.0	22.2	25.0	20.0	1.9	25,862.56	0.0
12/27/2010	24.8	31.7	20.8	83.5	94.0	55.0	21.6	24.9	19.7	3.1	25,027.17	0.0
12/28/2010	24.3	30.9	19.9	82.0	95.0	59.0	20.9	24.7	18.5	3.5	23,817.67	0.0
12/29/2010	24.4	32.0	19.0	79.8	95.0	53.0	20.4	24.3	18.0	2.7	26,749.14	0.2

Ave: Average; Max: maximum; Min: minimum. Source: Meteorological Station of Western Paraná State University.

without N and of 5,014 kg ha^{-1} at a N rate of 127.5 kg ha^{-1} N after four harvests during the summer season.

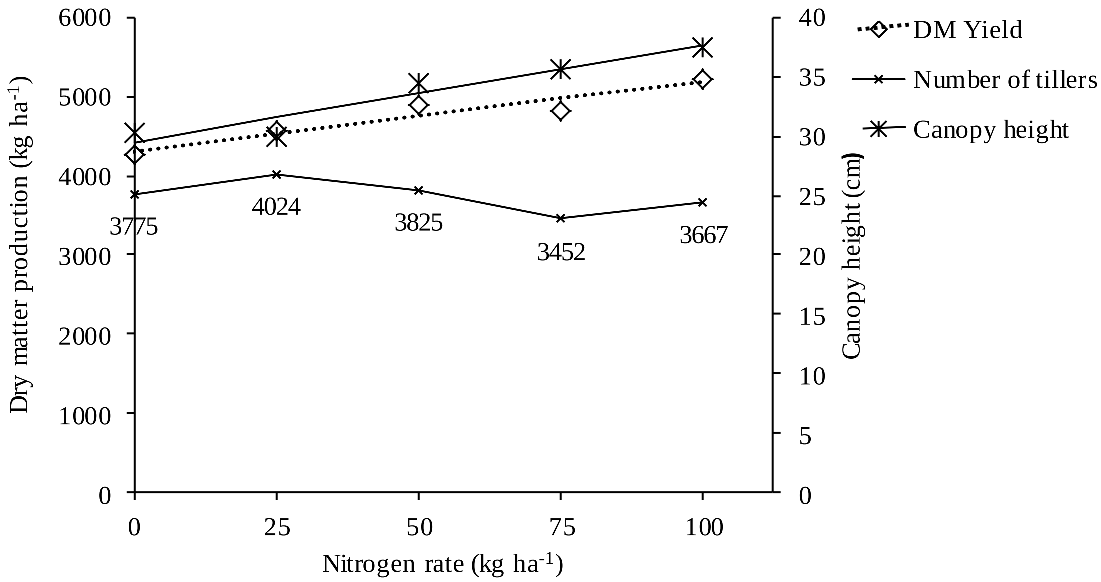
Sohm et al. (2014) suggested that DM and CP of forages are directly related to the N rate and harvest frequency. It was found that the DM of the first crop (dry period; average daily precipitation, 9.3 mm) was lower than that of the second crop (wet period; average daily precipitation, 17.1 mm), because the increased moisture in combination with N fertilization improved the forage yield. In addition, it was observed that the DM of leaves was lower than that of stems in the dry period. Michelangeli et al. (2010) also related the reduction in DM over the years with N fertilization.

As shown in Figure 2, canopy height increased with increasing N rate as follows: Y (Canopy height) = 29.5 + 0.081X (N rate). The average canopy height of the first crop was 20.5 cm, whereas that of the second crop was 46.6 cm, a difference that could be attributed to the higher precipitation after the first harvest (Figure 1) and also the greater responsiveness of the second crop to N fertilization (Oliveira et al., 2010). Our results were similar to those reported by Tiecher et al. (2016), which found that canopy height increased in relation to the N rate and rainfall.

No significant differences were identified in the number of tillers per square meter among the N rates (Figure 2) and no interaction was observed between the production periods or among the N rates. Vilela et al. (2005) reported that there is no variation in the number of tillers per square meter of *C. dactylon* 'Coastcross' in relation to season (spring, summer, and fall) and that a plant height of ≥20 cm reduces the incidence of solar radiation at the base of the tillers and consequently, their number. Ziech et al. (2016) reported that the number of tillers reduced from 2,846 to 2,090 m^2 for Tifton 85 and from 2,515 to 1,846 m^2 for 'Coastcross,' when the N rate increased from 0 to 75 kg ha^{-1}. Therefore, the number of tillers probably reduces with increasing N rate due to the higher rates of daily leaf growth, since there is a negative relation between plant density and plant height, which compete for nutrient assimilation.

The DM content of both crops increased significantly between harvest and baling (Table 2). At the baling phase, the moisture content decreases from approximately 80% to less than 20%, allowing the safe storage of hay and decreasing the loss indices (Calixto Junior et al., 2012). DM loses are small or even non-detectable when hay moisture after baling is 150 g kg^{-1} and storage lasts for one or two months (Collins and Coblentz, 2007). The moisture condition of 150 g kg^{-1} was not achieved when dehydration occurred in the shed (Table 1). It is known that direct radiation is more important than the pressure deficit between the plant, the environment, and the wind speed due to its effect on the internal moisture content (Rotz, 2003).

Forage dehydration in the field occurred at a



$\hat{Y}_{DM\ Yield\ ha^{-1}} = 4308.2817 + 8.79122X$ $R^2 = 90.18$ CV1 = 14,68% CV2 = 12.08% p = 0.0445

$\hat{Y}_{Canopy\ Height} = 29.5 + 0.081X$ $R^2 = 90.71\%$ CV1 = 7.10% CV2 = 13.77% p = 0.0000

Figure 2. Dry matter, canopy height, and numbers of tillers of ‘Tifton 85’ at different nitrogen fertilization rates. CV 1: Coefficient of variation of plot; CV 2: Coefficient of variation of subplot.

higher rate than that in the shed (2 g g^{-1} of MS h^{-1} and 0.4898 g g^{-1} of MS h^{-1}, respectively). The rates of dehydration can progressively be close to zero due to the balance between the water vapor pressure of the plant and that of the surrounding environment and may remain stable under favorable environmental conditions (Rotz, 1995). Forage dehydration in the shed requires more time that in the field (2 vs. 6 days) due to the lack of direct radiation. Any other forms of energy used for forage dehydration are uneconomical, since the production of 1 ton of hay involves the removal of 3 tons of moisture, which requires energy equivalent to 270 L of diesel oil or approximately 1.6719 billion calories (Rotz, 1995).

The high moisture content favors the growth of fungi and heating during baling. Fungi can lead to a reduced animal intake and the production of mycotoxins, whereas heating, especially over 40°C, causes the loss of soluble carbohydrates, proteins, lipids, and vitamins A and B (Cecava, 1995; Rotz, 2003). Thus, a fast dehydration process is important to obtain hay appropriate for storage and prevent any degradation in the nutritional value (Calixto Junior et al., 2012).

The least amount of MM of the first crop was found at the baling phase, whereas that of the second crop was found at the storage phase (Table 2). Our values were similar to those reported by Ribeiro and Pereira (2011) and Oliveira et al. (2016), but higher than those reported by Calixto Junior et al. (2012). The MM of the first crop showed a tendency ($p < 0.066$) to increase with increasing N rate; thus, it might be associated with the relatively high soluble N availability and the linear increase in the extraction of other minerals from the soil with the increase in the N rate (Lima et al., 2015). This trend was not observed in the second crop, probably because of the higher precipitation (dilution effect) and the consequent higher DM. Ribeiro and Pereira (2011) reported that the levels of P in the leaf blades and those of Mg in the whole plant of Tifton 85 increase with increasing N rate. However, significant effect was not observes for the different management practices, DM increments, soil type, and various elements on the mineral composition of Tifton 85.

The NDF of Tifton 85 is typically high, but does not affect the forage digestibility due to the low occurrence of ferulates linked to cell wall carbohydrates by ether bonds that contribute to an efficient rumen microbial action (Ribeiro and Pereira, 2010). In the present study, the NDF of the first crop was higher at the storage phase, followed by that at the baling and harvest phases, whereas the opposite trend was observed for the NDF of the second crop. Similarly, Pasqualotto et al. (2015) found that NDF, ADF, NDIP, ADIP, and LIG increase significantly during the first 12 days of storage, but then reach a plateau (Collins and Coblentz, 2007). Dehydration of the second crop occurred in the shed, and thus, the time to reach 30% DM was greater than that needed for dehydration of the first crop in the field,

Table 2. Dry matter (DM), mineral matter (MM), neutral detergent fiber (NDF), acid detergent fiber (ADF), neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP), crude protein (CP), lignin (LIG), cellulose (CEL), hemicellulose (HEM), and *in vitro* dry matter digestibility (IVDMD) of the first and second crop of 'Tifton 85' at the harvest, baling, and storage phases of hay production.

Crop	Hay production			CV 1 (%)	CV 2 (%)
	Harvest	Baling	Storage		
			DM (g kg^{-1})		
1st	221.4^{c}	802.7^{b}	841.7^{a}	5.95	6.89
2nd	216.2^{c}	682.1^{b}	800.5^{a}	3.77	4.15
			MM (g kg^{-1} DM)		
1st	77.8^{a}	67.8^{b}	80.8^{a}	12.64	11.69
2nd	74.8^{a}	77.44^{a}	60.7^{b}	11.50	12.61
			NDF (g kg^{-1} DM)		
1st	777.2^{b}	798.3^{ab}	810.2^{a}	5.55	4.68
2nd	827.5^{a}	738.3^{c}	790.0^{b}	6.24	4.81
			ADF (g kg^{-1} DM)		
1st	427.7^{c}	466.9^{b}	536.0^{a}	19.16	10.59
2nd	493.2^{a}	491.9^{a}	529.6^{a}	11.88	8.90
			ADIP (g kg^{-1} DM)		
1st	93.1^{b}	129.5^{a}	132.9^{a}	20.55	11.81
2nd	78.4^{a}	60.4^{b}	62.3^{b}	17.70	14.76
			NDIP (g kg^{-1} DM)		
1st	101.2^{b}	120.7^{a}	107.8^{b}	19.59	14.58
2nd	78.8^{a}	48.5^{b}	57.1^{b}	15.86	22.02
			CP (g kg^{-1} DM)		
1st	185.4^{ab}	189.4^{a}	175.9^{b}	15.95	8.61
2nd	140.0^{a}	135.2^{a}	135.9^{a}	5.02	6.85
			LIG (g kg^{-1} DM)		
1st	167.3^{c}	265.8^{a}	203.0^{b}	27.54	19.88
2nd	179.4^{b}	219.3^{ab}	237.3^{a}	28.96	34.53
			CEL (g kg^{-1} DM)		
1st	278.3^{a}	285.4^{a}	293.9^{a}	17.95	17.26
2nd	352.5^{a}	353.4^{a}	356.1^{a}	15.84	10.16
			HEM (g kg^{-1} DM)		
1st	349.5^{a}	331.4^{a}	274.2^{b}	28.70	19.81
2nd	334.3^{a}	246.4^{b}	260.5^{b}	31.10	17.79
			IVDMS (%)		
1st	52.26^{a}	48.95^{b}	49.88^{ab}	7.71	7.66
2nd	48.02^{a}	44.00^{ab}	40.97^{b}	8.16	12.82

CV 1: Coefficient of variation of plot; CV 2: coefficient of variation of subplot. Different letters indicate significant differences at $p < 0.05$.

resulting in a continuously increased plant respiration (Moser, 1995). Thus, the second crop had a lower content of HEM than the first crop (McDonald and Clark, 1987), due to an increase in LIG with time (Table 2).

