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Full Length Research Paper

Ammonium and nitrate levels of soil inoculated with *Azospirillum brasilense* in maize

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***Azospirillum brasilense* is a nitrogen fixing bacteria used in maize crop production due to its high capacity for plant growth promotion and yield increase. The present study aimed to evaluate ammonium and nitrate levels from soil inoculated with *A. brasilense* in maize crop production. The experiment was carried out in greenhouse conditions, using randomized blocks with split plots for 20 days with four replicates and two treatments where ammonium and nitrate levels were measured daily. The numbers of colony forming units of diazotrophic bacteria at initial and final stages of the experiment were counted in addition to the shoot and root dry mass measurement. The results were analyzed using F, Scott and Knott tests. The treatment which received inoculation did not show any statistically significant difference in the ammonium, nitrate levels either root or shoot dry mass as compared to the control. Also, there was no increase in the colony counts of diazotrophic bacteria. Taken together, the results showed that *A. brasilense* was not able to promote ammonium and nitrate levels after 20 days of its inoculation, suggesting that the plant growth promoting effect are not by fixing nitrogen during the initial plant development period and this period would be not appropriate for the plants to receive the inoculation.**

Key words: *Azospirillum brasilense*, maize, nitrogen fixer.

INTRODUCTION

Maize (*Zea mays* L.) is one of the largest cereal cultivated worldwide, has shown large adaptation capacity at different environmental conditions and being designated for human and animal feed due its high nutritional value (Peter et al., 2000). Nitrogen is the major nutrient, among the nutritional contents present in maize. Nevertheless, due to the complex dynamic of nitrogen in tropical soils, its availability is usually not enough to supply the necessity of the maize crop, so additional nitrogen fertilization is necessary for maize to express its

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Table 1. Soil chemical and physical characteristics.

pH	$CaCl_2$	MO	P resina	K	Ca	Mg	H+Al	SB	CTC	V (%)
		(g dm³)	(mg dm³)	.......................mmol$_c$dm³.......................						
6.3		7	6	0.4	21	6	15	27,5	42.8	64

high potential yield (Lemaire and Gastal, 1997).

Ferreira et al. (2001) claim that the nitrogen fertilization improves grain quality of maize, nutrients, minerals and proteins levels in addition to yield and yield related parameters such as number of cobs per plant, kernels per cob and kernel biomass. The nitrogen as mineral fertilization is applied in large quantities into soil because it is easily lost by volatilization, leaching, thereby increasing the cost of production up to 20% of total cost of production (Cantarella and Duarte, 2004)

In this context, the nitrogen fixing bacteria can be used as an important strategy to supply nitrogen, since plants are not able to assimilate nitrogen directly from the atmosphere. Other ways such as biological fixing, organic matter and synthetic fertilization must be used to supply plants' need (Amado et al., 2002). The atmospheric nitrogen fixing is fulfilled by a group of bacteria named "diazotrophs". Genus *Azospirillum* has been used as inoculant in several crops, such as cereals, cotton, sugarcane, coffee, grassland and others (Reis, 2007). Among the different genera of bacteria, *A. brasilense* is very useful, because of its ability in nitrogen fixation as well as phytohormones biosynthesis (Fallik et al., 1988).

The major challenge currently in agricultural production is reducing the production cost, by keeping the yield level with minimized environmental impact (Bhardwaj et al., 2014). In this context, utilization of plant growth promoting rhizobacteria can be a great strategy for this purpose. The present study aimed to evaluate the effect of *A. brasilense* on ammonium and nitrate nitrogen assimilation in soil planted with maize crop.

MATERIALS AND METHODS

Study site

The experiment was carried out in greenhouse conditions at Faculdade de Ciências Agrárias e Veterinárias de Jaboticabal (FCAV), Unesp, Sao Paulo State (21° 14' 05" S, 48° 17' 09" W and 615,01 m of altitude).

Maize cultivation in pot culture conditions

Five liter capacity pots were used in this experiment. They were filled with Oxisol Eutrophic soil (USDA, 2016). The chemical and physical characteristics of the soil are described in Table 1. The chemical analysis was done according to Instituto Agronômico de Campinas (IAC, 2011), and the fertilization were carried out according to Raij et al. (1997). No nitrogen formulation was added to the fertilization.

Each vase was seeded with four maize seeds. After seed germination, the less vigorous seedling were thinned out and left with three uniform seedlings in each pot in order to effectively achieve this study. The plants were irrigated to 70% water holding capacity of soil. In order to achieve that, all vases were weighted, replenished evapo-transpiration volume every day.

Azospirillum brasilense inoculum

The *A. brasilense* bacterium used in this study was obtained from a commercial liquid formulation, which belongs to Ab-V5 and Ab-V6 lineage. The inoculum was prepared by adding an aliquot of *A. brasilense* culture with the aid of inoculation handle into Erlenmeyer flask with 100 ml of *A. brasilense* specific culture medium. The medium formulation is glucose, 5 g ($C_6H_{12}O_6$); potassium phosphate monobasic, 0.4 g (KH_2PO_4); potassium phosphate dibasic, 0.4 g (K_2HPO_4); ammonium phosphate monobasic, 0.5 g ($NH_4H_2PO_4$); 0.1 g magnesium sulfate heptahidrate ($MgSO_4.7H_2O$); 0.2 g sodium chloride (NaCl); 0.017 g ferric chloride heptahidrate ($FeCl_3.6H_2O$), 0.002 g magnesse sulfate Hexahydrate ($MnSO_4.6H_2O$); 1 g yeast extract to 1000 ml of deionized water pH 7.4 and sterilized by autoclaving. The inoculum was inoculated as previously described then incubated at 28°C for 48 h. Then, the inoculum concentrations were adjusted to 1 x 10^8 colony forming unit (CFU) per ml. The study had a treatment which received the inoculum and control with no bacterial treatment. 3 ml of inoculum per vase were added with aid of pipette at the concentration of 3 x 10^8 CFU/vase, weekly starting after the seed germination. The control treatment did not receive the inoculum.

Analysis of ammonium and nitrate level from soil

Daily, for 20 days, four vases from each treatment were dismounted. Then, the soil samples were taken to the laboratory and dried at environmental temperature for 20 h. After that, the soil samples were sieved using 2 mm sieve and estimated ammonium (NH_4) and nitrate (NO_3) nitrogen levels according to Keeney and Nelson (1982).

Analysis of shoot and root dry mass

The shoot and root mass of the maize plants were separated and kept in kiln at 65°C up to constant weight. After complete drying at 65°C, all the plant materials were weighted and the values of shoot and root dry matter were recorded.

Counting of diazotrophic bacteria

The diazotrophic bacterial colony forming units were counted twice. First counting was done at zero time and second counting at 20th

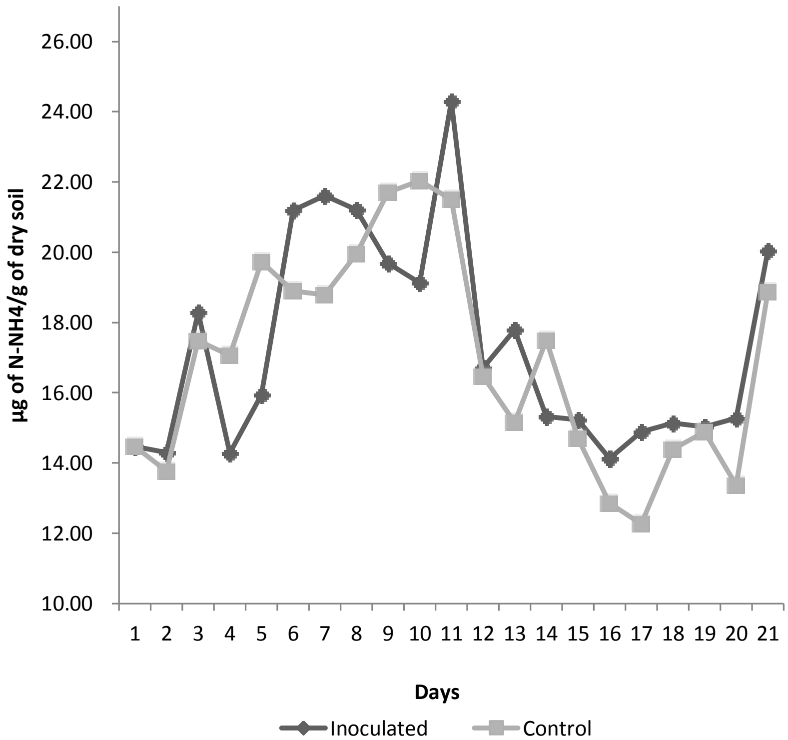

Figure 1. Means of ammonical nitrogen levels in the soil from treatment inoculated and control pots during 20 days under maize crop in greenhouse conditions.

day after germination in both treatment and control plants using the selective medium NFb (Döbereiner et al., 1995).

Statistic analysis

This study was designed in randomized blocks with split plot in the time with four repetitions with two treatments with or not inoculation with *A. brasilense* and the second factor were the days. The data were submitted to variance analysis by F test 5% and the mean values were compared by Scott and Knott test using Agroestat version 1.0 (Barbosa and Maldonado, 2010).

RESULTS AND DISCUSSION

After 20 days of evaluation, there was no observed statistical difference as to ammonium levels in the soils of bacterial inoculated plants, as compared to the control treatment. The measured range of ammonium level were from 12.26 to 22.03 and 14.13 to 24.30 µg NH_4-N g^{-1} of dry soil, for the control and inoculated treatment, respectively (Figure 1).

The ammonium levels measured daily from each treatment did not differ each other. The ammonium levels increased from fourth day up to 10^{th} day and decreased between the days 11 and 19 (Figure 2). *A. brasilense* is able to grow using atmospheric nitrogen as only nitrogen source (Eckert et al., 2001). According to the author, depending on situation, bacteria *Azospirillum* may use different nitrogen sources such as ammonia, nitrate, nitrite, molecular nitrogen and amino acid for its own metabolism without making it available for plants (Eckert et al., 2001).

The nitrate levels estimated in the soil from control treatment and the treatment inoculated with bacterium, did not differ statistically, the values varied from 6.10 to 13.83 and 6.52 to 15.47 µg NO_3-N g^{-1} of dry soil, respectively (Figure 3). There was a significant increase ($p<0.05$) in the soil nitrate levels between each day during the 20 days of experimentation (Figure 4). Probably, the *A. brasilense* who is a nitrogen fixer does not use this characteristic as mechanism of plant growth promotion at initial development period of maize. The *A. brasilense* is a phytohormone producing bacterium, and in certain conditions, this characteristic may promote a greater plant growth and development (Didonet et al., 2000).

Martínez-Morales et al. (2003) showed a phytohormone biosynthesis mainly by auxin by bacterial isolates belong

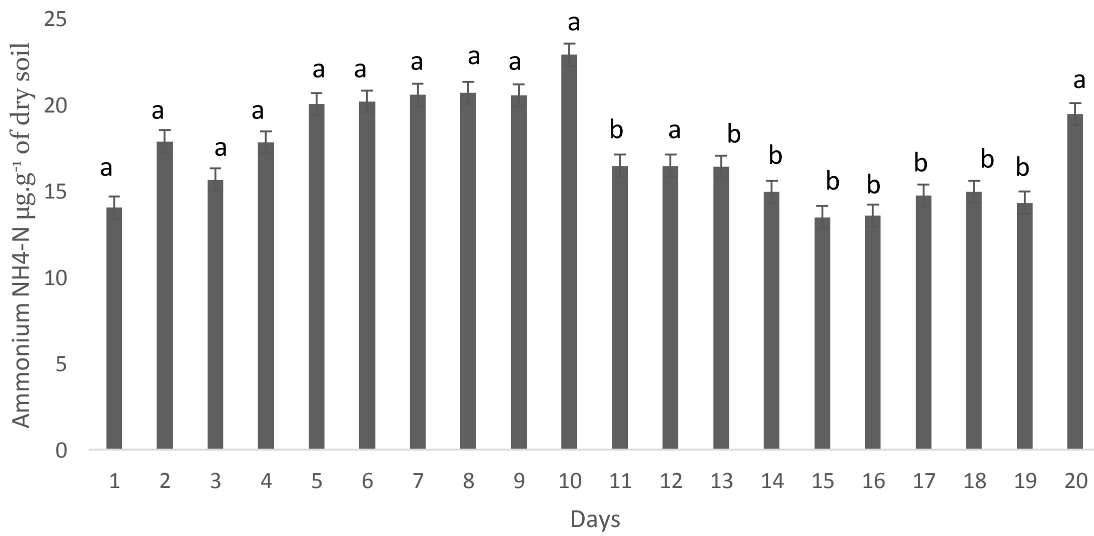

Figure 2. Means and standard deviation of ammonium levels during 20 days in the soil planted with maize crop under greenhouse conditions. Means followed by the same letter indicate no statistical difference between each other by Scott and Knott 5%.