Tifton 85 has a relatively high concentration of glucose and other sugars (Mandebvu et al., 1999; Hatfield et al., 1997), known as reactive structural carbohydrates, which may explain the negative relationship between hay heating as a function of the increased moisture content at the baling phase and the degradability of NDF in the rumen (Coblentz and Hoffmann, 2009).

The ADF of the first crop significantly increased during the hay production period (harvest, baling, and storage), whereas that of the second crop did not show any differences among the hay production phases. These results were in agreement with those reported by Pasqualotto et al. (2015). The N rates or the interaction of N rates and dehydration conditions did not significantly affect ADF; however, a decreasing trend was observed with the N rate, which was in accordance with the results reported by Sohm et al. (2014).

The NDF and ADF of the first crop were lower than those of the second crop (Table 2), results that were in agreement with those reported by Neres et al. (2012). Sohm et al. (2014) supported that NDF and ADF decrease with increasing N rates and are influenced by the harvest season and crop year.

The NDIP of the first and second crop was higher at harvest and baling, respectively (Table 2), results that were in agreement with those reported by Castagnara et al. (2011). Pasqualotto et al. (2015) showed that NDIP is reduced with time when hay production occurs under high conditioning intensity, whereas no change was observed when hay production occurs under low conditioning intensity.

The ADIP of the first crop increased between harvest and baling, whereas that of the second crop decreased (Table 2); thus, dehydration in the field increased the amount of ADIP, since this variable increases with temperature (Collins and Coblentz, 2007). The ADIP increases with storage time, similar to other fibrous components, but the greatest change occurs during the first two weeks of storage (Collins and Coblentz, 2007). In the present study, the ADIP of the first crop was higher at the baling and storage phase (Table 2), whereas that of the second crop at harvest, differences that can be attributed to the different dehydration conditions. The ADIP of Tifton 85 showed a higher increase compared with that of alfalfa when submitted to heating at temperatures higher than 30°C, probably due to the relatively higher HEM content of the former (Collins and Coblentz, 2007). Pasqualotto et al. (2015) and Ames et al. (2014) reported a higher ADIP at the storage phase, followed by that at harvest and baling phases.

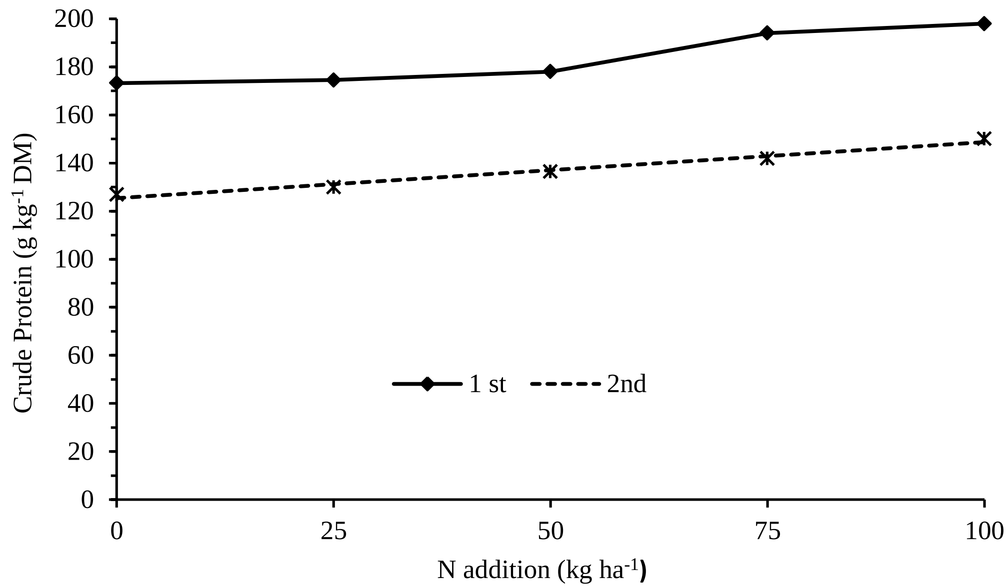
The higher NDIP and ADIP of the first crop could be explained by the high temperature in the field (>35°C; Figure 1 and Table 1), which is positively associated with the increased N concentration in the fiber after short-term storage (Turner et al., 2002). The NDIP and ADIP represent the N that remains in the NDF and ADF residue. Both indices represent an estimate of nutrient unavailability, mainly of CP caused by heating at temperatures higher than 55°C during the hay production period, since heating usually makes protein unavailable to animals (Pasqualotto et al., 2015; Ames et al., 2014). It has been estimated that an ADIP less than 100 g kg^{-1} is present in all forages and tends to increase linearly with heating in alfalfa and grasses due to Maillard reactions (Collins and Coblentz, 2007).

The CP of the first crop, but not of the second crop, differed among the hay production phases (Table 2). The CP of both crops was superior to that reported by Neres et al. (2014), but similar to that reported by Sanches et al. (2017). It has been reported that the protein content is affected by the use of conditioners and the frequency of revolving and turning during forage dehydration (Neres and Ames, 2014). The levels of most N components tend to slightly increase when the moisture is 200 to 300 g kg^{-1} due to heating, because the nonstructural carbohydrates are oxidized by plant enzymatic processes and microorganisms associated with storage (Turner et al., 2002). CP tends to reduce by approximately 0.25% per month of storage due to the volatilization of ammonia and other nitrogenous compounds (Neres et al., 2014; Pasqualotto et al., 2015). The CP content in the first harvest did not respond to the increase in N rates, whereas that in the second harvest increased with increasing N rate. These results were in agreement with those reported by Sohm et al. (2014) and Sanches et al. (2017) and could be explained by higher precipitation during the second production period that increased the availability and absorption of N (Figure 3).

As shown in Figure 3, the protein content increased with increasing N rate as follows: Y (Protein content) = 125.392178 + 0.233547X (N rate). The increase in CP per hectare occurs in synergy with the increase in DM (Figure 2). Overall, 100 kg ha^{-1} of N increased the DM of Tifton 85 by up to 20.40% and the protein content by 18.65%, which equals 514.27 kg of soybean meal.

Turner et al. (2002) supported that the content of fibrous components increases with storage time. In the present study, LIG was not affected by the different N rates (Table 2); however, it showed the highest value at the baling and storage phase in the first and second crop, respectively. Additionally, LIG increased during the hay production period (harvest, baling, and storage) by 21.33% in the first crop and by 32.27% in the second crop, results that were in agreement with those reported by Neres et al. (2014). The increase in LIG could be attributed to the loss of soluble nutrients that resulted in lower DM digestibility (Table 1).

CEL ranged between 278.3 and 356.1 g kg^{-1} MS in both crops and was not affected by the N rates or hay production phases (Table 2), similarly as reported by Neres et al. (2014). The HEM of both crops was significantly reduced at the storage phase (Table 2), probably due to the relatively high concentration of soluble sugars (Mandebvu et al., 1999; Hatfield et al.,



$\hat{Y}$ 2nd = 125.392178+0.233547*X CV1=5.02% CV2=6.41% R^2=97.95%

Figure 3. Crude protein of 'Tifton 85' hay according to nitrogen rates.

1997), which are reactive structural carbohydrates (Collins and Coblentz, 2007). These results were in disagreement with those reported by Ames et al. (2014), which showed that no changes occur in HEM between harvests when N fertilization is applied. However, Pasqualotto et al. (2015) reported that HEM decreases with storage time when hay production occurs under high conditioning intensity, whereas the highest levels of HEM were observed at 30 and 60 days of storage when hay production occurs under low conditioning intensity.

The IVDMD of the first crop was 52.2% and that of the second crop was 48.02%. The difference could be attributed to the higher precipitation after the first harvest (Figure 1), which affected DM. The DM digestibility of the first crop was reduced by 4.55%, whereas that of the second crop was reduced by 14.68%, a difference of 322.64%, which could be attributed to the longer dehydration time in the shed, which led to nutrient losses by plant respiration. IVDMD in the present study was lower than that reported by Pasqualotto et al. (2015). Calixto Junior et al. (2007) did not find any differences in the IVDMD of star grass between two N rates (50 and 100 kg ha^{-1}), whereas Quadros and Rodrigues (2006) reported that the DM digestibility of Tanzania and Mombaça grasses increases with increasing N rates (101 to 232 kg ha^{-1}).

Conclusions

The results confirmed that forage dehydration in the field is the most appropriate method for hay production, since it provides the recommended DM for baling. DM increased with increasing N rates, reaching the highest values (20.40%) at 100 kg ha^{-1} N. ADF increased during the hay production period in the first crop, but not in the second crop; however, it was not affected by the N rate. The protein content increased with increasing N rate, reaching approximately 18.65% at 100 kg ha^{-1} of N, but decreased during the hay production period. It was also concluded that the DM digestibility decreases by 4.55% when dehydration occurs in the field, whereas by 14.68% when dehydration occurs in the shed, a difference higher than 300%. Therefore, forage dehydration for hay production needs to be carried out under suitable conditions to prevent nutritional losses.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of lime and phosphorus fertilizer on acid soil properties and barley grain yield at Bedi in Western Ethiopia

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Soil acidity associated with soil fertility problems are the main constraints hindering barley production in most highlands of Ethiopia. Field experiment was conducted to evaluate effects of lime and phosphorus (P) fertilizer application to acid soils on grain yield of barley and soil chemical properties during 2009 to 2013 cropping seasons at Bedi in Western Ethiopia. The experiment was laid out in randomized complete block design with three replications. Five levels of lime (0, 0.55, 1.1, 1.65 and 2.2 t/ha) and four levels of P (0, 10, 20, and 30 kg/ha) were combined in a complete factorial arrangement. Lime requirement of the soil was calculated based on its exchangeable acidity. The combined analysis over years showed significant improvement of barley grain yield and soil chemical properties due to the main and interaction effects of lime and phosphorus. Grain yield was progressively increased with incremental levels of lime and Phosphorus application. The highest yield was obtained from 2.2 t/ha lime application coupled with 30 kg/ha phosphorus fertilizer, but on par with 1.65 t/ha lime and 20 kg/ha phosphorus application. Grain yield is increased by 274.0% with 1.65 t/ha lime and 20 kg/ha Phosphorus application in the initial year compared with control; however, this yield increment declined over years and reached 99.5% after five years. This yield reduction after five years of lime application may indicate re-acidification of the soil which warrants re-liming. In this study, lime application was the major source of variation for soil chemical properties. Soil pH was sharply increased by liming with the highest value (5.9) and thereafter slightly declined to 5.3 over five years. Exchangeable acidity decreased significantly with increase in lime application to as low as 0.1 cmol/kg, while available P and exchangeable Ca^{2+} were noticeably improved. Hence, lime application at the rate of 1.65 t/ha coupled with 20 kg/ha Phosphorus fertilizer could sustainably enhance barley production on acid soils of Bedi and similar areas with likely re-liming of the soils, every five years.

Key words: Acid soils, barely, lime application, phosphorus fertilizer, soil properties.

INTRODUCTION

Soil acidity is a major environmental and economic concern in many areas of Ethiopia which causes significant losses in crop production. Soil acidity is a complex of several factors involving plant nutrient deficiencies and toxicities, low activities of beneficial microorganisms, and reduced plant root growth which limits absorption of nutrients and water (Fageria and Baligar, 2003). Poor crop production on acidic soil has long been associated with aluminum (Al^{3+}) toxicity, reduced nodulation or mycorrhizal infections and low phosphorus (P) availability (Kochian et al., 2004; Wang et al., 2006).

Soil acidity and Al^{3+} toxicity in surface soil can be ameliorated through liming (Fegeria and Baligar, 2008; Rebecca et al., 2010). Changes in soil pH brought about by liming may have profound effects on the availability of many elements absorbed by crops. Liming increases soil pH and thus decreases Al^{3+} and Mn toxicities which also increase NO_3-N, Ca and P availability (Arshad and Gill, 1996; Caires et al., 2005).

In Ethiopia, large areas of highlands with altitude of >1500 m located in almost all regional states of the country are affected by soil acidity. According to Ethiosis (2014) about 43% of the Ethiopian arable land is affected by soil acidity. Also, Mesfin (2007) reports that moderately acidic soils with pH less than 5.5 considerably influence crop growth and require intervention. The main factors giving rise to increased soil acidity in Ethiopia include climatic factors such as high amount of precipitation (that exceeds evapo-transpiration which leaches appreciable amounts of exchangeable bases from the surface soil), temperature, severe soil erosion, morphological and anthropological factors. The largest areas of the Western Oromia highlands are dominated by Nitisols with high acidity (Mesfin, 1998; Temesgen et al., 2011).

Barley (*Hordeum vulgare* L.) is the dominant cereal crop grown in the high lands of Ethiopia where soil acidity is rampant. Barley production covers a total area of 1.02 million ha with a national average productivity of 1.87 t/ha (CSA, 2014). Soil acidity is considered to be one of the major bottlenecks to barley production in the highlands of Ethiopia. The problem still persists and has not been addressed sufficiently. Consequently, small-scale farmers in the highlands of the country have almost given up barley production to the severe soil acidity. Farmers practice barley– bare fallow–oats rotation system reduces the negative effects of soil acidity and improve soil fertility (Hailu and Getachew, 2011). However, this rotation system is not sustainable and in the long run will degrade the soil resource due to severe soil erosion on the bare fallow. Farmers are not encouraged to apply P fertilizer due to low response to P application as a result of P fixation.

Phosphorus reacts with Fe and Al oxides/hydroxides under acidic conditions to form insoluble phosphates, hence reducing P availability to plants (Kamprath, 1984). Phosphorus deficiency often, therefore, occurs simultaneously with Al^{3+} toxicity in these soils. Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available P in soils. Addition of lime to acid soils has long been widely adopted as, the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia.

Appropriate combination of lime and P fertilizer is therefore an important strategy for improving crop growth in acid soils. There is however, scarcity of information on interactive effects of lime and P fertilizer application on crop performance in western Ethiopia. The objective of this study was therefore, to investigate the interactive effects of lime and P fertilizer on barely grain yield and soil chemical properties under acid soil condition in Western Ethiopia.

MATERIALS AND METHODS

Study site

The study was conducted for five consecutive years during 2009 to 2013 main cropping seasons at Bedi in western Ethiopia. Bedi is located on longitude 9°05' N, latitude 38°36' E and 2565 m altitude in the central highlands of Ethiopia (Figure 1). The site is typically characterized by plains with cool subtropical climate.

The area receives an average annual rainfall of 1100 mm with bimodal distribution of January to March (small rain) and June to September (major season). The soils are classified as Nitisols with deep, red, and well-drained tropical soils. The following criteria were set for selecting suitable site: the soils should be fairly well representative for barley production in the area; the soil should have pH values of lower than 5.5, and the soils should have no previous liming history. Some of the physical and chemical characteristics of the experimental site are summarized in Table 1.

Experimental design and procedures

The experiment was laid out in a randomized complete block design with three replications. Five levels of lime (0, 0.55, 1.10, 1.65, 2.20 t/ha) and four levels of P (0, 10, 20, and 30 kg/ha) were combined in a complete factorial arrangement. Lime requirement of the soil was calculated based on its exchangeable acidity (Al^{3+} plus H^{1+}) adapted from (Kamprath, 1984).

The aforementioned five levels of lime correspond to 0, 50, 100, 150 and 200% of the lime are required to neutralize the exchangeable acidity of the soils. Good quality commercial grade agricultural lime ($CaCO_3$) with 98% neutralizing value and <250 µm in diameter was used. Lime was applied uniformly in broadcast by hand to every plot a month before sowing and soil incorporated by oxen plowing only in the initial year. The experimental plots were kept permanent to observe the residual effects of lime application over years.

Triple super phosphate (TSP) and urea were used as inorganic fertilizer sources and applied every year. The entire dose of TSP was applied at planting, while the recommended N rate (46 kg/ha) was applied in split, *viz*: half at sowing and the remaining half side dressed at tillering stage of barley. Gross and net plot sizes were 4

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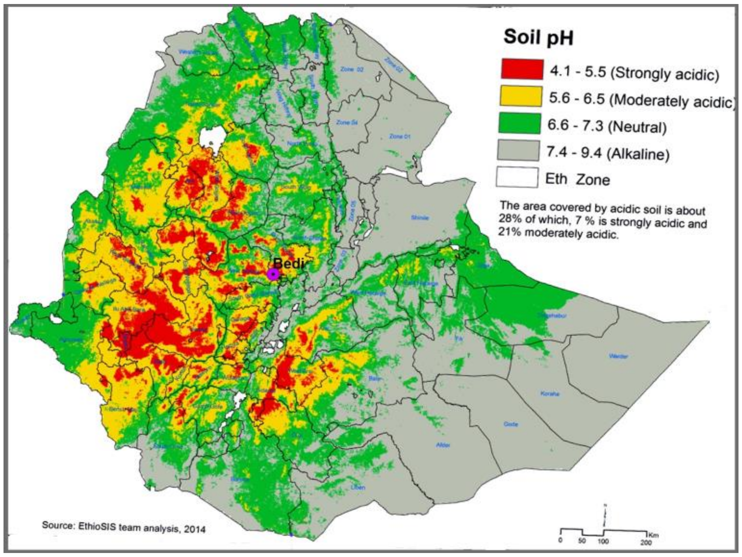

Figure 1. Bedi site and acid soil map of Ethiopia.

Table 1. Some physical and chemical soil characteristics of the Nitisols at Bedi site before commencement of the experiment.

Parameter	Value
Particle size distribution (%)	-
Sand	21.25
Silt	38.75
Clay	40.00
Bulk density (g cm^{-3})	1.15
pH (H_2O 1:2.5)	4.80
Organic carbon (%)	2.46
Total nitrogen (%)	0.22
Available phosphorus (mg kg^{-1})	6.40
CEC (cmol/kg)	7.36
Exchangeable Ca (cmol/kg)	4.17
Exchangeable Mg (cmol/kg)	1.43
Exchangeable K (cmol/kg)	1.09
Exchangeable Na (cmol/kg)	0.15
Exchangeable acidity (cmol/kg)	1.32

m × 5 m and 3 m × 4 m, respectively. Food barley variety BH-1307 was used as a test crop.

Soil sampling and analyses

Composite surface (0 to 20 cm) soil samples were collected from each plot and analyzed for soil physical and chemical properties during the initial year and subsequent alternative years. A 5 cm diameter auger was used to sample five randomly selected spots per plot. These sub-samples were thoroughly mixed, homogenized, air dried under shade, ground and passed through a 2 mm sieve.

The samples were analyzed for soil texture, pH, available P, total N, organic carbon, exchangeable acidity Al^{+3}, exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and cation exchange capacity (CEC) using the procedures outlined in Page et al. (1982).

Statistical analysis

Analysis of variance was conducted for each year separately and combined analysis over the five years. Analyses of variance were performed using the Statistical Analysis System (SAS) statistical program (SAS V8.2, SAS Institute Inc., Cary, NC, USA).

Whenever the ANOVA detected significant differences between treatments, mean separation was conducted using least significant difference (LSD). Pearson correlation coefficients were also used to assess the significance of the relationships between yield and some soil properties.

RESULTS AND DISCUSSION

Grain yield

The factorial analysis of variance indicated that lime and P fertilizer application significantly ($P<0.05$) affected barley grain yield in each year (Table 2). However, interaction effect of lime and P fertilizer application on grain yield of barley was found significant only during the initial three consecutive years. The combined analysis of variance over years showed highly significant ($P<0.05$) lime, P, lime × P interaction effects on barley grain yield (Table 2).

In general, progressive increases in grain yields were recorded with incremental levels of lime and P fertilizer application. Grain yield response was found more pronounced with the first than the second increment of lime and P application. The highest barley grain yields in each year and combined analysis were obtained from the

Table 2. Effects of lime and phosphorus fertilizer application on grain yield of barley (kg/ha) at Bedi during 2009 to 2013 cropping seasons.

Lime levels (t/ha)	2009					2010				
	P levels (kg/ha)					P levels (kg/ha)				
	0	10	20	30	Mean	0	10	20	30	Mean
0	1256	2059	2397	3060	2193	1446	2181	2556	2701	2221
0.55	2132	2501	3447	3833	2978	2263	2592	3166	3881	2975
1.10	2398	3184	4362	4675	3655	2375	3271	4276	4428	3588
1.65	2536	3995	4697	5117	4086	2751	3682	4687	4873	3998
2.20	2498	3769	4846	4976	4022	2895	3958	4973	5365	4298
Mean	2164	3102	3950	4332		2346	3137	3931	4250	-
	LSD (0.05) L= 176.72, P =158.06, L x P = 358.2					LSD(0.05) L= 244.2, P =218.4, L x P=751.0				
	CV (%) = 6.32					CV (%) = 8.66				
	2011					2012				
0	1716	2139	2443	2692	2248D	1352	1863	2489	2627	2083
0.55	2270	2638	3189	3540	2909	2413	2571	2921	3251	2789
1.10	2410	3657	3951	4302	3580	2599	2836	3307	3634	3094
1.65	2648	4300	4718	4858	4131	2766	3143	3569	3716	3298
2.20	2832	4490	4571	4885	4170	2814	3222	3639	3721	3349
Mean	2375	3445	3774	4035		2389	2727	3185	3390	
	LSD (0.05) L= 225.7, P =201.9, L x P = 430.2					LSD(0.05) L= 217.15, P =194.22, L x P= NS				
	CV (%) = 8.02					CV (%) = 9.0				
	2013					2009-2013				
0	1559	1919	2278	2311	2017	1466l	2032k	2433	2678	2152
50	1736	2282	2441	2664	2281	2163k	2517	3033	3434	2786
100	1936	2509	2633	2988	2517	2344	3091	3706	4005	3286
150	2093	2650	3111	3366	2805	2559	3554	4156	4386	3664
200	2172	2645	3157	3414	2847	2642	3617	4237	4452	3737
Mean	1899D	2401	2724	2949		2235	2962	3513	3791	
	LSD (0.05) L= 189.42, P = 169.42, L X P = NS					LSD(0.05) L = 87.92, P = 78.63, L x P=175.8				
	CV (%) = 9.19					CV (%) = 7.81				

application of 2.2 t/ha lime and 30 kg/ha P which was on par with 1.65 t/ha lime and 20 kg/ha P application, suggesting increasing lime and P application beyond this rate is not worthwhile in terms of grain production (Figure 2).