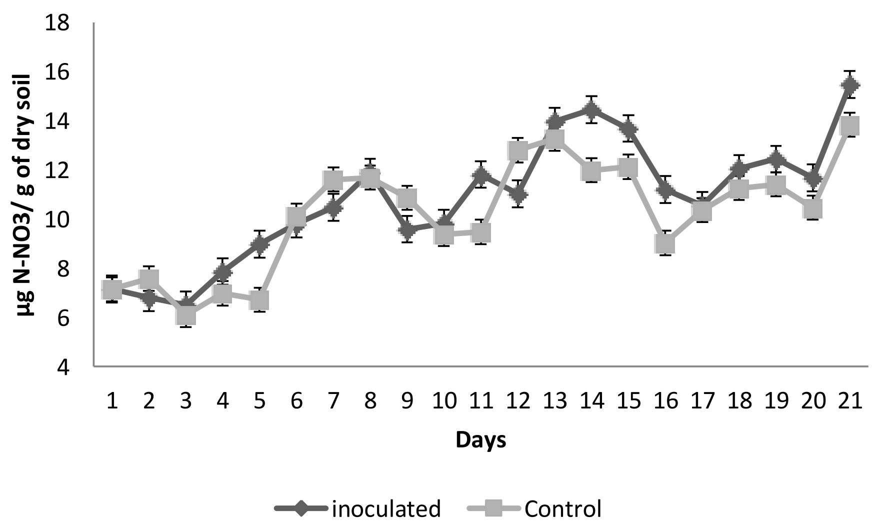

Figure 3. Means and standard deviation of nitrate levels in the soil from inoculated and control treatment during the 20 days of experimental period.

to the *Azospirillum* genus. This auxin may promote the plant growth and development by mainly affecting root morphology and increasing radicular hair strength and number (Barbieri et al., 1986). In addition to auxin, *Azospirillum* can also produce other phytohormones such as cytokine, gibberellin and indole acetic acid (Moreira et al., 2010) and has proven bio-control effect (Raaijmakers et al., 2009).

The survival and establishment of diazotrohic bacteria in soil was measured two times during the experiment one at zero time before planting another at the 20th day (while the termination of experiment) by plating the soil sample in diazotrohic bacterial specific nutrient media. Comparing the cfu of diazotrophic bacteria between two different times, the later (20 days after planting) was higher than the initial time point (Figure 5). It suggests

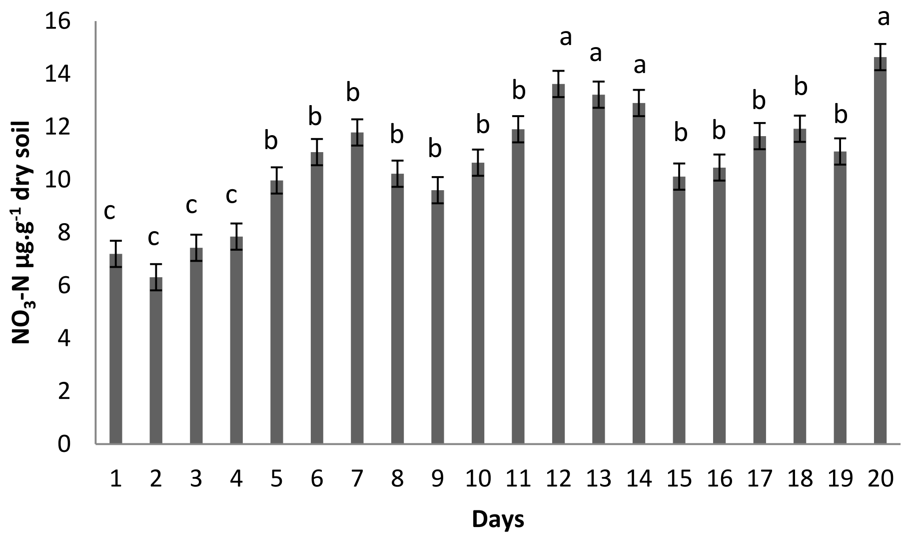

Figure 4. Means and standard deviation of ammonium levels during 20 days. Means followed by the same letter indicate no statistical difference between each other by Scott and Knott 5%.

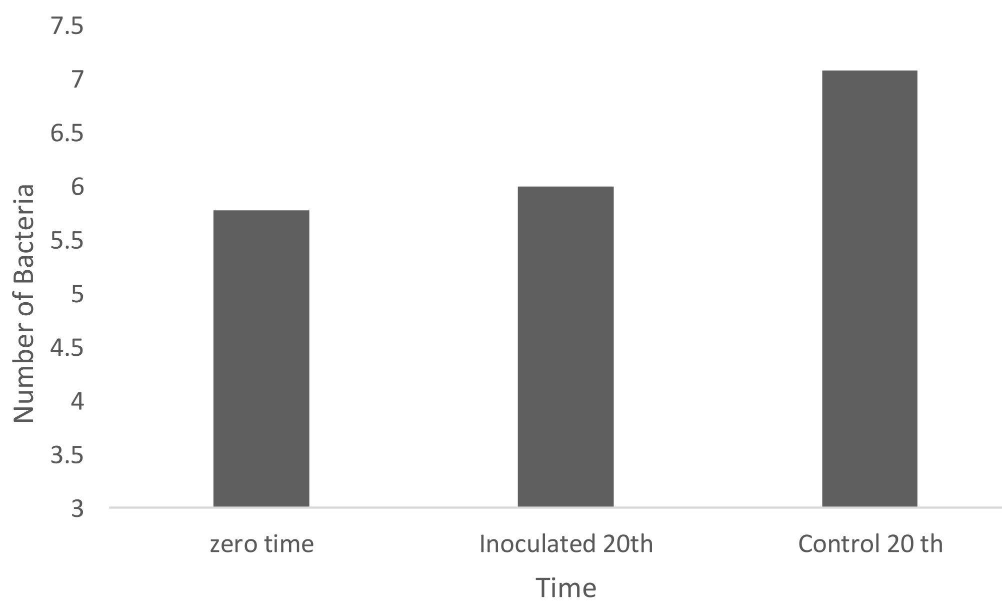

Figure 5. Number of diazotrophic bacteria in the soil before maize planting (zero time) and at 20th day of both treatment inoculated and control under greenhouse conditions. Means followed by the same letter indicate no statistical difference between each other by Scott and Knott 5%.

that, probably the plant has induced the nitrogen fixing bacterial growth under nitrogen deficiency conditions. Moreover, the number of diazotrophic bacteria from inoculated treatment was higher than control treatment, even though they were not statistically significant.

This indicates that *A. brasilense* inoculum did not increase the number of diazotrophic bacteria when compared with the control treatment as unexpected. This result suggests that *A. brasilense* inoculum may have promoted a competition with other soil microbiota, then led to a population rearrangement, that might have caused the delay in diazotrophic bacterial inoculum

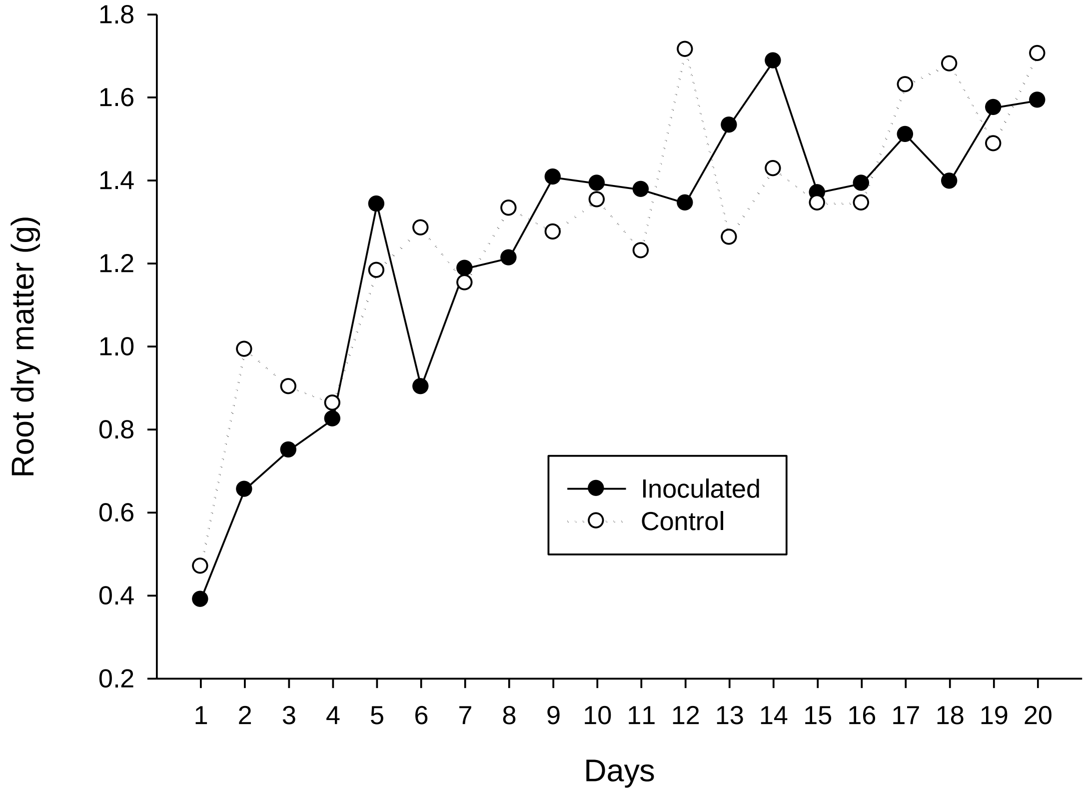

Figure 6. Root dry matter biomass (means) of maize plants which received *A. brasilense* treatment in comparison with control treatment, which did not receive any treatment during the 20 days trial period at greenhouse conditions.

establishment. Didonet et al. (2000) also reported that the inoculation of *A. brasilense* may promote a competition between normal soil microbiota.

The root dry mass varied from 0.47 to 1.72 g and from 0.39 to 1.69 of treatments control and inoculated with *A. brasilense*, respectively (Figure 6). There was no significant difference in both root and shoot dry mass of maize plants between the treatments. The values of shoot dry mass varied from 0.18 g to 1.16 g in control and from 0.26 g to 1.70 in inoculated plants (Figure 7). Probably, the duration of evaluation period was not appropriate to measure the plant development enhanced by the plant growth promoting bacteria *A. brasilense*. Quadros et al. (2014) reported an increase of root dry matter inoculated with *A. brasilense* when the evaluation was done at V_{12} stage of maize and this result was attributed to auxin produced by *A. brasilense*.

Dartora et al. (2013) verified a growth promoting effect in maize inoculated with *A. brasilense* and *Herbaspirillum* at reproductive stage, this effect probability was not found because maize was evaluated in initial stage of development. Certainly, the evaluation period of maize growth promotion at initial stages, to study the growth promoting effect of *A. brasilense*, is not appropriate.