Mean barley grain yield increment in the combined analysis at 1.65 t/ha lime coupled with 20 kg/ha P application was 183.5% cf. control. Similarly, in the initial year of 2009 grain yield increment was 274.0% cf. control, but in subsequent years grain yield advantage has steadily decreased to 224.0, 174.9, 164.0 and

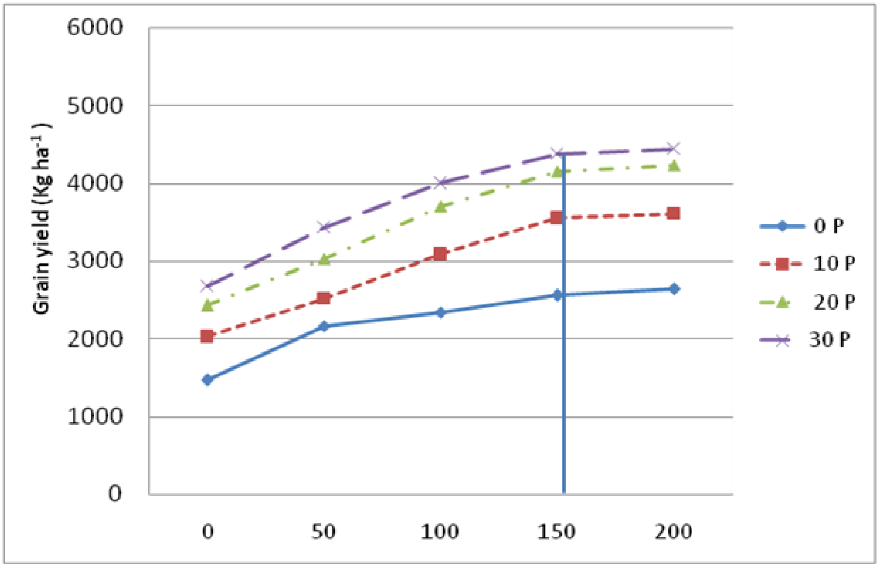

Figure 2. Effect of the combined use of lime and phosphorus fertilizers on the grain yield of barley Pooled over five years. The perpendicular line drawn shows optimum lime and P rate where maximum grain yield was achieved.

99.5% in 2010, 2011, 2012 and 2013, respectively. In a nutshell, the effect of lime on acid soil amelioration and barley grain yield were the highest during the initial four years, but in the final year grain yield was declined substantially. This yield reduction in the final year may indicate re-acidification of the soil. It is thus perceived that maximum amelioration of acid soils with lime could be achieved only after the elapse of four years since re-acidification would probably balance the slower amelioration reaction associated with less reactive lime particles. Meng et al. (2004) reported that crop yield increment at 50, 100, 150 and 200% lime application rates were lasted for 5, 7, 12, and 14 years, respectively.

The present findings are in agreement with Farhoodi and Coventry (2008), who reported that a year after lime application resulted in substantial yield increments of barely, wheat and faba beans (70 to 75%), and durum wheat at about 30%. Many researchers also revealed that lime application improved grain yield of crops (Liu et al., 2004; Achalu et al., 2012; Caires et al., 2005). According to Achalu et al. (2012), the increase in crop yield through application of lime may be attributed to the neutralization of Al^{3+}, supply of Ca^{2+} and increasing availability of some plant nutrients like P. Furthermore, increase in grain yield with the application of lime is ascribed to its favorable effect on the chemical, physical, and microbial properties of the soil. Numerous authors (Scott et al., 1999; Farhoodi and Coventry, 2008) reported that application of lime at an appropriate rate brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils.

In the present study, the higher grain yield realized from calcitic lime application during the initial four years indicates fast dissolution reaction and high acid neutralization capacity of calcite lime. Similar behavior and performance were reported by other researchers about the fast dissolution and high reactivity of calcite (Hartwig and Loeppert, 1992), as well as its high effect (Bailey et al., 1989), and high solubility in acid (Merry et al., 1995).

Changes in soil chemical properties

The results of soil analysis in 2009, 2011 and 2013 showed that lime application had significantly ($P<0.05$) increased soil pH and available P, while exchangeable acidity and Al^{3+} had significantly reduced (Table 3). Soil pH was sharply increased by liming in the first year and thereafter slightly declined over years. Increasing lime application rates resulted in increase in soil pH values.

Application of 2.2 t/ha lime increased soil pH from the initial 4.8 to 5.9 in 2009, but on par with 1.65 t/ha lime applications with pH value of 5.66. Subsequently, after five years of lime application soil pH dropped to 5.3. Essentially, amelioration of soil acidity comprises detoxification of Al and Mn activity with the aid of lime amendment. Detoxification of Al can be achieved by increasing soil pH which in turn certainly result in

Table 3. Lime and its residual effects on soil pH, available P and exchangeable acidity at Bedi during 2009 - 2013 cropping seasons.

Lime rates (t/ha)	Soil pH			Available P (ppm)			Exchangeable acidity (cmol/kg)			Exchangeable Al (cmol/kg)		
	2009	2011	2013	2009	2011	2013	2009	2011	2013	2009	2011	2013
0	4.52	4.96	4.60	10.65	12.35	12.27	1.32	1.32	1.34	1.19	1.19	1.21
0.55	5.30	5.33	5.11	14.23	12.54	12.24	0.46	0.41	0.80	0.41	0.37	0.73
1.10	5.53	5.65	5.20	16.00	15.54	14.11	0.20	0.21	0.44	0.19	0.20	0.40
1.65	5.66	5.67	5.24	17.36	17.18	16.78	0.14	0.12	0.35	0.13	0.12	0.32
2.20	5.91	5.88	5.30	18.92	17.31	16.76	0.10	0.11	0.35	0.10	0.11	0.32
LSD0.05	0.30	0.128	0.114	1.33	1.45	1.71	0.04	0.02	0.04	0.04	0.02	0.04
CV (%)	6.89	2.83	2.72	10.51	11.75	14.39	13.06	6.70	8.36	13.07	6.88	8.41

decrease in Al solubility thereby minimizes its toxic effect on plants. However, after five years pH of the non-limed plot remained almost static and close to the initial level.

Exchangeable Al only becomes significant at pH levels less than 5.5 (Cregan, 1980) and the Al^{3+} cation can be toxic to roots which is one of the major reasons that soil acidity can affect plant growth (Fenton and Helyar, 2007). The present findings are in agreement with Murata et al. (2002) who reported that application of lime at the rate of 2 t ha^{-1} significantly increased topsoil pH values from 4.6 to 6.0. Meng et al. (2004) also showed soil pH increment of 0.64 to 2.14 units due to lime application which values were maintained for five years, while pH of the limed soil remained above the initial pH value up to 15 years.

In concomitance with increase in soil pH, available P level was also improved. Application of 2.2 t/ha of lime was on par with 1.65 t/ha in increasing available P in all years except in the initial year 2009. In a nutshell, application of lime improved P availability by 77.6, 40.0 and 36.6% as compared to no liming in 2009, 2011 and 2013, respectively. Sven et al. (2015) showed an increase in P availability with comparable amounts of added lime in field trials. Sarker et al. (2014) observed the highest available phosphorus in the soil with the application of lime at 2 t/ha measured with four soil test P extraction methods which probably explain the Ca^{2+} and Mg^{2+} in lime, displaced Al^{3+}, Fe^{2+} and H^{+} ions from the soil sorption sites resulting into reduction in soil acidity and P fixation. In general, on acid soils with a low initial pH, it can be expected that extractable P increases after lime application. This is due to the increase of the pH, causing desorption of P from Fe- oxides, Al-oxides and -hydroxides and the dissolution of Fe and Al-phosphates (Haynes, 1984).

Application of lime and its residual effect highly decreased exchangeable acidity and Al^{+3} as the level of applied lime rates increased. Interestingly, all lime rates significantly (P<0.01) decreased exchangeable acidity from the initial level of 1.32 to 0.1 cmol/kg (Table 3). As could be expected, the effect of lime on exchangeable Al^{3+} was almost similar to that of exchangeable acidity. Meng et al. (2004) reported similar findings with surface application of lime; acidity, particularly exchangeable Al^{3+}, was significantly reduced from 5.46 to 1.52 cmol/kg in the first year and these values are maintained up to five years which gradually increased to the original level after 14 years

Relationships between grain yield and soil properties

Barely grain yield was positively correlated with soil pH and available P and inversely correlated with exchangeable acidity and exchangeable Al^{3+} and the correlation was significant at P<0.01 (Table 4). However, grain yield was correlated most strongly with soil pH (r = 0.93), available P (r = 0.86), and exchangeable Al^{3+} (r = -0.86). This illustrates that available P and soil pH and exchangeable Al^{3+} are the most important yield limiting factor in acid soils.

Similarly, positive and significant correlation coefficients were observed among soil properties of each other. The data also revealed a strong and inverse correlation between exchangeable Al^{3+} and Ca^{2+} (r = -0.90). The positive correlation of soil pH with the grain yield implies that as the pH increases the yield also increase and as the

Table 4. Correlation of grain yield with soil properties under acid soil condition (Pearson Correlation Coefficients, N = 15).

Parameter	pH	Available P	Exchangeable acidity	Exchangeable Al	Exchangeable Ca
Grain yield	0.93**	0.86**	-0.86**	-0.86**	0.79**
pH	-	0.86**	-0.92**	-0.92**	0.85**
Available P	-	-	-0.85**	-0.85**	0.93**
Exchangeable acidity	-	-	-	0.98**	-0.90**
Exchangeable Al	-	-	-	-	-0.90**

exchangeable acidity reduces, the plant roots performances are enhanced (Kamprath, 1984).

Conclusion

Poor barley production in Bedi area has been associated with soil acidity viz. Al-toxicity and/or P deficiency. Application of lime and P fertilizer had significantly improved grain yield of barley and soil chemical properties. Barley grain yield increased progressively with higher lime and P application rates. The highest yield was 2.2 t/ha lime and 30 kg/ha P fertilizer application, but at par with 1.65 t/ha lime and 20 kg/ha P application. During the initial year of lime application, barely grain yield was increased by 274.0% cf. control, while after five years of liming grain yield increased only by 99.5%. This yield reduction after five years of liming may indicate re-acidification of the soil which necessitates re-liming of the soil.

Though there was no significant differences between 1.65 and 2.2 t/ha lime applications, both rates raised soil pH close to the optimum pH requirement of barley, but drastically decreased the exchangeable Al^{3+} to a minimum level of 0.1 cmol/kg, which enhanced available P as a result of increased pH and decreased acidity level. Hence, lime application at the rate of 1.65 t/ha (150% of the lime requirement of the soils based on its exchangeable acidity) coupled with 20 kg/ha P fertilizer could serve as a reference to boost barley production in the study area and in similar areas with possible re-liming of the soils in every five years.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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African Journal of Agricultural Research

Full Length Research Paper

Spatial distribution of adults and nymphs of stink bug, *Edessa meditabunda* (Fabricius, 1974) (Hemiptera: Pentatomidae) on soybean Bt and non-Bt

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Knowledge of the dispersion of adults and nymphs of *Edessa meditabunda* in soybean model is needed to determine the control actions and thus enable proper use of strategies to avoid losses in production. This research aimed to conduct probabilistic analysis of the spatial distribution patterns of adults and nymphs of *E. meditabunda* in two regions in soybean Bt and non-Bt. For the evaluations, the method of cloth-to- beat was used, where one sample per plot was collected randomly from each experimental area. Evaluations were performed at 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91 and 98 days after emergence. For data analysis, the rates of dispersion (variance/average Morisita index and exponent k Negative Binomial Distribution) and theoretical frequency distributions (Poisson, Binomial and Negative Binomial Positive) at 5% probability were calculated. The peak population of adults and nymphs of *E. meditabunda* was observed in the reproductive stage of soybean Bt and non-Bt in Dourados and Douradina. From the results obtained, it can be concluded that the Bt technology had the spatial arrangement of adults and nymphs of *E. meditabunda*, and is set in probabilistic arrangements with negative binomial distribution (aggregate) in the two regions surveyed. In non-Bt soybeans for adults and nymphs of *E. meditabunda,* spatial arrangements had set in probabilistic arrangements of positive and negative binomial distribution (uniform), as the days after emergence, for the region of Dourados and Douradina.

Key words: *Glycine max* L., damage, horizontal dispersion, spatial arrangement.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] worldwide, plays the primary role of oilseed production and for consumption (Leal-Costa et al., 2008; Silva et al., 2012; Vianna et al., 2013). This fact is explained by importance of both

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products for animal consumption through soybean meal, and for human consumption by the oil (Silva et al., 2010). Brazil has great relevance for agribusiness, verified by the increase of cultivated areas, mainly by increasing productivity through the use of new technologies (Zadinello et al., 2012; Fonseca et al., 2013a).

For maximum potential of soybean production, it is necessary to have the best conditions for integrated pest management. Bedbugs, considered the most important pest of soybean by feeding directly from the seed, is responsible for damages that reflect the reduced production, seed quality and transmission of diseases (Belorte et al., 2003; Marsaro Junior et al., 2010; Souza et al., 2013).

The stink bug, *Edessa meditabunda* (Fabricius, 1974) (Hemiptera: Pentatomidae) is a major pest in many regions of Brazil, due to its occurrence from the vegetative stage to grain maturity (Corrêa-Ferreira and Panizzi, 1999; Golin et al., 2011). Adults of *E. meditabunda* use their mouthparts to feed on stems of soybean plants and drill the pods, seeds, soy, making them shrunken and wrinkled, affecting consequently the yield and quality of grain (Panizzi and Parra, 2009). The Edessa is the largest genus of the family Pentatomidae, and is neotropical in occurrence (Silva et al., 2006).

The damage caused by *E. meditabunda* when uncontrolled can cause leaf retention, reduced seed size, reduced oil content and germination and reduction in soybean yield (Lourenção et al., 1999; Gonçalves et al., 2008).

To reduce losses, control of this insect is accomplished by chemical insecticide applications from the vegetative phase of the plant and are not always efficient and selective to natural enemies (Sosa-Gomez and Silva, 2010; Fiorin et al., 2011).

To reduce the use of insecticides, there was a long search for specific technologies with low persistence in the environment, including integrated pest management, based on plant resistance to insects. With the advent of plant breeding, the genes of bacteria such as *Bacillus thuringiensis* (Bt) and *Bacillus sphaericus*, the main bodies were used to confer resistance of plants to insects on a commercial scale (Sharma et al., 2000; Theoduloz et al., 2003).

Recent advances in agricultural biotechnology have resulted in transgenic plants that are efficient alternatives and have less environmental impact for lepidopteran control in areas where they are considered pests (Williams et al., 1998; Lolas and Meza-Basso, 2006).

Studies of population dynamics provides useful information on the development models involving pest management (Gilbert et al., 1976), considering the possibility of obtaining data on the distribution of the population over a certain period of time (Odum, 1988). Therefore, such studies can be successfully employed in IPM programs (Neto et al., 1976).

The management of *E. meditabunda* in soybean should include the adoption of control measures based on population levels of species monitored by periodic sampling. The first step in designing a sampling plan is the knowledge of the spatial distribution of the species of interest, to establish appropriate criteria on population (Barbosa, 2003). Thus, knowledge of a fast and efficient way of sampling the pest, especially on large areas of cultivation, is essential and the MIP is satisfactorily applied (Fernandes et al., 2003).

The spatial distributions of pests in crops are aggregated, uniform and random. Such distributions are called negative binomial, Poisson and binomial positive, respectively (Barbosa and Perecin, 1982). This classification is based on the relationship between the variance and mean of the data (Elliott, 1979). However, despite the benefits obtained from the Bt cultivar, exactly how transgenic plants affect the populations of organisms in an agroecosystem is not well known (Rodrigues et al., 2010).

Knowledge of the spatial distribution of soybean stink bugs can be an important parameter to be considered to support the decision making of the place and time most suitable to increase the efficiency of their control in integrated pest management and reduce control costs and damage environmental (Kuss-Roggia, 2009).

In this context, this study aimed to evaluate the spatial distribution of adults and nymphs of *E. meditabunda* in soybean Bt and non-Bt in two regions under field conditions.

MATERIALS AND METHODS

The experiment was conducted under field conditions in two experimental areas located at Farm Rincão Porã, the geographic coordinates are 22°14'25'' S, 54°42'60.7'' W and altitude of 403 m in the town of Dourados and Farm Boa Sorte in the geographical coordinates 22°01'07'' S, 54°32'15'' W and altitude of 310 m in the municipality of Douradina during harvest 2011/2012. The soil of the area is classified as Typic Distroferric (RH) of loamy soil. The climate, according to Köppen's humid mesothermal, is Cwa type, with annual average temperatures and precipitation ranging from 20 to 24°C and 1.250 to 1.500 mm (Fietz and Fisch, 2006). For management of two experimental areas with soybean, the no-tillage system was used, and corn (*Zea mays* L) was used as preceding crop. The area of this experiment was dried with glyphosate combined with mineral oil (2.0 $l.ha^{-1}$ + 0.5 $l.ha^{-1}$), respectively.

The seeds used were Bt soybean AL 6910 Intact RR2 PRO™ and non-Bt RR BMX Potencia®, constituting the 2 treatments in the two different locations. Sowing was performed in the experimental areas, the first area was Farm Rincão Porã, sowing was done on 22/10/2011; in Farm Boa Sorte, second area, sowing was done on 29/10/2011, with a density of 15 seeds per meter, adopting a population of approximately 300.000 plants ha^{-1}. The row spacing was 0.50 m. For fertilizer application in both cultivar, 300 kg ha^{-1} of NPK formulation (2:18:18) was used. The weed and disease control was carried out with application of herbicides, fungicides, and the application of insecticides was not carried out in the areas studied.

The spatial distribution of adults and nymphs of the stink *E. meditabunda* was evaluated in two regions (Dourados and Douradina) with two fields each containing 100 plots in each area, each plot consisted 11 rows with 5 m long, totaling 27.5 m^2 with soybean Bt and non Bt, constituting the two treatments. The sampling methodology used was the method of cloth-to-beat, consisting of two sticks of wood connected by a white cloth, with a length of 1 m and width of 1.4 m. For the samples, one end of cloth was placed between the rows of soybeans, adjusted to the base of a row of plants and other plants extended over the adjacent row. The plants of a row (0.50 m^2) were shaken vigorously in order to bring down the pest insects on the cloth (Sturmer et al., 2012). Samples were taken at 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91 and98 days after emergence (DAE) in soybean Bt and non-Bt.

For data analysis, the mean and variance of the number of adults and nymphs of *E. meditabunda* per plot were obtained at each sampling date, using the relationship between these values as an indicator of the spatial distribution (Elliott, 1979). The dispersion indexes, as described below, were calculated using the Excel® program.

Variance/mean ratio: ratio between the variance and mean ($I = s^2/m$), used to measure the deviation of a random arrangement of conditions, where values equal to unity indicates random spatial distribution, values smaller than unity are uniform distribution and values greater than the aggregate are distribution unit (Rabinovich, 1980). The departure from randomness can be tested using the Chi-square test with n-1 degrees of freedom, $\chi 2 = (n-1)\ s^2/m$ (Elliott, 1979). Morisita index: the index of Morisita (I_δ) is relatively independent on the medium and the number of samples. So when $I_\delta = 1$, the distribution is random, when $I_\delta > 1$, the distribution is contagious type of I_δ and when <1, it indicates a regular distribution (Morisita, 1962).

Exponent k of the negative binomial distribution: the exponent k is a suitable dispersion index when the size and numbers of sample units are the same in each sample, as often this is influenced by the size of the sampling units. This parameter is an inverse measure of the degree of aggregation, in this case, negative values indicate a regular or uniform distribution, positive, values close to zero indicate aggregate provision and higher values indicate willingness for random eight (Pielou, 1977; Southwood, 1978; Elliot, 1979). On this point, Poole (1974) used another interpretation for it when 0<k<8, the index indicates a clustered distribution, and when 0>k>8, it points to random distribution.

Theoretical frequency distribution: Theoretical frequency distributions used to evaluate the spatial distribution of the observed species are presented according to Young and Young (1998). Poisson distribution: also known as random distribution, is characterized by having variance equal to the mean ($m = s^2$). Positive binomial distribution: This describes the uniform distribution and has less average ($s^2<m$) variance.

Negative binomial distribution: This has higher average variance, thus indicating clumped distribution, and has two parameters: the mean (m) and the parameter k (k>0). Chi-square test of grip: To check the fit of the data collected in the field to the theoretical frequency distribution test, the Chi-square test was used to compare the total grip of the observed frequencies in the sampled area, with frequencies expected according to Young and Young (1998); these frequencies are defined by the product of the probabilities of each class and the total number of sampling units used. To conduct these tests, to fix a minimum expected frequency equal to unity was chosen. Statistical analysis was performed using Chi-square test at 1 and 5% probability test.

RESULTS AND DISCUSSION

The presence of adult *E. meditabunda* on soybean plants in Dourados was detected at 35 days after emergence (DAE) in soybean cultivars with Bt and non-Bt in Dourados and Douradina (Figure 1A and 1B). In 14 samples, a total of 470 insects were found, which is 52.76% for the Bt cultivar and 47.23% in non-Bt in Dourados and a total of 415 insects in Douradina, which is 53.73% for the Bt cultivar and 46.26% for non-Bt (Figure 1A and 1B). The peak population of adults was observed at 77 DAE (month of January) for cultivars Bt and non-Bt, respectively, in Dourados and Douradina (Figure 1A and B).