Conclusion

The experimental findings indicate that *A. brasilense* did not promote an increase of nitrogen in the soil either nitrate or ammonical form during the initial 20 days of planting, suggesting that the growth promotion effects are not via nitrogen fixing at the initial period of plant development. Also, this early period would not be appropriate for the plants to receive *A. brasilense* inoculum, also in this period, the mode of interaction of this microorganism with plants may not be predominately nitrogen fixing. Probably, it will occur at later growth stages.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

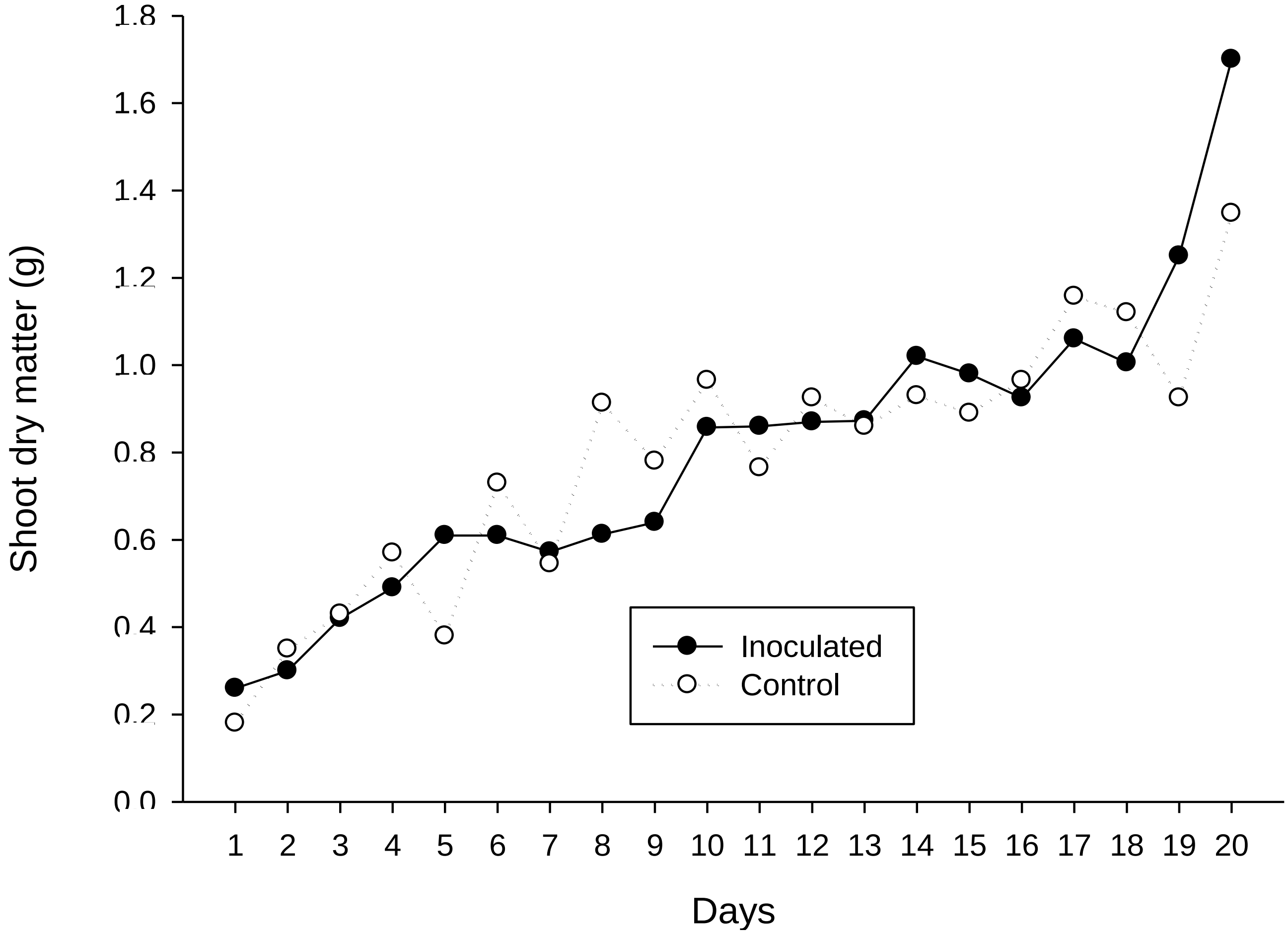

Figure 7. Shoot dry matter biomass (means) of maize plants which received *A. brasilense* treatment in comparison with control treatment, which did not receive any treatment during the 20 days trial period at greenhouse conditions.

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Full Length Research Paper

Carbon sequestration and assessment of fertility status of soil under different land uses for agronomic potentials in Abakaliki South Eastern Nigeria

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Abakaliki is predominantly agrarian but continuous cropping is largely practiced due to population pressure. Consequently, there is effort to evolve strategies that would ensure sustainable productivity. This necessitated a research which was carried out to study carbon sequestration and assessment of fertility status of soil for agronomic potentials under different land use systems. Six different land uses each of 20 m × 20 m equivalent to 0.04 ha were identified with Global Positioning System (GPS) and used for the study. Auger and Core samples were randomly collected at 0-15 cm depth in ten different points in each land use for determination of carbon sequestration and fertility assessment. Data were subjected to standard deviation. Results of standard deviation showed high carbon sequestration of 66.83±16.03, 43.73±5.69, 34.51±1.57 and 32.90±0.85 t ha^{-1} for alley cropping, forest, fallow and grazing land uses compared to 4.56±11.82 and 3.48±12.30 t ha^{-1} for mixed cropping and continuously cultivated soil. Bulk densities and total porosities were not limiting to soil fertility for alley cropping, forest, fallow and grazing land uses but moderately limiting for mixed cropping and continuously cultivated soil. Soil pH, available phosphorus, nitrogen, organic carbon, calcium, magnesium and exchangeable acidity were generally high and not limiting to fertility status in alley cropping, forest, fallow and grazing land uses but low and limiting in mixed cropping and continuously cultivated soil. Alley cropping, forest, fallow and grazing fell into grade 2 ranking while mixed cropping and continuously cultivated soil were in Grades 3 and 4 fertility ranking for agronomic potentials, respectively. Deep feeder crops are recommended for alley cropping, forest, fallow and grazing land uses while shallow and nitrogen fixers are suitable for mixed cropping and continuously cultivated soil. It is advocated that farmers adopt good and efficient land use management systems for high carbon sequestration, soil fertility sustainability and climate change mitigation.

Key words: Agronomic, assessment, carbon sequestration, fertility status, land uses.

INTRODUCTION

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide (CO_2) in soil or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change (https://en.m.wikipedia.org, 2016). According to Lal (2008), the process removes carbon pool and is primarily mediated by plants through photosynthesis where carbon is stored in form of soil organic carbon. Since industrial revolution which is exacerbated by rapacious urbanization, there has been unusual conversion of natural ecosystem for agricultural use or other uses resulting in depletion of soil organic carbon to about 50 to 100 GT of carbon captured from the atmosphere (Lal, 2015). The reductions occur largely from plant roots and residues not returned to soil or through erosion (Lemus and Lal, 2005) leading to depletion of organic carbon stocks or carbon deficits in soil and sometimes through a variety of land mismanagement approaches. Other causes of low soil carbon storage include low carbon dioxide concentration with consequent poor carbon fixation by plants (Drake et al., 1997) as well as increased plant respiration, low moisture content and high microbial activity (Maracchi et al., 2005).

Land use and management have profound influence on quantity of carbon stored in soil (Abril and Bucher, 2001). For instance, forestation or reforestation, grassland restoration, continuous cultivation, conservation tillage, cover crops or amendment practices have their relative impacts on carbon storage and soil properties (Amalu, 2012). Similarly, Batjes (2011) noted that impact of land use on carbon stocks and soil properties in Nigeria and sub-Sahara Africa is challenging because of spatial heterogeneity of soils. The author further observed that climate management was not easy largely because of lack of data on soil carbon pools as obtained in most agro-ecosystems.

Land use might be a dominant factor influencing soil properties and behavior temporarily and spatially (Wang et al., 2001). Land use or management practices to a large extent determine available soil nutrients and could modify processes such as erosion, oxidation, leaching and rate of mineralization (Celik, 2005) especially, as land use are critical since it relates to soil nutrients availability and physicochemical properties. Since the current rise in atmospheric CO_2 is thought to be mitigated in part by carbon storage in agricultural soils, interest has increased in possible impacts of various agricultural management practices on soil organic carbon dynamics (Abril and Bucher, 2001) as well as of soil properties. This study has become imperative as population is increasing geometrically with a fixed land mass. In response, farmers now cultivate every available land space ignoring normal and recommended agricultural practices for sustainable soil productivity (Anikwe, 2015).

Intensity of land use has obvious impacts on soil physicochemical properties (Celik, 2005) and sometimes leads to productivity decline. In order to facilitate soil carbon storage and improve its physical, chemical and hydrological functions, the adoption of effective land uses management practices by farmers that would be enduring and sustainable cannot be overemphasized. The objectives of this study were to study effect of different land uses on soil carbon sequestration and assessment of fertility status of soil under different land use systems for agronomic potentials in Abakaliki agro environment.

MATERIALS AND METHODS

Study area

The study was carried out partly in Teaching and Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University and adjoining areas near the Faculty. The Faculty lies by latitude 06° 4'N and longitude 08° 65'E while adjoining areas lie by latitude 06° 9'N and longitude 08° 69'E in the derived savanna area of the southeast agro ecological zone of Nigeria. The area experiences bimodal pattern of rainfall usually spread from April-July and September- November with dry spell in August. The rainfall ranges from 1700 to 2000 mm for minimum and maximum with mean annual rainfall of 1800 mm. Temperature varies from 27°C during cold (harmattan) period to 31°C for dry season normally between December and March. The relative humidity is highest (80%) during rainy periods but declines to 60% when the rains cease (ODNRI, 1989). The soils of the area are formed from sedimentary deposits from cretaceous and tertiary periods. It is associated with "Asu River" group as Abakaliki soil is believed to have been derived from shale residuum. The soil is unconsolidated up to 1 m depth and belongs to order ultisol and classified as typic haplustult (FDALR, 1985). The area is recently classified as derived savannah since it is characterized by growth of shrubs, herbs and common tropical grasses such as *Tridax procumbens, Imperata cylindrica, Panicum maximum, Elephant grass, (pennisetum purpurem), sporobulus pyramidalis* and *Sida acuta.* There are also traces of *centrosema* and *Pueriaria* as legume grasses. There are abundant palm trees but scanty economic trees like Obeche, Mahogany or "Afara". The indigenes are mainly farmers specializing in crops, fishing and hunting as major means of livelihood. Due to state creation the area largely known for its agrarian nature has abandoned it for "greener pastures" and many of the people could now be found in different vocations and civil service (Figure 1).

Identification of different land uses and their description

Six different land uses were used for the study. The land uses were carefully identified and characterized for the experiment. Each land use type measured 20 m × 20 m equivalent to 0.04 ha and was located using a hand held Global Positioning System (GPS).

1. Forest land designated as FL is located at Azugwu adjacent to Faculty of Agriculture and Natural Resources Management, Ebonyi State University. The forest was established during the colonial era for preservation of forestry resources spanning for 50 years. *Gmelina aborea* is dominant tree among other vegetations in the forest. Hunting and farming activities are prohibited although poaching is not completely eliminated as people still encroach in the forest for faming related activities.
2. Fallow land (UC) was identified behind Bishop Otubelu convent about 2 km away from Faculty of Agriculture and Natural Resources

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Figure 1. Map of Abakaliki, Ebonyi State.

Management, Ebonyi State University. The fallow has lasted for more than 15 years without being put under cultivation. There are different types of vegetations covering the land but among major ones are herbs, shrubs and grasses while carpet grass appears to be predominant.

3. Alley cropping (AC) is located behind Faculty of Agriculture and Natural Resources Management of the University for Research Purposes. The alley was established by Department of Soil Science and Environmental Management and has spanned 23 years since establishment. The alley trees are *Gliricidia sepium and Leucena leucophella* interspersed with *Cajanus cajana*. Their leaves are pruned periodically and deposited on the soil or used to feed animals. It has been expanded recently to include *Gmelina aborea* and *Accia bartari.*

4. Continuously cultivated soil (CCS) is located behind Law Faculty of Ebonyi State University. The land has been under yearly cultivation for more than 10 years by staff of the university. Common crops grown in rotation include yam (*Dioscorea* spp.), Cassava (*Manihot* spp.) and maize (*Zea mays L.*). Farming practices employed is that of subsistence one which is devoid of scientific approach.

5. Grazing land referred to as GL is located behind Department of Animal Science of Faculty of Agriculture and Natural Resources Management, Ebonyi State University. The land is solely dedicated for cattle grazing in the Faculty. The land is grown with moderately tall trees, shrubs, herbs and dominated by short local grasses. Grazing has taken place in the land since the inception of the Faculty spanning for more than 18 years.

6. Mixed cropping (MC) is located behind Law Faculty of the university. The land is used to grow mixture of crops which are intercropped on yearly basis. Common crops intercropped are maize (*Z. mays L.*), Yam (*Dioscorea* spp.), Cassava (*Manihot* spp.), Cocoyam (*Colocasia esculentum*), Cowpea (*Vignia urnguiculata*), Bambara (*Phaseolus vulgaris*) and sweet potato (*Ipomea batata*). This practice is in vogue in the land and commonly accepted practice within the agro environment.

Soil sampling

A hand held global positioning system (GPS) was used in determining positions for collection of soil samples in each land use. Auger and Core soil samples were collected at 0-15 cm depth in each land use believed to be within plough layer since local hoe is commonly used for cultivation. Samples were collected at ten points per each land use. Auger samples were composited after being air dried at 26°C, ground and sieved with 2 mm sieve and used for determination of soil chemical properties. The mean of core samples after laboratory determinations were used to evaluate soil physical properties.