Typically, colonization of soybean fields by bedbugs starts at the end of the vegetative stage (Panizzi and Vivan, 1997), a fact that occurred in this study, which had infestations in the vegetative phase and peak population in the reproductive phase. This may be explained by the appearance of the pods; soybean becomes more nutritionally adequate for the development of bedbugs, which results in the increase of the population. The end of the development of pods and early grain filling period was considered critical (Corrêa-Ferreira and Panizzi, 1999; Husch et al., 2012).

Depending on the search for more suitable host plants for feeding, oviposition and development of their offspring, adult bed bugs migrate from one region to another, which results in different behavior and infestations, adjusting to the environment (Panizzi, 1991).

The results of the nymphs of *E. meditabunda* in Bt and non-Bt cultivars arose from the fifth sample, 35 DAE in Dourados and Douradina (Figure 1C and D). The largest numbers of nymphs of *E. meditabunda* were found in Bt cultivar, which represented 52.32% of total plots sampled in Dourados and Douradina, with 55.43% of sampled plots (Figure 1C and D). Thomazoni et al. (2010) and Barros and Degrande (2012) reported that the bedbug infestation in Bt cultivar was more intense as compared to non-Bt, requiring more sprays.

The highest population density of adults and nymphs of *E. meditabunda* found in Bt cultivar was due probably to the reduction of inter-specific competition between the various populations that made up the community of arthropods culture, it was caused probably by reduced caterpillar population as the major defoliating caterpillars culture as soybean caterpillar *Anticarsia gemmatalis* (Hübner, 1818), false-medideira caterpillar *Chrysodeixis includens* (Walker, 1857) and naked *Rachiplusia* (Guenée, 1852) and drill underarm *Crocidosema aporema* (Walsingham, 1914), those species that are regarded toxin Cry1Ac and therefore, were not found in this cultivar due to the resistance offered by these transgenic lepidopteran (Bernardi et al., 2012).

No preference of adults and nymphs of *E. meditabunda* were observed in relation to cultivars versus regions for soybean Bt and non-Bt. Fonseca et al. (2013) reported no difference in bedbug infestation between Bt and non-Bt varieties. Likewise, the number of attacked structures incurs no significant differences between plants Bt and non-Bt (Tomquelski, 2009; Kodama and Degrande, 2012). Cultivated areas throughout the year provide ideal conditions for the survival of polyphagous insects such as

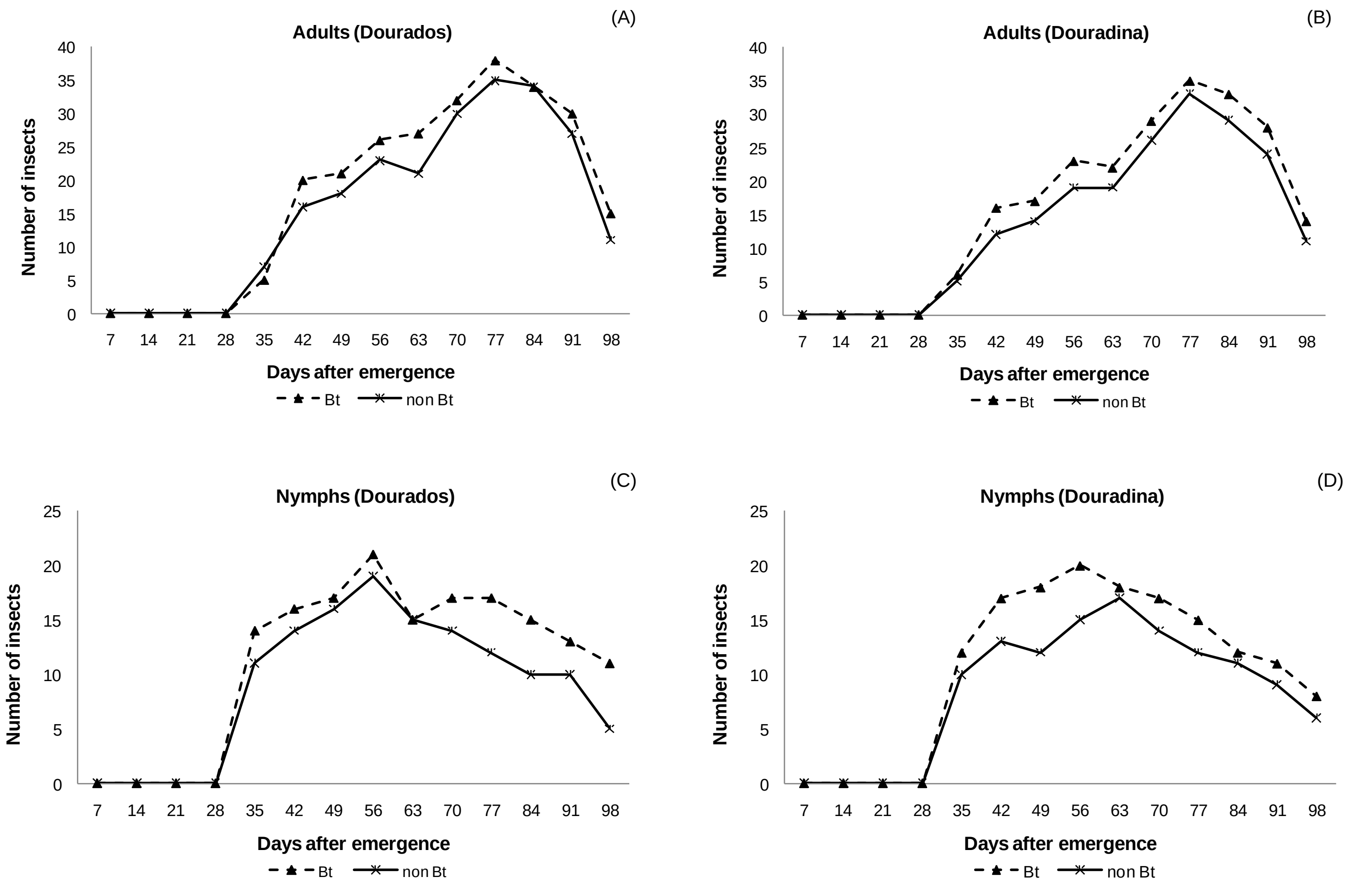

Figure 1. Percentage of the number of adults and nymphs of *Edessa meditabunda* occurring in soybean [*Glycine max* (L)] Bt and non-Bt as a function of days after emergence in Dourados and Douradina, MS, 2012.

stink, whose population may increase to cause significant damage in several cultures (Corrêa-Ferreira and Panizzi, 1999; Chocorosqui, 2001).

Aggregation indices for adults of *E. meditabunda*

The variance/mean ratio (I) calculated for adults of *E. meditabunda* in cultivating Bt showed six samples in Dourados, seven in Douradina, with statistically higher values indicating the unit aggregation, and scored in four samples and three Dourados and Douradina in cultivating Bt, with values equal to unity indicating uniformity (Table 1).

In non-Bt soybeans in Dourados, index I had five samples with statistically higher values than unity (aggregate) and six values equal to unity and theoretical distribution is uniform. In Douradina index I had six samples with statistically higher values than unity (aggregate) and five values equal to unity and theoretical distribution is uniform (Table 1).

In summary, the results of Morisita index (I_δ) for the treatment Bt, *E. meditabunda* adults, showed six samples in Dourados and five in Douradina, a total of ten larger than the unit (aggregate score) values. Analyzing the test Morista (I_δ) index for the non-Bt culture, Dourados was observed in ten samples, six values were greater than unity (aggregate score) and the unit in four equal values indicated uniformity; in no soy Bt in Douradina, ten samples were observed, six values were greater than unity (aggregate arrangement) and two equal to unity, tha t is, indicated uniformity (Table 1).

Analyzing the exponent K for Bt soybeans in Dourados, ten samples were found, seven indicated aggregate provision for adults of *E. meditabunda*, because the values were variable from 1.438 to 7.364, and three samples showed uniform with respective values -1.061, -2.200 and -2.677, while in Douradina, for this index and this cultivar, eight samples indicated aggregate provision and three uniform (Table 1).

Ten samples of soybean non-Bt were found in the field in Dourados, six of which showed aggregate provision for adults, and two showed uniform distribution. Five samples were observed in Douradina showing aggregated arrangement, uniform and five (49 DAE) had random arrangement dispersion index K (Table 1).

Table 1. Dispersion indices for *Edessa meditabunda* in soybean [*Glicine max* (L)] Bt and non-Bt function of days after emergence. Dourados and Douradina, MS, 2012.

		Dourados					Douradina				
Numbers	**(DAE)**	**Mean**	S^2	***I***	I_δ	***K***	**Mean**	S^2	***I***	I_δ	***K***
						Soybean (Bt)					
1ª	7	0.000	-	-	-	-	0.000	-	-	-	-
2ª	14	0.000	-	-	-	-	0.000	-	-	-	-
3ª	21	0.000	-	-	-	-	0.000	-	-	-	-
4ª	28	0.000	-	-	-	-	0.000	-	-	-	-
5ª	35	0.050	0.068	1.364 *	10.000 *	0.138 [AG]	0.060	0,077	1.286 *	6.667 *	0.210 [AG]
6ª	42	0.200	0.182	0.909 [NS]	0.526 [NS]	-2.200 [UN]	0.160	0.256	0.975 [NS]	0.833 [NS]	-6.336 [UN]
7ª	49	0.210	0.228	1.087 *	1.429 *	2.426 [AG]	0.170	0.163	0.957 [NS]	0.735 [NS]	-3.974 [UN]
8ª	56	0.260	0.235	0.903 [NS]	0.615 [NS]	-2.677 [UN]	0.230	0.219	0.953 [NS]	0.791 [NS]	-4.941 [UN]
9ª	63	0.270	0.280	1.037 [NS]	1.140 *	7.364 [AG]	0.220	0.234	1.063 *	1.298 *	3.472 [AG]
10ª	70	0.320	0.361	1.129 *	1.411 [NS]	2.485 [AG]	0.290	0.329	1.135 *	1.478 [NS]	2.146 [AG]
11ª	77	0.380	0.480	1.264 *	1.707 *	1.438 [AG]	0.350	0.432	1.234 *	1.681 *	1.497 [AG]
12ª	84	0.340	0.408	1.201 *	1.604 *	1.688 [AG]	0.330	0.385	1.167 *	1.515 [NS]	1.982 [AG]
13ª	91	0.300	0.354	1.178 *	1.609 *	1.681 [AG]	0.280	0.325	1.160 *	1.587 [NS]	1.748 [AG]
14ª	98	0.150	0.129	0.859 [NS]	-	-1.061 [UN]	0.140	0.182	1.302 *	3.297 *	0.464 [AG]
						Soybean (non-Bt)					
1ª	7	0.000	-	-	-	-	0.000	-	-	-	-
2ª	14	0.000	-	-	-	-	0.000	-	-	-	-
3ª	21	0.000	-	-	-	-	0.000	-	-	-	-
4ª	28	0.000	-	-	-	-	0.000	-	-	-	-
5ª	35	0.070	0.126	1.805 *	14.286 *	0.087 [AG]	0.050	0.048	0.960 [NS]	-	-1.238 [UN]
6ª	42	0.160	0.156	0.975 [NS]	0.833 [NS]	-6.336 [UN]	0.120	0.107	0.889 [NS]	-	-1.080 [UN]
7ª	49	0.180	0.169	0.941 [NS]	0.654 [NS]	-3.026 [UN]	0.140	0.142	1.013 *	1.099 *	10.780 [AL]
8ª	56	0.230	0.199	0.866 [NS]	0.395 [NS]	-1.711 [UN]	0.190	0.176	0.925 [NS]	0.585 [NS]	-2.517 [UN]
9ª	63	0.210	0.208	0.990 [NS]	0.952 [NS]	-21.830 [UN]	0.190	0.176	0.925 [NS]	0.583 [NS]	-2.517 [UN]
10ª	70	0.300	0.354	1.178 *	1.609 *	1.681 [AG]	0.260	0.275	1.058 *	1.231 *	4.462 [AG]
11ª	77	0.350	0.452	1.291 *	1.849 *	1.201 [AG]	0.330	0.385	1.167 *	1.515 *	1.982 [AG]
12ª	84	0.340	0.408	1.201 [NS]	1.604 *	1.688 [AG]	0.290	0.309	1.065 *	1.232 *	4.429 [AG]
13ª	91	0.270	0.320	1.186 *	1.709 *	1.449 [AG]	0.240	0.265	1.104 *	1.449 *	2.299 [AG]
14ª	98	0.110	0.099	0.899 [NS]	-	-1.089 [UN]	0.110	0.119	1.083 *	1.818 *	1.331 [AG]

*Not significant at 5% probability. DAE = Days after (plant) emergence. Not significant at 5% probability. [AG]Aggregate; [UN] uniform; [AL]random. S^2 variance, *I* Mean-variance ratio, I_δ Morisita index, *K* Exponent of the negative binominal.

Aggregation indices for nymphs of *E. meditabunda*

The variance/mean (I) calculated for nymphs of *E. meditabunda* in cultivating Bt presented seven samplings in Dourados and four in Douradina, with statistically higher than the unity values, indicating aggregation, and had three samplings in Dourados, six in Douradina, in cultivating Bt, and values equal to unity indicate uniformity (Table 2). In soy non-Bt in Dourados and Douradina, the index I had five samples with statistically higher values than the unity (aggregate) and five values equal to unity with theoretical distribution are uniform (Table 2).

In summary, the results of Morisita index (I_δ) for the treatment Bt nymphs *E. meditabunda*, showed seven samples in Dourados and four in Douradina, a total of ten larger than the unity (aggregate score) values. Analyzing the test Morista (I_δ) index for the non-Bt culture, Dourados was observed to have ten samples, six values were greater than unity (aggregate arrangement) and two equal to unit with values indicating uniformity; in no soy Bt, Douradina was observed to have ten samples, eight had greater than unity (aggregate arrangement) and two identical with the drive statistical values equal to unity, is indicated uniformity values (Table 2).

Analyzing the exponent K for nymphs on biotech soybean in Dourados, showed the ten samples, seven indicated willingness to aggregate the nymphs of *E. meditabunda*, because the values were variable from 0.413 to 10.780, and three samples showed uniformity with respective values -1.061, -6.336 and -22.275; already in Douradina, there was found, the index and cultivar for four samples indicating aggregate willingness-six uniform arrangement (Table 2).

It was found in Dourados field that soy with no Bt, had ten samplings, indicating that five of them had nymphs aggregate provision, and three showed uniform distribution and (42 and 70 DAE) random arrangement by dispersion index K. In Douradina, eight samples were observed, indicating aggregate arrangement, uniform (56 DAE) and random (49 DAE) for the dispersion index K (Table 2).

Theoretical frequency distributions for adults of *E. meditabunda*

The adjustment tests of the frequencies of numerical classes for adult *E. meditabunda* observed in 10 samples had sufficient numbers of classes to carry out the adjustment test for Bt soybean and Dourados, Douradina (Table 3).

The values of adult *E. meditabunda* for cultivating Bt in Dourados and Douradina indicate that the data did not fit the theoretical models of negative binomial distribution (aggregate score) (Table 3). In the context of ecological statistics, the best fit is represented by the frequency distribution that has the lowest value of the value of Chi-square (χ^2) calculated (Melo et al., 2006). Like most adult samples, the value of χ^2 not mean of the negative binomial distribution method, consequently showed a better fit to this type of dispersion.

For non-cultivation of Bt Dourados, 10 samplings showed sufficient numbers of classes to carry out the adjustment test for the adults of *E. meditabunda*. The values of χ^2 calculated for adults indicated that the count data obtained from the field does not conform to theoretical models of Poisson distribution, and set negative binomial for six and three samples with binomial positive (Table 3).

10 samples in the region of Douradina have been found to have sufficient numbers of presented classes to carry out the adjustment test for adults *E. meditabunda*. The values of χ^2 calculated for adults *E. meditabunda* indicated that the count data obtained from the field does not conform to theoretical models of Poisson distribution, and adjusted for eight samples and two negative binomial positive samples (Table 3).

Theoretical frequency distributions for nymphs of *E. meditabunda*

The adjustment tests of the frequencies of numerical classes for the nymphs of *E. meditabunda* observed in 10 samples had sufficient numbers of classes to carry out the adjustment test for Bt soybean in Dourados and Douradina (Table 4).

The values of the nymphs of *E. meditabunda* for Bt cultivar in Dourados and Douradina and indicate that the data fitted to theoretical models of the negative binomial distribution (aggregate score) in the samples analyzed (Table 4). In the context of ecological statistics, the best fit is represented by the frequency distribution that has the lowest value of the value of Chi-square (χ^2) calculated (Melo et al., 2006). Most samples of nymphs showed the value of χ^2 with no mean by the negative binomial distribution method, and consequently showed a better fit to this type of dispersion.

For not cultivating Bt, Dourados and Douradina 10 samples had sufficient numbers of classes to carry out the adjustment test for the nymphs of *E. meditabunda*. The values of χ^2 calculated for the nymphs indicated that the count data obtained in the field do not fit the theoretical models of the Poisson distribution, and adjusted for sampling 35, 42, 49, 77, 84, 91 and 98 DAE, in addition to the arrangement (negative binomial) and for samples of 56, 63 and 70 DAE, the uniform arrangement (positive binomial) (Table 4).

The colonization of soybean fields, by bedbugs often begins at the edges due to their migration from one area to another in soybean under different stages of development and areas with alternative hosts (Panizzi et al., 1980; Panizzi, 1991). This dynamic shift has been

Table 2. Dispersion indexes nymphs *Edessa meditabunda* in soybean [*Glicine max* (L)] Bt and non-Bt function of days after emergence. Dourados and Douradina, MS, 2012.

		Dourados					Douradina				
Numbers	**(DAE)**	**Mean**	S^2	I	I_δ	K	**Mean**	S^2	I	I_δ	K
						Soybean (Bt)					
1ª	7	0.000	-	-	-	-	0.000	-	-	-	-
2ª	14	0.000	-	-	-	-	0.000	-	-	-	-
3ª	21	0.000	-	-	-	-	0.000	-	-	-	-
4ª	28	0.000	-	-	-	-	0.000	-	-	-	-
5ª	35	0.140	0.142	1.013 *	1.099 *	10.780 ^{AG}	0.120	0.107	0.889 ^{NS}	-	-1.080 ^{UN}
6ª	42	0.160	0.156	0.975 ^{NS}	0.833 ^{NS}	-6.336 ^{UN}	0.170	0.163	0.957 ^{NS}	0.735 ^{NS}	-3.974 ^{UN}
7ª	49	0.170	0.203	1.195 *	2.206 *	0.872 ^{AG}	0.180	0.189	1.053 *	1.307 *	3.412 ^{AG}
8ª	56	0.210	0.228	1.080 *	1.429 *	2.426 ^{AG}	0.200	0.182	0.909 ^{NS}	0.526 ^{NS}	-2.200 ^{UN}
9ª	63	0.150	0.129	0.859 ^{NS}	0.000 ^{NS}	-1.061 ^{UN}	0.180	0.169	0.941 ^{NS}	0.654 ^{NS}	-3.026 ^{UN}
10ª	70	0.170	0.203	1.195 *	2.206 *	0.872 ^{AG}	0.170	0.163	0.957 ^{NS}	0.735 ^{NS}	-3.974 ^{UN}
11ª	77	0.170	0.183	1.076 *	1.471 *	2.235 ^{AG}	0.150	0.149	0.993 ^{NS}	0.952 ^{NS}	-22.275 ^{UN}
12ª	84	0.150	0.149	0.993 ^{NS}	0.952 ^{NS}	-22.275 ^{UN}	0.120	0.127	1.057 *	1.515 *	2.096 ^{AG}
13ª	91	0.130	0.134	1.034 *	1.282 *	3.803 ^{AG}	0.110	0.119	1.083 *	1.818 *	1.331 ^{AG}
14ª	98	0.110	0.139	1.266 *	3.636 *	0.413 ^{AG}	0.080	0.095	1.182 *	3.571 *	0.440 ^{AG}
						Soybean (non-Bt)					
1ª	7	0.000	-	-	-	-	0.000	-	-	-	-
2ª	14	0.000	-	-	-	-	0.000	-	-	-	-
3ª	21	0.000	-	-	-	-	0.000	-	-	-	-
4ª	28	0.000	-	-	-	-	0.000	-	-	-	-
5ª	35	0.110	0.099	0.899 ^{NS}	-	-1.089 ^{UN}	0.100	0.111	1.111 *	2.222 *	0.900 ^{AG}
6ª	42	0.140	0.142	1.013 *	1.099 *	10.780 ^{AL}	0.130	0.134	1.034 ^{NS}	1.282 *	3.803 ^{AG}
7ª	49	0.160	0.176	1.101 *	1.667 *	1.584 ^{AG}	0.120	0.127	1.057*	1.515 *	2.096 ^{AG}
8ª	56	0.190	0.196	1.031 ^{NS}	1.170 *	6.162 ^{AG}	0.150	0.149	0.993 ^{NS}	0.952 ^{NS}	-22.275 ^{UN}
9ª	63	0.150	0.149	0.993 ^{NS}	0.952 ^{NS}	-22.275 ^{UN}	0.170	0.183	1.076 ^{NS}	1.471 *	2.235 ^{AG}
10ª	70	0.140	0.142	1.013 ^{NS}	1.099 ^{NS}	10.780 ^{AL}	0.140	0.142	1.013 ^{NS}	1.099 ^{NS}	10.780 ^{AL}
11ª	77	0.120	0.127	1.057 *	1.515 *	2.096 ^{AG}	0.120	0.127	1.057 *	1.515 *	2.096 ^{AG}
12ª	84	0.100	0.111	1.111 *	2.222 *	0.900 ^{AG}	0.110	0.119	1.083 ^{NS}	1.818 *	1.331 ^{AG}
13ª	91	0.100	0.111	1.111 *	2.222 *	0.900 ^{AG}	0.090	0.103	1.144 *	2.778 *	0.626 ^{AG}
14ª	98	0.050	0.048	0.960 ^{NS}	-	-1.238 ^{UN}	0.060	0.077	1.286 *	6.667 *	0.210 ^{AG}

*Not significant at 5% probability. DAE = Days after (plant) emergence. Not significant at 5% probability. ^{AG}Aggregate; ^{UN} uniform; ^{AL}random.
S^2 variance, I Mean-variance ratio, I_δ Morisita index, K Exponent of the negative binominal.