Soil carbon sequestration determination

Total carbon sequestered in soil was calculated using procedure used by Mbah and Idike (2011). The procedure is as follows:

$$\text{Carbon sequestered in soil} = \frac{\%C}{100} \times \text{Soil BD (mgm}^{-3}) \times \text{area of land (m}^2) \times \text{soil depth (cm)} \quad (1)$$

Where %C = percent carbon; BD = bulk density (mgm^{-3}); area = area of land used for study equivalent to 1 ha (m^2), and soil depth = 0.15 cm.

Rating index for agronomic potentials

Soils under different land uses were rated based on their individual suitability for sustaining arable crops according to Storie Index (1953) rating as corroborated by Akamigbo (2010) which is based on the following characteristics related to crop growth and yield.
These soil characteristics include:

Soil characteristics	**Factor**
Soil profile depth-	A
Texture of surface soil-	B
Sloppiness-	E
Other factors (drainage, salts, alkali and erosion)-	X

Each factor is evaluated on the basis of 100%. A rating of 100% implies most favourable or ideal condition and lower percentage ratings are for less favourable conditions for crop production (Akamigbo, 2010). The index rating for individual factors for alley cropping, forestry, grazing and fallow land uses are 90% since they did not impose limitation for crop production. Mixed cropping has 90% for factors A-E and 60% for X while 70% was assigned to continuously cultivated soil for factors A-E and 50% for X, respectively. Where A, B, E are 90% for AC, FL, GL and UC and A,B,E are 90% and X is 60% for MC while A, B, E are 70% and X is 50% Grades for suitability for intensive production of crops were based on summation of values for factors A × B × E × X.

Laboratory methods

Particle size distribution was determined using Gee and Or (2002) hydrometer method. The result of particle size distribution was reported in percentages while the textural class determination was determined using USDA textural triangle (Obi, 2000). Bulk density was evaluated using core method as follows:

$$Bd = \frac{\text{Weight of oven dry soil (Mg)}}{\text{Volume of Core } (M^3)} \quad (2)$$

Where Bd = bulk density (Mgm^{-3}).

Whereas total porosity value was obtained as described by Obi (2000) using the formula:

$$\text{Total porosity} = \left(\frac{1\text{-Bd}}{P_p}\right) \times \frac{100}{1} \quad (3)$$

Where, Bd = bulk density (mgm^{-3}), and Pp = particle density assumed to be 2.65 Mgm^{-3}.

Soil pH determination was done using soil/water suspension ratio of 1:2.5. The pH values were read using electrode pH meter. Organic carbon was determined by the method described in Page et al. (1982). Total nitrogen determination was done using the modified macro-Kjedahl method (Bremner and Mulvancey, 1982). Exchangeable calcium, magnesium, potassium and sodium were extracted using the method described by Mba (2004). The values of potassium and sodium were obtained using flame photomertry method. Available phosphorus was determined by colorimetric method of Page et al. (1982). Exchange acidity was determined using titrimetric method of Mclean (1982).

Data analysis

Data from the study were subjected to standard deviation analysis according to Obi (2002). Chart was used where possible to further illustrate the results.

RESULTS

Soil carbon sequestration

Soil carbon sequestration under different land uses is presented in Table 1 and Figure 2. The results showed strong variations in carbon sequestration among the different land uses. The results of carbon sequestration in different land uses ranged from 3.48±12.30-66.83±16.03t ha^{-1} for the land uses. The variations recorded in carbon sequestration for the alley cropping, forest land, grazing land and fallow land were 54, 29, 6 and 10% higher from their mean values, respectively. On the other hand, continuously cultivated soil and mixed cropping land uses had 88 and 85% lower variations of carbon sequestration from their mean values. The order of value of carbon sequestration for the different land uses is AC > FL > UC > GL > MC > CCS.

Table 1. Carbon sequestration under different land uses.

Land use	Carbon storage (t ha^{-1})
Alley cropping	66.83± 16.03
Forest land	43.73 ±5.69
Uncultivated land	34.51±1.57
Grazing land	32.90±0.85
Mixed cropping	4.56±11.82
Continuous cultivation soil	3.48±12.30
Mean	31.00

Soil physical properties under different land uses

Table 2 and Figure 3 show soil physical properties under different land uses. Particle size distribution ranged from 55-69, 10-34 and 15-24%, respectively for sand, silt and clay fractions in the land uses, respectively. Generally, percent sand, silt and clay varied in the land uses with sand being predominantly higher. Clay fraction was dominant in alley cropping land use compared to corresponding values in other land uses. Textural class was sandy loam for the different land uses. Bulk density and total porosity ranged from 1.29±0.03-1.52±0.14 Mgm^{-3} and 42.75±2.39-51.75±1.64% and varied from their mean values in the land uses. Lowest values of bulk density were obtained in forest and grazing land uses while highest value was recorded in continuously cultivated soil. Total porosity followed the trend obtained in bulk density for the different land uses.

Chemical properties of soil under different land uses

Chemical properties of soil under different land uses are presented in Table 3. Results showed that chemical properties of soil generally varied from one land use to another and from their mean values with highest values obtained under alley cropping, forest, grazing and fallow land uses compared to their counterparts in mixed cropping and continuously cultivated soil. The values of soil pH obtained under different land uses ranged from

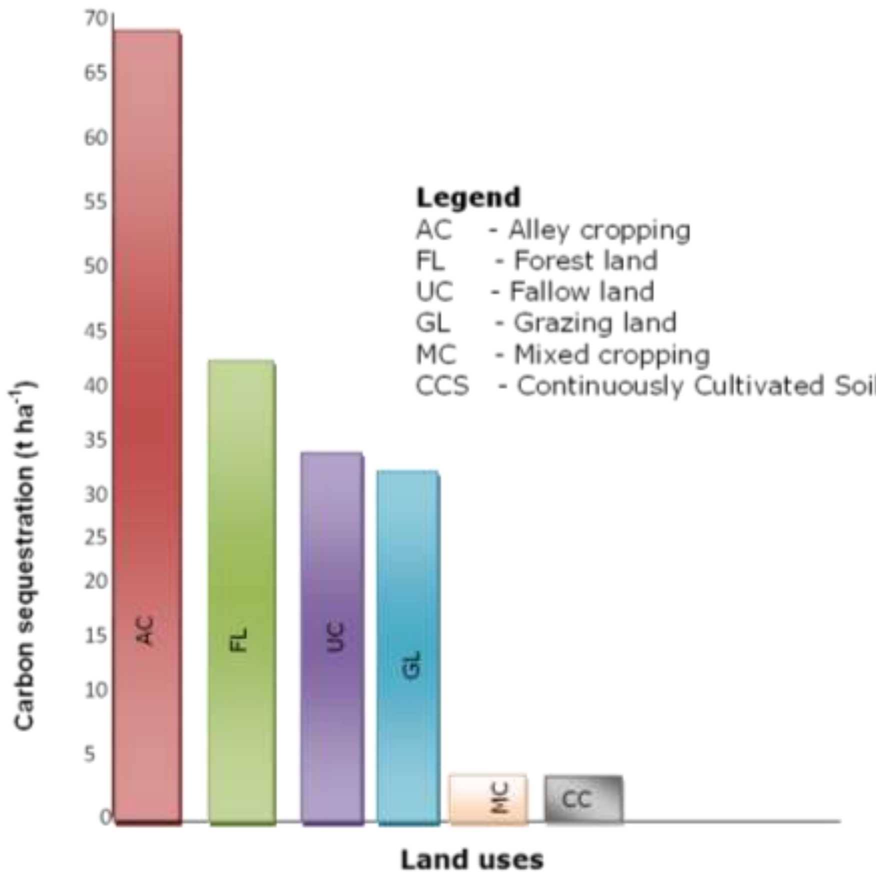

Figure 2. Carbon sequestration under different land uses.

Table 2. Physical properties of soil under different land uses.

Land uses	Sand (%)	Silt (%)	Clay(%)	Texture	BD (Mgm^{-3})	TP (%)
Alley cropping	58	18	24	SL	1.33±0.22	50.25±0.96
Forest land	68	16	16	SL	1.29±0.03	51.50±1.53
fallow land	64	18	18	SL	1.39±0.01	47.54±0.59
Grazing land	69.	10	21	SL	1.29±0.03	51.75±1.64
Mixed cropping	55	27	18	SL	1.45±0.03	45.50±1.20
Continuous cultivated soil	61	20	19	SL	1.52±0.14	42.75±2.39
Mean	**45**	**34**	**20**		**1.38**	**48.08**

BD, bulk density; TP, total porosity; SL, sandy loam.

5.50±0.18 to 6.20±0.13 and slightly varied from their corresponding mean values. The respective values of available phosphorus ranged from 14.00±3.53 to 31.60±4.34 mgkg^{-1} under alley cropping, forest, grazing and fallow land uses and were comparable with their mean values more than values obtained for continuously cultivated soil and mixed cropping land uses. There were higher deviations in values of available phosphorus under continuously cultivated soil and mixed cropping systems when compared to their counterparts recorded for other land use systems except for forest land. Nitrogen values 0.08±0.01 to 0.16±0.02% in alley cropping, forest fallow and grazing land uses were higher than their mean values and varied from those of fallow land, continuously cultivated soil and mixed cropping systems. The values of organic carbon in alley cropping and forest land uses were higher than their mean values and differed from values in continuously cultivated soil, fallow and mixed cropping land uses, respectively. The values of organic carbon ranged from 0.20±0.60 to 3.35±0.08% for the

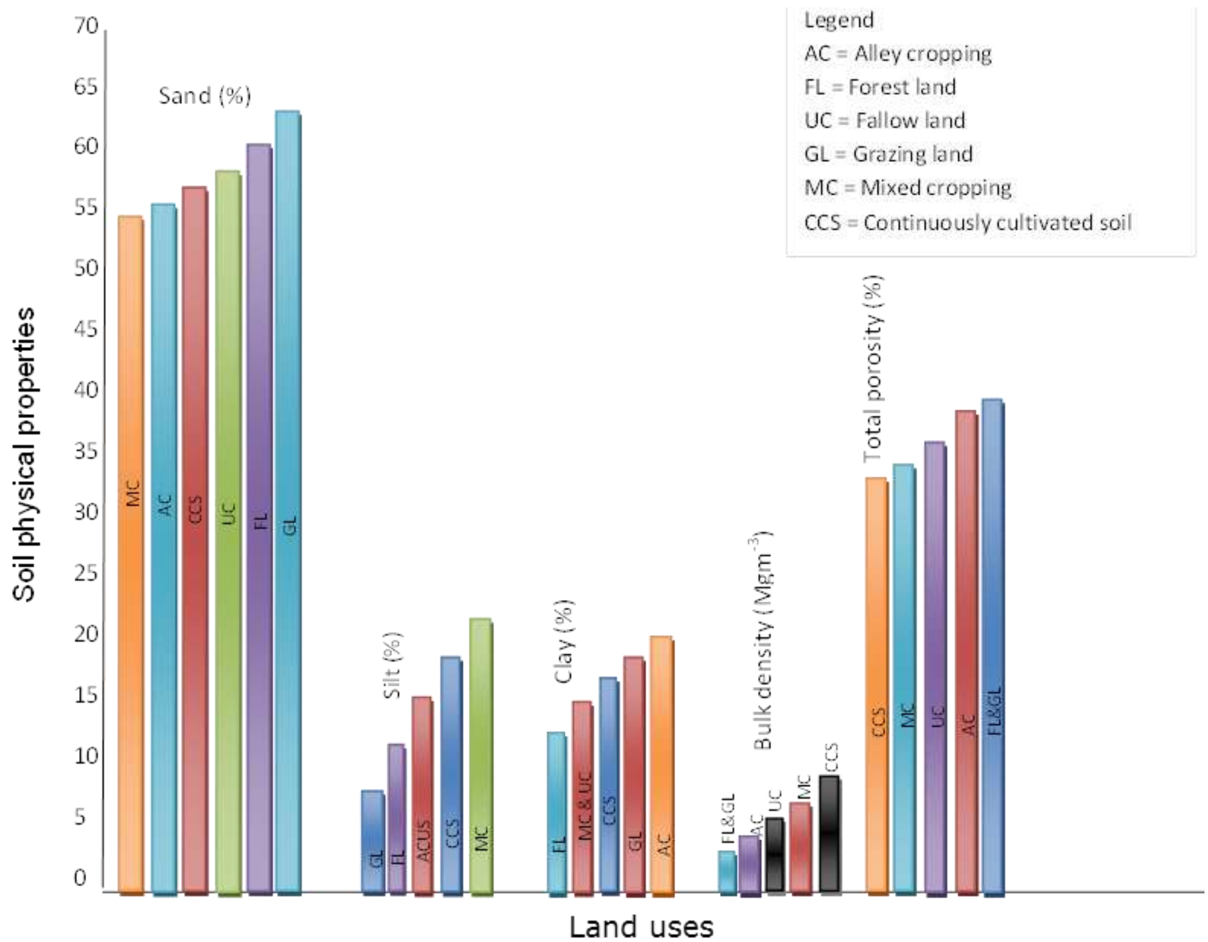

Figure 3. Soil physical properties under different land uses.

different land use systems. Generally, exchangeable cations of calcium and magnesium predominantly dominated exchange complex of soil in the land uses than potassium and sodium. The values of exchangeable cations ranged from 2.40±0.57-4.80±0.51, 1.20±0.21-2.46±0.33, 0.05±0.04-0.18±0.02 and 0.15±0.01-0.23±0.02 cmolkg-1 respectively for calcium, magnesium, potassium and sodium. Exchangeable acidity ranged from 0.16±0.18-1.20±0.29 cmolkg^{-1} and was higher under continuously cultivated soil more than in any other land use system. In contrast, least value of exchangeable acidity was obtained under alley cropping land use relative to other land uses. The respective fertility ranking for the different land use systems is in the order of AC > GL > FL > UC > MC > CCS (Table 1).

DISCUSSION

The highest carbon sequestered under alley cropping, forest, fallow and grazing land uses compared to their counterparts obtained under continuously cultivated soil and mixed cropping land uses could be attributed to efficiency or effectiveness of vegetations and/or trees which trapped and sequestered carbon in the soil. This implies that adoption of forestation, fallowing or conservation farming could have purifying effect on the atmosphere through carbon iv dioxide removal and its consequent storage in soil. This could lead to mitigation of climate change and global warming. This finding is in tandem with reports of Anikwe (2015) which made similar observations and corroborated by Lal (2008) that trees trapped carbon dioxide of the atmosphere and sequestered it in plants' parts and finally as soil carbon. Sloughed off parts' of plants as well as death and decomposed plants parts form soil carbon (Oelkers and Cole, 2008). Highest carbon sequestration obtained under alley cropping land use compared to other land uses could be linked to higher efficiency of legume trees in conversion of carbon dioxide to soil carbon pool. This finding is supported by Mbah and Idike (2011) and Okonkwo et al. (2011) who reported that alley cropping system had higher carbon sequestration potential compared to other types of land uses. Low level of

Table 3. Chemical properties of soil under different land uses.

Land uses	pH	P	N	OC	Ca	Mg	K	Na	EA
	(kcl)	(mgkg^{-1})	(%)	(%)			Cmolkg^{-1}		
Alley cropping	6.20±0.13	24.50±1.16	0.16±0.02	3.35±0.08	4.40±0.33	2.46±0.33	0.18±0.02	0.23±0.02	0.16±0.18
Forest land	6.20±0.13	31.60±4.34	0.14±0.03	2.26±0.30	4.80±0.51	1.66±0.04	0.17±0.02	0.17±0.04	0.40±0.07
Grazing land	6.00±0.04	24.30±1.07	0.11±0.00	1.70±0.01	42.0±0.15	1.60±0.03	0.16±0.01	0.17±0.04	0.32±0.07
fallow land	6.00±0.04	21.80±0.02	0.10±0.09	1.62±0.03	3.20±0.21	1.60±0.03	0.10±0.01	0.17±0.04	0.5±0.09
Mixed cropping	5.90±0.00	15.10±3.04	0.08±0.01	0.20±0.60	3.20±0.21	1.60±0.03	0.09±0.02	0.17±0.04	0.32±0.01
Continuously cultivated soil	5.50±0.18	14.00±3.53	0.08±0.01	0.16±0.60	2.40±0.57	1.20±0.21	0.05±0.04	0.15±0.01	1.20±0.29
Mean	5.9	21.9	0.11	1.55	3.67	1.67	0.13	0.18	0.56

P, phosphorus; N, nitrogen; OC, organic carbon; Ca, Mg, K, Na, exchangeable cations; EA, exchangeable acidity.

sequestered carbon under continuously cultivated soil could be due to losses as a result of dissipation, high mineralization and exposure to high temperatures, hazards of erosion and harvesting of crops without replacement. Low value of carbon sequestered under mixed cropping is attributable to competition of the crops as well as low ratio of leaves to plants which hampered carbon fixation in soil. These findings are supported by the report of Thompson and Kolka (2005) that land uses and management have large influence on local temperature, erosion and sediment deposition all of which ultimately controlled carbon inputs variation in soils. For instance, increased temperature might have impact on soil carbon balance reducing rate of photosynthesis (Zak et al., 2000). As a result, poor land use and management have the negative consequence of elevated carbon dioxide concentration in the atmosphere leading to global warming and climate change which is adverse to soil productivity. The carbon storage in alley cropping, forest, fallow and grazing land uses are high (Mbah and Idike, 2011) while value obtained under mixed cropping and continuously cultivated soil are low. Crops which make use of high efficiency of carbon such as C3 and C4 (maize and cow pea) plants could perform optimally in soils under high carbon storage.

High clay fractions under alley cropping and grazing land uses are attributable to effective rooting network system of vegetation which allowed for high concentration of clay fraction in the soil. This observation was corroborated by Okonkwo et al. (2011) that clay fraction was higher under alley cropping system compared to non-alley system. Furthermore, sandy loam texture obtained in all the land uses could be linked to good distribution of particle sizes in the soil due to management practices. Sandy loam texture has good attribute of high aeration propensity and sustenance of yields of arable crops, because of its high water and nutrients supply potentials (Nwite et al., 2016). The predominance of sand fraction in different land uses could be attributed to parent material rather than influence of land uses. Soils of Abakaliki area is reported (FDALR, 1987) to have been formed from unconsolidated deposits from sandstone. Low clay fraction under forest land is expected since tree roots could create channels for clay eluviations.

The lower bulk densities and higher total porosities in forest, grazing and alley cropping land uses could be adduced to be effect of animal droppings and leaf litter as well as recycling of nutrients to upper horizons of soil due to pedoturbation. The bulk densities except under continuously cultivated soil ranged from non-limiting to moderate values according to Anikwe (2006), Obi (2000) and Grossman and Berdanier (1982) that enhance soil productivity. Several researchers including Ohaekwiro (2016), Anikwe et al. (2007) and Mbah et al. (2009) corroborated that continuous cultivation and cropping increased soil compaction and hindered root proliferation which limited soil productivity. Similarly, total porosity ranged from non-limiting values for alley cropping, forest fallow and grazing land uses to moderate values in mixed cropping and continuously cultivated soil (Obi, 2000). Bulk density and total porosity have reciprocal relationship and their negative effects could affect nutrient retention and supply, water supply, root proliferation, leaching and nutrient losses all of which could severely limit soil productivity. Consequently, alley cropping, grazing, forestation and fallow system management could have high agronomic potentials.

Slightly different values of pH of the soil under different land uses could be attributed to effect of land use management practices prevalent in the study area. Low soil pH values obtained under continuously cultivated soil and mixed cropping systems compared to their counterparts from other land uses could be due to continuous cultivation, utilization of nutrients by crops and inorganic fertilizer application commonly practiced by farmers. However, soil pH between 5.50 and 6.20 do not constitute limitation to soil productivity (Schoenerberger et al., 2002) as most soil major nutrients such as nitrogen, phosphorus, potassium, sulphur and magnesium are precipitated and made available to crops (Anikwe, 2006; Asadu and Nweke, 1999). Moderate values of available phosphorus (FMARD, 2002) obtained in alley cropping, grazing, forest and fallow land use systems compared to values from continuously cultivated soil and mixed cropping land uses could be attributed to recycling of nutrients by roots of plants, decomposition and mixing of decomposed leaf litter through microbial action (Kaur et al., 2005). The phosphorus status in alley cropping, grazing, forest and fallow land uses is at critical levels that is limiting to soil productivity (Asadu and Nweke, 1999). Low nitrogen status under different land uses could be attributed to rapid mineralization under tropical condition (Asadu, 1990) as obtained in Abakaliki Nigeria and other subsaharan environment and is limiting to soil productivity (Raju et al., 2006). The organic carbon ranged from low to moderate values under different land uses and this could be linked to influence of different land use systems. Alley cropping, grazing, forest and fallow land use systems have potentials for nutrient recycling more than continuously cultivated soil and mixed cropping as corroborated by earlier findings of Anikwe (2015) and Okesiji et al. (2012) that conservation practices increased organic carbon status of soil. The high and dominant values of exchangeable calcium and magnesium under alley cropping, forest, grazing and fallow land uses relative to continuously cultivated soil and mixed cropping systems are attributable to improvements arising from improved pH conditions of the soil (Table 3) and moderate available phosphorus and organic carbon (Asadu et al., 2012). High exchangeable calcium and magnesium is advantageous as it could skew up soil fertility status as they improve soil pH, reduce soil exchangeable acidity and precipitate release of nutrients such as available phosphorus, nitrogen and potassium. Essentially, calcium and magnesium except potassium and sodium (Asadu and Nweke, 1999) are not limiting to soil productivity. Sodium generally is not important in plant nutrition but could improve both base saturation and cation exchange capacity of soil. Trend of exchangeable acidity obtained under different land uses could be due to improvements from soil pH and nutrient status in the land use systems. High exchangeable acidity in continuously cultivated soil system could be linked to effect of nutrient depletion, low acidity and poor base saturation of the soil. High soil pH is favourble for stimulation and precipitation of exchangeable Al^{3+} saturation of soil. It is advocated that management practices which could ensure and promote forestation or reforestation, fallowing and farming could be revolutionary and a step towards sustainable soil productivity (Ezeaku, 2011). Higher deviations obtained in values of available phosphorus in CCS and MC land uses could be due to error in handling and calculation of samples as the values in those land uses except in fallow land use were even lower (Table 3).

Agronomic potentials of different land uses

The different land uses have great agronomic potentials based on their fertility status ranking. Individual capability or suitability ratings for sustaining crop production was calculated based on Storie (1953) rating and used to characterize land uses for agronomic potentials. The land uses were further grouped into grades as determined by favourable conditions or otherwise that could enhance and sustain crop production or limit it. Based on this, land uses such as alley cropping, forest, grazing and fallow fall into grade 2 implying soils which are good and could support intensive and high production of arable crops such as yam (*Dioscorea* spp), Cassava (*Manihot* spp), Maize (*Zea mays* L.), Cocoyam (*Colocasia esculenta*), Amaranthus, garden egg (*Solanum* spp) and fluted pumpkin (*Occidentalis* spp.). Mixed cropping land use is grouped under grade 3 which means that the soil is fairly well suited for production of yam (*Dioscorea* spp), cassava (*Manihot* spp), Maize (*Z. mays* L.), groundnut (*Arachis hypogea*), Bambara nut (*P. vulgarise*), cowpea (*V. unguculata*), *Cajanus cajan* and pepper (*Capasicum annum*). Continuously cultivated soil has grade 4 which implies that such soil is poorly suited for crop production. The soil could support production of arable crops such as maize (*Z. mays* L.) although not at economical level, cowpea (*V. vulgarise*) and groundnut (*A. hypogea*). These three grades of soil could also be suitable for production of economic tree crops such as oil palm (*Ealeis guinensis*), coconut, orange tree, mango (*Magnifera indica*), cashew and guava at economical and productive levels (Obi, 2000).