Table 3. Chi-square test of adherence by the expected Poisson distributions, negative binomial (Bn) positive binomial (Bp), spatial arrangement for *Edessa meditabunda* in soybean [*Glicine max* (L)] Bt and non-Bt frequencies in the days after emergence. Dourados and Douradina, MS, 2012.

Samples		Dourados				Douradina			
Nº	(DAE)	Poisson	Bn	Bp	Arrangement	Poisson	Bn	Bp	Arrangement
					Soybean (Bt)				
1ª	7	i	i	i	NP	i	i	i	NP
2ª	14	i	i	i	NP	i	i	i	NP
3ª	21	i	i	i	NP	i	i	i	NP
4ª	28	i	i	i	NP	i	i	i	NP
5ª	35	49.623 **	26.119 NS	55.058 **	Aggregate	51.245 **	27.807 NS	56.673 **	Aggregate
6ª	42	1.674 *	3.785 NS	1.495 *	Aggregate	0.078 *	0.827 NS	0.047 NS	Aggregate
7ª	49	12.416 **	5.812 NS	15.586 **	Aggregate	0.180 *	1.085 NS	0.127 NS	Aggregate
8ª	56	0.588 *	3.271 NS	0.388 **	Aggregate	0.484 *	1.728 NS	0.443 NS	Aggregate
9ª	63	2.565 *	2.645 NS	2.885 *	Aggregate	0.889 *	0.687 NS	1.109 NS	Aggregate
10ª	70	4.327 *	2.661 NS	4.929 *	Aggregate	3.770 *	2.083 NS	4.315 *	Aggregate
11ª	77	16.782 **	11.696 NS	18.192 **	Aggregate	11.165 *	7.1803 NS	12.237 **	Aggregate
12ª	84	8.510 *	5.250 NS	9.407 **	Aggregate	6.337 *	3.783 NS	7.071 **	Aggregate
13ª	91	5.788 *	3.210 NS	6.495 *	Aggregate	4.484 *	2.364 NS	5.079 *	Aggregate
14ª	98	1.289 *	2.623 NS	1.155 *	Aggregate	24.171 **	6.006 NS	31.671 **	Aggregate
					Soybean (non-Bt)				
1ª	7	i	i	i	NP	i	i	i	NP
2ª	14	i	i	i	NP	i	i	i	NP
3ª	21	i	i	i	NP	i	i	i	NP
4ª	28	i	i	i	NP	i	i	i	NP
5ª	35	i	i	i	NP	4.826 *	5.043 NS	4.802 *	Aggregate
6ª	42	0.078 *	0.827 NS	0.047 *	Aggregate	0.843 *	1.715 NS	0.754 *	Aggregate
7ª	49	0.242 *	1.486 NS	0.152 *	Aggregate	0.934 *	0.941 NS	0.980 NS	Aggregate
8ª	56	1.287 *	3.672 NS	1.083 NS	Uniform	2.005 *	2.590 NS	2.001 *	Uniform
9ª	63	0.184 *	0.995 NS	0.199 NS	Uniform	0.387 *	1.800 NS	0.278 NS	Uniform
10ª	70	5.846 *	3.245 NS	6.592 *	Aggregate	1.206 *	1.097 NS	1.467 NS	Aggregate
11ª	77	15.471 **	10.333 NS	16.779 *	Aggregate	6.527 *	3.972 NS	7.327 **	Aggregate
12ª	84	8.510 *	5.250 NS	9.407 **	Aggregate	1.803 *	1.440 NS	2.115 NS	Aggregate
13ª	91	5.312 *	2.779 NS	5.954 NS	Aggregate	2.178 *	1.172 NS	2.517 NS	Aggregate
14ª	98	1.055 *	1.493 NS	1.016 NS	Uniform	0.681 *	0.231 NS	0.839 NS	Aggregate

** Significant at 1% and * Significant at 5% probability. DAE = Days after (plant) emergence. [ns] - Not significant at 1 and 5% probability.
[i] – Class insufficiently. [NP] – not present.

studied (Kuss-Roggia, 2009; Guedes et al., 2012). According to Panizzi and Vivan (1997), in soybean crops, leave eating bed bugs infestations occur in

Table 4. Chi-square test of adherence by the expected Poisson distributions, negative binomial (Bn) positive binomial (Bp), spatial arrangement nymphs *Edessa meditabunda* in soybean [*Glicine max* (L)] Bt and non-Bt frequencies in the days after emergence. Dourados and Douradina, MS, 2012.

Samples		**Dourados**				**Douradina**			
Nº	**(DAE)**	**Poisson**	**Bn**	**Bp**	**Arrangement**	**Poisson**	**Bn**	**Bp**	**Arrangement**
					Soybean (Bt)				
1ª	7	i	i	i	NP	i	i	i	NP
2ª	14	i	i	i	NP	i	i	i	NP
3ª	21	i	i	i	NP	i	i	i	NP
4ª	28	i	i	i	NP	i	i	i	NP
5ª	35	1.775 *	1.964 NS	1.864 NS	Aggregate	1.499 *	2.527 NS	1.391 *	Aggregate
6ª	42	0.385 *	1.230 NS	0.353 *	Aggregate	0.824 *	1.972 NS	0.759 *	Aggregate
7ª	49	39.027 **	10.992 *	51.099 **	Aggregate	4.236 *	3.390 NS	4.621 *	Aggregate
8ª	56	12.416 **	5.812 NS	15.586 **	Aggregate	0.838 *	2.820 NS	0.668 *	Aggregate
9ª	63	1.594 *	3.129 NS	1.435 *	Aggregate	1.450 *	2.921 NS	1.350 *	Aggregate
10ª	70	67.820 **	18.711 NS	89.180 **	Aggregate	5.058 *	6.060 NS	5.058 *	Aggregate
11ª	77	7.367 *	5.274 NS	8.022 **	Aggregate	2.626 *	3.067 NS	2.688 *	Aggregate
12ª	84	6.390 *	6.428 NS	6.557 *	Aggregate	2.734 *	2.090 NS	2.975 NS	Aggregate
13ª	91	9.541 *	8.070 NS	10.010 **	Aggregate	6.243 *	4.383 NS	6.753 **	Aggregate
14ª	98	20.199 **	10.545 NS	22.477 **	Aggregate	4.108 *	1.809 NS	4.666 *	Aggregate
					Soybean (non-Bt)				
1ª	7	i	i	i	NP	i	i	i	NP
2ª	14	i	i	i	NP	i	i	i	NP
3ª	21	i	i	i	NP	i	i	i	NP
4ª	28	i	i	i	NP	i	i	i	NP
5ª	35	0.913 *	1.709 NS	0.830 *	Aggregate	0.803 *	0.179 NS	0.979 NS	Aggregate
6ª	42	0.069 *	0.366 NS	5.710*	Aggregate	0.193 *	0.245 NS	0.247 NS	Aggregate
7ª	49	3.184 *	1.803 NS	3.626 NS	Aggregate	0.271 *	0.129 NS	0.363 NS	Aggregate
8ª	56	0.398 *	0.657 NS	0.504 NS	Uniform	0.526 *	0.812 *	0.541 NS	Uniform
9ª	63	0.133 *	0.694 NS	0.132 NS	Uniform	1.688 *	1.056 *	1.971 NS	Uniform
10ª	70	1.775 *	1.964 NS	1.864 NS	Uniform	1.775 *	1.964 *	1.864 NS	Uniform
11ª	77	0.803 *	0.547 NS	0.940 NS	Aggregate	0.803 *	0.547 NS	0.940 NS	Aggregate
12ª	84	1.759 *	0.757 NS	2.038 NS	Aggregate	2.100 *	1.268 NS	2.361 NS	Aggregate
13ª	91	5.156 *	3.131 NS	5.684 *	Aggregate	4.445 *	2.273 NS	4.989 *	Aggregate
14ª	98	4.826 *	5.043 NS	4.802 *	Aggregate	4.561 *	2.065 NS	5.140 *	Aggregate

** Significant at 1% and * Significant at 5% probability. DAE = Days after (plant) emergence. ns - Not significant at 1 and 5% probability.
i – Class insufficiently. NP – not present.

the vegetative phase, which agrees with the data of the present work, in which at 28 DAE there was infestations of adults and nymphs of *E. meditabunda*.

With the emergence of legumes, soy becomes more nutritionally adequate for the development of bedbugs, which results in the increase of the population, especially nymphs (Panizzi and Vivan, 1997). Thus there is increase in the population of adults and nymphs of *E. meditabunda* with the development of vegetables, having their peak population during grain filling. These data demonstrated the importance of management of bedbugs in agricultural areas, contributing to the realization of chemical or biological control by the time it reaches the economic injury level, and seeking to reduce the population peaks.

Likewise, it is very important to understand the dispersion and spatial distribution of soybean stink bugs, the study of these various indices of dispersion is used to calculate the spatial arrangement of a pest (Barbosa, 2003), and as a single index, it does not provide all considered ideal attributes of a statistical standpoint; the use of more than one index can provide greater certainty to conclusions (Martins et al., 2012).

The spatial arrangement of adults and nymphs of *E. meditabunda* in soybean Bt, when there is sufficient number of tests of fit, the theoretical frequency distribution classes proved to be aggregated in the two study areas. According to Rodrigues et al. (2010) and Fonseca et al. (2013b) report, aggregate behavior of adult insects on cultivation genetically, is modified. However, with respect to non-Bt soybean, adults and nymphs of *E. meditabunda* set the distribution of aggregate type and even the theoretical frequency distribution. These results are in agreement with Souza et al. (2013) that relate the spatial arrangement of the stink bug adults and nymphs in soybean fields.

It is possible to conclude that the spatial arrangement was influenced by cultivar genetically modified, versus days after emergence, since, in both cultivars, the individuals in the populations were assessed based on differences presented in the form of aggregated and uniform spatial distribution.

The aggregate spatial distribution model for the soybean crop requires a larger number of sample units than any other type of spatial distribution when performing a sampling process. The precise number of sample units for the sampling process of these insects is extremely important since these species are causing significant direct damage to the soybean crop.

So as to control these insect pests, it is possible to recommend the application of selective insecticides when necessary in localized areas of culture, where groups of these individuals are found. With this point, the number of sample units is dependent on the required degree of accuracy, which varies according to the purpose of research: population dynamics, crop damage, levels of economic development, losses and pest control (Silva and Costa, 1998; Guedes et al., 2012). Furthermore, such information should be considered in developing new sampling plans for pest to reduce the sampling time and increase the reliability of the results (Grigolli et al., 2012).

Conclusion

The peak population of adults and nymphs of *E. meditabunda* was observed in the reproductive stage of soybean Bt and non-Bt in Dourados and Douradina. From the results obtained, it can be concluded that the Bt technology had the spatial arrangement of adults and nymphs of *E. meditabunda*, and is set in probabilistic arrangements as negative binomial distribution (aggregate) in the two regions surveyed. In non-Bt soybeans for adults and nymphs of *E. meditabunda*, spatial arrangements had set in probabilistic arrangements for negative (aggregate) and positive binomial distribution (uniform), as the days after emergence, for the regions of Dourados and Douradina.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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