Conclusion

The results of this study have shown that carbon sequestration could be high under vegetation cover than bare soil condition and continuously cultivated soil. The sequestrated soil carbon could play strategic role in climate change mitigation and global warming reduction as well as enhance crop production. Furthermore, bulk density and total porosity were ideal for soil productivity in alley cropping, forest grazing and fallow land uses but limiting in continuously cultivated soil and mixed cropping land uses. Similarly, soil pH, nitrogen available phosphorus, organic carbon, exchangeable bases and exchangeable acidity do not impose limitation to soil productivity in AC, FL, UC, and GL land use. Alley cropping, forest, fallow and grazing land use could support intensive crop production just as mixed cropping is fairly well suited and continuously cultivated soil is poorly suited for arable crop use. Essentially, different land uses have different capacities for agronomic uses and potential. Generally, conservative farming such as practice of alley cropping, forestry, fallowing, and grazing land rather than mixed cropping, slash and burn or and continuously cultivated soil management practices are restorative measures on soil nutrients and physicochemical properties. The latter practices are depletive on soil nutrients and deteriorate physical properties. A good and effective land management practice such as alley cropping and forestry are advocated for enhanced carbon sequestration, climate change mitigation, sustained soil fertility status and increased productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Selectivity of pre-and post-emergent herbicides for cowpea (*Vigna unguiculata*)

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Historically, cowpea farming has been concentrated to the north and northeast of Brazil, and is usually cultivated with low level of technology. However, in recent years, there has been an increase in the area planted with the crop in the central west, using technology, and there is therefore now a need to study, among other factors, the chemical control of weeds. Two experiments were carried out with the aim of making a preliminary study during the vegetative phase of the cowpea, the first using pre-emergent herbicides and the second with post-emergent herbicides, in a greenhouse at the Federal University of Paraíba, in Areia, state of Paraiba, Brazil. The experimental design was completely randomized with four replications. The Relative Chlorophyll Content (SPAD index) was evaluated together with a visual evaluation of phytotoxicity. Promising results for selectivity in the cowpea were seen in relation to the herbicides under evaluation, whether applied prior to or after emergence of the crop. For weed control prior to crop emergence, the herbicides Diuron, S-metolachlor, Metribuzin, Diquat dibromide and Sulfentrazone gave promising results. In addition to these products, Clethodim and Haloxyfop-p-methyl should be noted as potential post-emergent herbicides.

Key words: Chemical control, phytotoxicity, tolerance, *Vigna unguiculata*, weed management.

INTRODUCTION

The cowpea (*Vigna unguiculata* (L.) Walp.) is among the most important species used for food in the human diet. Historically in Brazil, cowpea production has been concentrated in the north and northeast (55.8 million hectares and 1.2 thousand hectares, respectively), where it is cultivated mainly by small producers, generally using a low level of technology. However, the crop has been gaining ground in the central west, due to the development of erect and semi-erect cultivars, favouring mechanised cultivation (Freire Filho, 2011), and arousing

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Table 1. Mean values for chemistry, fertility and granulometry analysis of the soil.

pH (1:2.5)	P	K^+	Na^+	H+Al	Al^{+3}	Ca^{+2}	Mg^{+2}	OM
	mg dm^{-3}			$cmol_c kg^{-1}$				g kg^{-1}
5.2	1.9	0.22	0.07	6.6 [b]	0.4	1.1	0.7	25.0

Textural class			Dispersed clay	Degree of flocculation	Textural classification
Sand	Silt	Clay			
g kg^{-1}					
532	49	420	9	979	Sandy clay

the interest of large producers who practice a mechanised agriculture, and who plant the cowpea during the soybean off-season (Freitas et al., 2009).

The cowpea (*Vigna unguiculata*) is one of the most consumed and cultivated legumes in Brazil, especially in the north and northeast. However, in recent years, there has also been a great expansion of the cultivated area in the central west, where it is incorporated into such productive arrangements as the off-season harvest, after the soybean and rice crops, and in some places, as the main crop (Freire Filho, 2011).

The crop has become an excellent alternative as an off-season crop in the savannah of the northeast, especially in the areas, where soybeans and maize are cultivated in the south of the states of Maranhão and Piauí. It is estimated that there were approximately 50 thousand hectares under cultivation in these regions in the 2014 to 2015 season, with average yields greater than 1400 kg ha^{-1}.

Its rusticity, low production cost and economically viable productivity are the main characteristics that make this an ever-expanding crop. However, one of the major problems faced by producers in the region is the interference of weeds due to the lack of herbicides registered for the crop, and weed control by mechanical methods being impractical and impossible to use in large areas.

As they compete for light, nutrients and water, the interference of weeds is one of the factors that most influence growth, development and productivity in *Vigna unguiculata* (L.) Walp, which is directly reflected in a quantitative and qualitative reduction in production, in addition to increasing the operational costs of harvesting, drying and processing the grain, where weed control is considered one of the main components of the production costs. When uncontrolled, weeds may reduce grain yield by up to 90% (Freitas et al., 2009).

Chemical control using herbicides has several advantages, such as less dependence on labour, efficiency even during the rainy season, effectiveness in controlling weeds in the planting furrow and not affecting the root system of the crops, allowing for minimum cultivation or direct planting, and being efficient in controlling vegetative propagation in the weeds. However, the use of these methods in the cowpea is limited due to the scarcity of studies into the selectivity of herbicides for the crop (Silva et al., 2009; Souza et al., 2016). Most of the information on the use of herbicides is related to the common bean (*Phaseolus vulgaris* L.) or the soybean (*Glicyne maxima* (L.) Merr.) (Freitas et al., 2009).

Taking this information into consideration, the aim of the present work was to study the selectivity of herbicides for the cowpea crop when applied pre- and post-emergence during the initial phase of crop growth.

MATERIALS AND METHODS

Location of the experiments

Two experiments were carried out in a greenhouse at the Centre for Agrarian Sciences of the Federal University of Paraíba, Areia Campus, Brazil, during October and November 2014. Analysis of chemistry, fertility and granulometry of the soil used to fill out the cups is presented in Table 1.

Experimental design and statistical procedures

The experimental design was completely randomized with four replications, eight herbicides applied pre-emergence as treatments in the first experiment and 8 herbicides applied post-emergence as treatments in the second experiment (Table 2). The experimental units consisted of disposable 250 ml capacity cups with substrate. The cowpea cultivar used was IPA 207. Plants were irrigated every two days to maintain the soil at field capacity.

The herbicides were applied with a backpack spray at a constant pressure of 206.85 kPa, by compressed CO_2, using XR 110-02 flat fan spray tips. The equivalent of 200 L ha^{-1} of solution was applied. The operation was carried out soon after sowing the seeds. The application of the post-emergent herbicides was carried out in plants after 15 days of emergence and display of four to five distinct folioles. The following conditions were noted at the time of the applications, a wind speed of 1.6 km h^{-1}, ambient temperature of 34.3°C, and relative humidity of 47.6%.

The selectivity of the herbicides was evaluated visually at 07, 14 and 21 days after application of the herbicides (DAA) (in the first experiment), and at 07, 14, 21 and 28 days after application (in the second experiment). A percentage scale was adopted for the visual evaluation of phytotoxicity in the cowpea plants, where zero indicates the absence of symptoms, and 100% means death of the plant (Frans and Talbert, 1977). The Relative Chlorophyll Content (RCC) was determined by readings taken at 7, 14 and 21 days after

Table 2. Treatment (doses of herbicides in active ingredient – a.i.) applied pre and post-emergence.

Experiment 1: Pre-emergent	Experiment 2: Post-emergent
T1 - Flumioxazin (52.5 g a.i. ha^{-1})	T1 -Fluazifop-p-butyl (187.5 g a.i. ha^{-1})
T2 - Diuron (1.6 kg a.i. ha^{-1})	T2 -Quizalofop-p-ethyl (80 g a.i. ha^{-1})
T3 - S-metolachlor (1.2 kg a.i. ha^{-1})	T3 -Fenoxaprop-p-ethyl (44 g a.i. ha^{-1})
T4 - Metribuzin (422.4 g a.i. ha^{-1})	T4 - Sethoxydim (276 g a.i. ha^{-1})
T5 - Clomazone (1.64 kg a.i. ha^{-1})	T5 - Clorimuron-ethyl (17 g a.i. ha^{-1})
T6 - Diquat dibromide (350 g a.i. ha^{-1})	T6 – Clethodim (96 g a.i. ha^{-1})
T7 - Sulfentrazone (600 g a.i. ha^{-1})	T7 - Haloxifop-p-methyl (43.75 g a.i. ha^{-1})
T8 - Lactofen (180 g a.i. ha^{-1})	T8 – Bentazon (720 g a.i. ha^{-1})

Table 3. Summary of the analysis of variance (mean squares) for relative chlorophyll content and phytotoxicity in cowpea seedlings verified at intervals of seven days after application (DAA) of pre-emergent herbicides.

SOV	d.f	7 DAA	14 DAA	21 DAA
		Relative chlorophyll content		
Herbicides	6	239.419**	36.99**	28.87^{ns}
Residual	28	7.587	9.33	12.89
CV (%)	-	8.82	9.39	12.76
		Phytotoxicity		
Herbicides	7	46.376**	56.923**	29.35**
Residual	32	0.8802	0.6137	1.213
CV (%)	-	22.42	19.85	23.38

SOV: Sources of variation; d.f: degrees of freedom; CV: coefficient of variation; **Significant 1% probability. ^{ns}Not significant.

application of the treatments, using the Minolta SPAD-502 chlorophyll meter.

The data were evaluated for variance and error normality. Variance analysis was used to analyse the data, and mean values were compared by Tukey's test at 5% probability.

RESULTS

In the first experiment, selectivity of cowpea to pre-emergent herbicides was evaluated. The treatments were significantly different (p <0.01) among them for all RCC and phytoxicity evaluations, with the only exception for this first one at 21 DAE (Table 3). Furthermore, the fair to good value obtained for the coefficient of variation indicated good experimental procedure.

Multiple comparison tests were applied to the mean values for RCC and phytotoxicity visual evaluation, carried out 7, 14 and 21 days after application of the herbicides (Table 4). At seven days after application of the herbicides, the highest values for RCC were found for the herbicides sulfentrazone (350 g a.i. ha^{-1}) and lactofen (180 g a.i. ha^{-1}).

Fourteen days after application of the treatments, death of the lots occurred with the herbicide Flumioxazin (T1). From this point, then statistical analysis considered only seven treatments, with this product excluded from the analysis.

The highest values for RCC were seen using the herbicides Lactofen (36.16) and Clomazone (34.85) when analyzed at 14 days after treatment application. However, when analysed at 21 days after application of the herbicides, no significant differences were found by Tukey's test at 5% probability.

According to phytotoxicity visual evaluation, cowpea was more selective to the herbicide Metribuzin, having the lowest value (0.1%), followed by the herbicides Diuron (0.7%), Diquate Dibromide (1.6%) and S-metolachlor (7.4%). Similar behaviour was seen when evaluating phytotoxicity after 14 days of application, where the herbicide Diquat dibromide had the lowest evaluation (0.4%), followed by the herbicides Metribuzin (0.5%), Diuron (0.7%) and S-metolachlor (3.9%), with no statistical difference at 5% probability by Tukey's test. Twenty-one days after application, the crop was seen to be more selective to the herbicide Diuron (5.3%), with levels of toxicity significantly lower than those for

Table 4. Relative chlorophyll content and phytotoxicity in cowpea seedlings verified at intervals of seven days after application (DAA) of pre-emergent herbicides.

Herbicide	7 DAE	14 DAE	21 DAE
	Relative chlorophyll content		
Flumioxazin (52.5 g a.i. ha^{-1})	16.19[d]	NE	NE
Diuron (1.6 kg a.i. ha^{-1})	29.60[bc]	28.29[b]	28.81[a]
S-metolachlor (1.2 kg a.i. ha^{-1})	34.06[ab]	33.61[ab]	24.72[a]
Metribuzin (422.4 g a.i. ha^{-1})	27.86[c]	30.31[ab]	30.96[a]
Clomazone (1.64 kg a.i. ha^{-1})	34.59[ab]	34.85[a]	29.13[a]
Diquat dibromide (350 g a.i. ha^{-1})	33.08[abc]	31.32[ab]	26.53[a]
Sulfentrazone (600 g a.i. ha^{-1})	37.31[a]	33.09[ab]	30.75[a]
Lactofen (180 g a.i. ha^{-1})	37.17[a]	36.16[a]	26.11[a]
	Phytotoxicity (%)		
Flumioxazin (52.5 g a.i. ha^{-1})	61.3 (7.86)[a]	100 (10.03)[a]	100 (10.03)[a]
Diuron (1.6 kg a.i. ha^{-1})	0.7 (1.07)[b]	0.7 (1.04)[d]	5.3 (2.39)[d]
S-metolachlor (1.2 kg a.i. ha^{-1})	7.4 (2.54)[b]	3.9 (1.91)[d]	17.7 (4.14)[bcd]
Metribuzin (422.4 g a.i. ha^{-1})	0.1 (0.78)[b]	0.5 (0.90)[d]	31.6 (5.19)[bc]
Clomazone (1.64 kg a.i. ha^{-1})	39.3 (6.27)[a]	35.7 (5.96)[b]	18.1 (4.26)[bcd]
Diquat dibromide (350 g a.i. ha^{-1})	1.6 (1.29)[b]	0.4 (0.88)[d]	9.3 (3.07)[cd]
Sulfentrazone (600 g a.i. ha^{-1})	55.7 (7.44)[a]	44.3 (6.66)[b]	8.3 (2.95)[cd]
Lactofen (180 g a.i. ha^{-1})	40.3 (6.21)[a]	18.7 (4.19)[c]	32.1 (5.66)[b]

Mean values followed by the same letter in a column do not differ by Tukey's test at 5% probability. NE: Not evaluated. Original data in parentheses; transformed data (Root x + 0.5).

Table 5. Summary of the analysis of variance (mean squares) for relative chlorophyll content and phytotoxicity in cowpea seedlings verified at intervals of seven days after application (DAA) of post-emergent herbicides.

SOV	d.f	7 DAA	14 DAA	21 DAA	28 DAA
		Relative chlorophyll content			
Herbicides	7	45.968[ns]	122.668**	118.918**	NE
Residual	24	30.192	17.164	16.117	NE
CV (%)	-	26.99	18.56	19.30	NE-
		Phytotoxicity			
Herbicides	7	0.3972[ns]	1.9502**	2.0709**	4.1489**
Residual	24	0.4537	0.5556	0.2982	0.4088
CV (%)	-	15.47	15.59	10.64	10.84

SOV: Sources of variation; d.f: degrees of freedom; CV: coefficient of variation; **Significant 1% probability. [Ns]not significant; NE: not evaluated.

Metribuzin (31.6%), Lactofen (32.1%) and Flumioxazin (100%).

In the second experiment, eight herbicides applied in post-emergence of cowpea crop were evaluated. Table 5 presents the data for RCC and phytotoxicity at 7, 14 and 21 days after application of the post-emergent herbicides. No significant difference was found among treatments for RCC in the first evaluation (7 DAE), but in the remaining evaluations (14 and 21 DAA) significant effect of treatments on both variables were observed.

For visual evaluations of phytotoxicity, it was observed that only in the first evaluation, there was no significant effect for treatments (Table 5). Hence, these products influenced significantly ($p < 0.01$) this variable, according to evaluations carried out at 14, 21 and 28 DAA.

Statistical difference among treatments for RCC values at the first evaluation (7 DAA) was not noticed, but higher values of this variable were obtained for the treatment with Quizalofop-p-ethyl (80 g a.i. ha^{-1}) throughout other evaluations (Table 6). On the other hand, the treatment

Table 6. Relative chlorophyll content and phytotoxicity in cowpea seedlings verified at intervals of seven days after application (DAA) of post-emergent herbicides.

Herbicide	7 DAA	14 DAA	21 DAA	28 DAA
	Relative chlorophyll content			
Fluazifop-p-butyl (187.5 g a.i. ha^{-1})	21.18^{a}	26.78^{ab}	25.00^{ab}	NE
Quizalofop-p-ethyl (80 g a.i. ha^{-1})	21.79^{a}	29.79^{a}	27.88^{a}	NE
Fenoxaprop-p-ethyl (44 g a.i. ha^{-1})	21.18^{a}	17.38^{bc}	16.04^{bcd}	NE
Sethoxydim (276 g a.i. ha^{-1})	20.40^{a}	17.23^{bc}	15.35^{cd}	NE
Clorimuron-ethyl (17 g a.i. ha^{-1})	21.59^{a}	24.76^{ab}	23.10^{abc}	NE
Clethodim (96 g a.i. ha^{-1})	12.23^{a}	14.53^{c}	13.09^{d}	NE
Haloxifop-p-methyl (43.75 g a.i. ha^{-1})	21.23^{a}	21.24^{abc}	20.34^{abcd}	NE
Bentazon (720 g a.i. ha^{-1})	23.30^{a}	26.88^{ab}	25.60^{a}	NE
	Phytotoxicity (%)			
Fluazifop-p-butyl (187.5 g a.i. ha^{-1})	18.8 $(4.38)^{a}$	19.4 $(4.41)^{b}$	42.5 $(6.50)^{a}$	57.5 $(7.60)^{a}$
Quizalofop-p-ethyl (80 g a.i. ha^{-1})	17.9 $(4.27)^{a}$	15.8 $(4.00)^{b}$	22.9 $(4.83)^{bc}$	32.5 $(5.72)^{bc}$
Fenoxaprop-p-ethyl (44 g a.i. ha^{-1})	15.4 $(3.99)^{a}$	18.3 $(4.30)^{b}$	20.8 $(4.61)^{bc}$	5.84 $(33.8)^{bc}$
Sethoxydim (276 g a.i. ha^{-1})	24.2 $(4.92)^{a}$	24.2 $(4.94)^{ab}$	23.8 $(4.91)^{bc}$	36.3 $(6.04)^{bc}$
Clorimuron-ethyl (17 g a.i. ha^{-1})	17.3 $(4.18)^{a}$	25.0 $(5.03)^{ab}$	30.4 $(5.54)^{ab}$	47.5 $(6.88)^{ab}$
Clethodim (96 g a.i. ha^{-1})	22.1 $(4.69)^{a}$	39.2 $(6.24)^{a}$	30.8 $(5.58)^{ab}$	27.5 $(5.26)^{cd}$
Haloxifop-p-methyl (43.75 g a.i. ha^{-1})	16.3 $(4.05)^{a}$	24.6 $(4.96)^{ab}$	23.8 $(4.88)^{bc}$	4.22 $(17.50)^{d}$
Bentazon (720 g a.i. ha^{-1})	19.2 $(4.35)^{a}$	19.2 $(4.35)^{b}$	17.1 $(4.18)^{c}$	31.3 $(5.6)^{bcd}$

Mean values followed by the same letter in a column do not differ by Tukey's test at 5% probability. NE: Not evaluated. Original data in parentheses; transformed data (Root x + 0.5).

with Clethodim (96 g a.i. ha^{-1}) resulted in statistically lower values than the other treatments at those evaluation periods.

It was found that as visual analysis of phytotoxicity symptoms continued, different behaviours were observed when the mean values were tested at 5% probability, as can be seen in Table 6. In the first evaluation, 7 days after herbicide application, there was no difference found among treatments. However, in the evaluation at 14 DAA, it was found that the herbicide Clethodim did the most damage to the crop, followed by the herbicides Chlorimuron-ethyl (17 g a.i. ha^{-1}), Sethoxydim (276 g a.i. ha^{-1}) and Haloxifope-p-methyl (43.75 g a.i. ha^{-1}), where there was no difference. When carrying out the evaluation at 21 DAA, it was found that Fluazifop-p-butyl (187.5 g a.i. ha^{-1}) resulted in the greatest phytotoxicity among the herbicides used. Similar behaviour occurred when the visual evaluation was carried out at 28 DAA, where the herbicides that displayed the most phytotoxicity were Fluazifop-p-butyl (187.5 g a.i. ha^{-1}) and Chlorimuron-ethyl (17 g a.i. ha^{-1}), whereas the herbicides that produced the least phytotoxicity were Haloxyfop-p-methyl (43.75 g a.i. ha^{-1}) and Clethodim (96 g a.i. ha^{-1}).

DISCUSSION

In the present study, Diuron, S-metolachlor, Metribuzin, Diquat dibromide and Sulfentrazone showed promising results as pre-emergent herbicides for cowpea crop. Some studies has been done to evaluate the use of herbicides in the cowpea, where the following herbicides were noteworthy for selectivity: Imazamox + Bentazon (Linhares et al., 2014; Mesquita, 2011); Imazamox (Silva et al., 2003; Mesquita, 2011); Bentazon, Fluazifop-p-butyl, Imazethapyr, Trifluralin, S-metolachlor (Mesquita, 2011) and Fenoxaprop-p-ethyl (Silva et al., 2003). Severe intoxication with a reduction in productivity was found in the cowpea with applying the herbicides Fomesafen (Linhares et al., 2014) and Lactofen, while the mixtures of Metribuzin and Chlorimuron-ethyl + Fluazifop-p-butyl caused death of the crop (Mesquita, 2011).

The cause of the reduction in the RCC seen with some of the herbicides studied may be related to the active ingredient of the molecules, since most of the substances act by inhibiting the synthesis of photosynthetic pigments. Thus, the applied herbicides cause injury to the leaves, reducing the reflectance of the green colouration, which directly or indirectly represents the presence of chlorophyll (Arantes et al., 2013).

Symptoms of phytotoxicity in plants of the cowpea, as well as a great variability in the tolerance of the cowpea genotypes to different herbicides, are commonly seen after herbicide application (Silva et al., 2003; Ishaya et al., 2008; Souza et al., 2016). A number of factors could be related to this, such as soil type, precipitation, irrigation management, temperature and the cultivar used (Kunkel et al., 1996; Silva et al., 2003). In this way, Silva et al. (2003) confirmed the selectivity of Fenoxaprop-p-ethyl to cowpea, which exclusively controls grasses, and Imazamox, which has an effect on dicotyledonous plants; nevertheless, these authors did not find the latter herbicide to be effective on *Chamaesyce hirta* or *Euphorbia heterophylla*.

In a study evaluating the selectivity of herbicides applied post-emergence, Freitas et al. (2009) found that the herbicide Bentazon and the mixture Imazamox + Bentazon did not cause intoxication in the cowpea, whereas Fomesafen, both alone and in a mixture with Bentazon, caused severe and moderate injury to the crop, respectively. Souza et al. (2016) also observed that a mixture of the herbicides glyphosate + imazethapyr + flumioxazin caused phytotoxicity in the cowpea crop, placing limitations on the production components. Evaluating the herbicides Fomesafen and Lactofen, both protoporphyrinogen oxidase (Protox) inhibitors, Correa and Alves (2009), found symptoms of severe intoxication in the cowpea, with later recovery of the plants at 14 DAA, and moderate symptoms of intoxication at 30 DAA. These results corroborate with the results observed here with respect to these herbicides.

In the first experiment, it was observed that 14 days after application of Flumioxazin, there were massive elimination of plants from this treatment. Silva et al. (2014), also working in a greenhouse experiment evaluating the selectivity of pre- and post-emergent herbicides, found that application of the herbicide Metribuzin resulted in death of the cowpea plants. Lactofen and Fomesafen, applied alone or mixed with other herbicides, also caused injury to the cowpea plants, which resulted in reduced production.

The use of Fluazifop-p-butyl (187.5 g a.i. ha^{-1}) as a pre-emergent herbicide resulted in higher RCC and lower phytotoxicity percentages. Similarly, Silva et al. (2014) verified that Fluazifop-p-butyl caused mild intoxication in this crop, without affecting grain production. Furthermore, Silva et al. (2003) did not note any visual symptoms characteristic of toxicity in the cowpea plants when evaluating the selectivity of the herbicides Imazamox and Fenoxaprop-p-ethyl. Apparently, those herbicides can be used for chemical management of weeds in cowpea without major issues regarding crop phytotoxicity.

S-metolachlor (1.2 kg a.i. ha^{-1}) applied as a pre-emergent herbicide in cowpea showed good results in this work. Minimal damages caused by this product through the visual evaluations were observed. Divergent results were found by Deuber and Novo (2006), reporting inhibition of root development by the action of Trifluralin that has the same mechanism of action as the herbicide S-metolachlor, both inhibitors of tubulin polymerisation in main root growth and in secondary root emission.

According to our results, the use of Fomesafen is not totally safe for weed control in areas with this crop, once this product caused moderate phytotoxity in seedlings. These results agree with those of Linhares et al. (2014), who found that Fomesafen caused severe intoxication in the crop, delaying its cycle, and leading to a delay of 7 days in flowering and harvesting. In addition, Fontes et al. (2013) observed intoxication of cowpea plants when applying Fomesafen alone or together with Fluazifop-p-butyl post-emergence.

Other literature works also corroborate with our results regarding phytoxical effects of Lactofen on cowpea seedlings. Silva et al. (2014), also working in a greenhouse experiment evaluating the selectivity of pre- and post-emergent herbicides, verified that the herbicides. Lactofen and Fomesafen, both alone and when mixed together, caused severe intoxication in the plants. According to these authors, Fomesafen delayed flowering and harvesting by 13 days in relation to the control with no application, although the cowpea plants did recover from the injuries caused by the herbicide. Nevertheless, according to Mancosi et al. (2016), Fomesafen during early establishment of the crop gives greater weed control and, despite noting phytotoxicity at the end of the trial, the treatment resulted in similar productivity to the control treatment with weed control.

Treatment with applying Bentazon (720 g a.i. ha^{-1}) showed an increase in phytotoxicity levels throughout the time. Harrison Jr. and Fery (1993), in an experiment to evaluate the tolerance of cowpea germplasm to the herbicide Bentazon, found both susceptible and highly tolerant genotypes, demonstrating the need for studies on the selectivity of herbicides for different varieties. Mancuso et al. (2016), studying selectivity and weed control, concluded that the herbicide Bentazon resulted in the lowest levels of intoxication in the cowpea. They also stated that mixture of the herbicides Bentazon + Imazamox did not affect characteristics related to the growth of the plants nor the production components.

Although, the relatively low RCC and moderate phytotoxicity in seedlings in which was applied Clethodim and Haloxyfop-p-methyl were verified, these ones recover well throughout the time. Thereafter, those treatments presented increased RCC values, as well as decreased phytotoxycity percentages by the end of the experiment. Thus, these herbicides should be noted as potential post-emergent herbicides for cowpea crop.

According to Linhares et al. (2014), environmental conditions of high temperatures and high rainfall can favour vegetative growth in the crop and result in a high leaf area index, leading to self-shading and consequently reducing the photosynthetic efficiency of the plant, which may reflect negatively on productivity. This fact may have favoured plants treated with Clethodim and Haloxyfop-p-methyl in the second research, which, with the moderate intoxication, acted as a growth regulator, reducing the rate of vegetative growth and increasing the RCC. However, under suitable environmental conditions for the crop, the intoxication caused by this herbicide is not expected to be beneficial.

Despite being a preliminary study in the evaluation of selectivity to herbicides, their potential for use in the cowpea was noted. However, in the present work a need was found to take these studies further, especially under field conditions, using different types of soils and different doses of herbicides, since selectivity can be achieved through various types of crop managements. Nonetheless, some herbicides were preliminarily identified for use with the crop in question.

Conclusion

There were promising results regarding the selectivity of the cowpea in relation to the herbicides applied in both pre-emergence and post-emergence. It is also possible to highlight the pre-emergent herbicides Diuron (1.6 kg a.i. ha^{-1}), S-metolachlor (1.2 kg a.i. ha^{-1}), Metribuzin (422.4 g a.i. ha^{-1}), Diquat dibromide (600 g a.i. ha^{-1}) and Sulfentrazone (600 g a.i. ha^{-1}). A potential use of the herbicides applied post-emergence to this crop was noted for Clethodim (96 g a.i. ha^{-1}) and Haloxyfop-p-methyl (43.75 g a.i. ha^{-1}).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Determinants of Adoption of Improved Technologies in Rice Production in Imo State, Nigeria

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In Imo State, an increasing number of improved rice production technologies and management techniques have been introduced to rice farmers across the State. Despite the introduction of the rice production technologies, rice production continues to be low. This study therefore analyzed factors associated with adoption of improved rice production technologies in Imo State of Nigeria. Random sampling technique was used in selecting one hundred and thirty (135) rice farmers from the communities where rice is produced in the State. Data were collected with the aid of a structured questionnaire, and analyzed using descriptive statistics and logit regression. The result obtained shows that 73.33, 67.41, 78.52, 86.67 and 45.4% of the rice farmers adopted improved rice varieties, use of agrochemicals, fertilizer application, optimum seed rate, and mechanical harvesting, respectively. Farmers' socioeconomic factors such as age, income, cooperative membership, household size, level of education, farm size and number of contacts with extension agents affected adoption. These key factors need to be taken into consideration when expanded program on technology adoption is to be considered.

Key words: Adoption, rice production technologies, farmers, socioeconomic determinants, Imo State, Nigeria.

INTRODUCTION

Rice is an important staple food in Nigeria. Very significant proportions of the Nigerian population depend on rice for their food needs. Rice is grown in all the States of the federation and Federal Capital Territory though production varies from State to State and the prevalent types of rice production systems in Nigeria include rainfed upland, rainfed lowland, irrigated lowland, deep water floating and mangrove swamp (FMARD, 2011). Table 1 shows major features of Nigerian rice production systems. Imo State rice production system is that of upland rainfed.

Domestic production of rice is below the demand in Nigeria and rising per capita is now complemented with huge import. Estimated national demand for rice is put at 5.2 million ton per annum, production is estimated at 3.3 million tons leaving a demand gap of 1.9 million tons

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Table 1. Major features of Nigerian rice production systems.

Production system	Major states covered	Estimated share of National rice area (%)	Average yield (Ton/ha) (%)	Share of rice production (%)
Rainfed Upland	Ogun, Ondo, Abia, Imo, Osun, Ekiti, Oyo, Edo, Delta, Niger, Kwara, Kogi, Sokoto, Kebbi, Kaduna, FCT and Benue States	30	1.9	28
Rainfed Lowland	Adamawa, Ondo, Ebonyi, Ekiti, Delta, Edo, Rivers, Bayelsa, Cross River, Akwa Ibon, Lagos, all Major river valleys, e.g shallow swamps, of Niger basin, Kaduna basin, and inland of Abakaliki and Ogoja areas	52	2.2	43
Irrigated	Adamawa, Niger, Sokoto, Kebbi, Borno, Benue, Kogi, Adamawa, Enugu, Ebonyi and Cross River, Kano, Lagos, Kwara, Akwa Ibom, Ogun State	16	3.7	29
Mangrove swamp	Ondo, Delta, Edo, Rivers, Bayelsa, Cross River, Akwa Ibom, Lagos	1%	2.0	1

Source: FMARD, 2011.

which is imported with the attendant drain on foreign reserve (FMARD, 2011) making Nigeria the largest importer in West Africa (USAID, 2010).

Disseminating improved varieties and other modern inputs to rice farmers is very important to reduce the rate of rice importation in Nigeria (Saka and Lawal, 2009). Adoption of improved rice production technologies should lead to significant yield increase in rice production. Nigeria produces only about 2.8 million metric tons with a deficit of 1.6 million metric tons excluding the large quantity smuggled through the porous borders (USAID, 2010). In a bid to address these problems, research institutes (IITA and NCRI) introduced varieties accompanied by other management practices that will produce higher yield in order to boost food security. Despite all these efforts, research findings still indicate that rural farmers in most cases find it difficult to obtain improved rice production inputs that are suitable to their local conditions (Awotide et al., 2012a; Awotide et al., 2012b; BATNF, 2015). Reasonable proportions of the farmers are aware of the existence of improved rice production technologies, but they have not adopted them. Therefore, certain socioeconomic conditions differentiate farmers who are aware but have not been adopted and those who are aware and have been adopted. Most peasants are uneducated and ageing, the introduction of sustainable credit into agriculture will attract the youth and the educated, but in Imo State, the population of the youths in the rural area has been greatly vitiated by rural-urban migration, as most youth want to obtain white collar jobs and are not interested in farming (Nwajiuba, 2012; Saliu et al., 2016). Lawal and Shittu (2006) posited that lack of access to credit causes setbacks to the productivity of farmers as a result of the fact that, these farmers do not have resources to procure improved seedlings, chemicals and hired labour, as well as transport and market their produce which would have improved their productivity.

Imo State is endowed with vast arable land and human resources for rice production. However, it seems that rice farmers in Imo State have not been able to explore all these favourable variables to farmers to adopt and achieve desirable increase in yield. This could be due to some problems such as the inability of the farmers to adopt improved seed varieties, credits, use of agrochemicals and other technologies, poor socioeconomic background of the farmers as asserted by Byron et al. (2005). In order to improve on the production of rice in Imo State, one may want to know the following:

i. What are the socio-economic characteristics of rice farmers in the area?
ii. What is the level of adoption of improved rice technologies by farmers in the area?
iii. What are the factors affecting adoption of improved rice technologies in the area?

LITERATURE REVIEW

It is believed that the adoption of new agricultural technology, such as the high yielding varieties that kick-started the green revolution in Asia, could lead to significant increases in agricultural productivity in Africa and stimulate the transition from low productivity subsistence agriculture to a high productivity agro-industrial economy (World Bank, 2008). In this regard, Mendola (2007) observes that the adoption of high yielding varieties has had a positive effect on household well-being. In addition, empirical studies show that gains from new agricultural technology influenced the poor directly, by raising incomes of farm households and, indirectly, by raising the employment and wage rates of functionally landless laborers, and by lowering the price of food staples (de Janvry and Sadoulet, 2002; Irz et al., 2002; Bellon et al., 2006; Evenson and Gollin, 2003; Diagne et al., 2009).

Research findings carried out by some scholars and Institutes on technology adoption in developing countries on factors that influenced technology adoption can be grouped into the following three broad categories (Feder et al., 1985): (1) factors related to the characteristics of producers; (2) factors related to the characteristics and relative performance of the technology and (3) institutional factors. Nasiru (2014) stated that the factors related to the characteristics of producers include educational level, experience in the activity, age, gender, level of wealth, farm size, labour availability, risk aversion, etc. He asserted that the factors related to the characteristics and performance of the technology include food and economic functions of the product, the perception of individuals of the characteristics, complexity and performance of the innovation, its availability and that of complementary inputs, the relative profitability of its adoption compared to substitute technologies, the period of recovery of investment, the susceptibility of the technology to environmental hazards etc. He further opined that the institutional factors include availability of credit, the availability and quality of information on the technologies, accessibility of markets for products and inputs factors, the land tenure system, and the availability of adequate infrastructure etc. Also, Matata et al. (2001) listed factors like personal, institution, environmental and socio- economic factors as influencing technology adoption. Adesina and Baidu-Forson (1995) found that age was negatively related to probability of participating in rice development projects, though Asante et al. (2011) recorded a positive relationship.

Saliu et al. (2016) examined the socio-economic determinants of the adoption of improved rice technologies by small scale farmers in Kogi State, Nigeria using multistage random sampling to select 120 registered rice farmers with the Kogi State Agricultural Development Project (ADP). Frequencies, percentages, mean, mode, mean scores and ordered probit regression were used to analyze the data. Their findings revealed that all the farmers adopted the use of agrochemicals and they categorized the farmers into low, medium and high adopters. However, the marginal effects of the ordered probit revealed that farm size, household size and contact with extension agents favoured the adoption of all the eight most important rice technologies which could be used as a measure towards pleasant disposition to commercial rice farming.

Oladele and Kolawole (2013) examined the ex-ante adoption of Sawah rice production technology in Kwara State Nigeria using random sampling techniques in the selection of respondents and logit regression in their analysis. They found the significant determinants of adoption of Sawah rice production technology in Kwara State to be practicability of the technology, labour requirement, extension support/training, age, education, farming experience, and gender. Other factors are knowledge of rice cultivation, returns to investment, access to credit and loans, use of family labour, availability of seeds/planting materials, cultivate rice on lowland, existing farmers groups, information on rice from input dealers, information on rice from extension officers, information on rice mobile phones and distance to market.

Arimi and Olajide (2016) investigated the differences between male and female adopters of improved rice production technology in Ogun and Ekiti States using t-test and the factor analyses. The result indicated that there was significant difference between male and female farmers' adoption of improved rice production technology in the study areas. Institutional, motivational, innovational, attitudinal, environmental and different socio-economic variables are the key factors influencing male and female farmers' decisions on technology adoption. They concluded that these key factors need to be taken into consideration when expanded program on technology adoption is to be considered.

Oladele and Wakatsuki (2012) analyzed whether and how a farmer's decision to adopt a new technology depends upon the adoption decision of other farmers in their social group. The specific application of the socio-economic and dynamics of farmers association to adoption was explained through a cross sectional data collected from adopters and non- adopter of Sawah rice technology in Ghana and Nigeria. The findings indicate that the use of various technologies depends on socioeconomic variables and the existence of different dimensions of social dynamics. Overall the evidence from their study suggests that network effects are important for individual decisions, and that, in the particular context of agricultural innovations, farmers share information and learn from each other. Individual adoption decisions depend upon the choices of others in the same social networks. Since farmers anticipate that they will share information with others, farmers are expected to be more likely to adopt when they know many other adopters.

Dontsop-Nguezet et al. (2012) used the local average treatment effect (LATE) to estimate the impact of adoption of improved rice varieties on rice farmers' productivity in the three major rice ecologies of Nigeria. Findings of the study indicate that adoption of improved varieties helped raise farmers' area harvested and yield per hectare, respectively, by 0.39 ha and 217.9 kg/ha for NERICA and 0.51 ha and 210.4 kg/ha for other improved varieties, thereby increasing their productivity.

In addition, NERICA varieties performed better than any other upland improved variety and the impact of its adoption on both area harvested and yield was greater among female rice farmers than among their male counterparts.

Alarima et al. (2011) examined factors affecting the adoption of sawah technology in Nigeria using regression analysis and descriptive statistics. Their descriptive results stipulates that the farmers were predominantly male, married and had Quranic education, with mean age of 42.30 years with mean household size of 14, farm sizes ranged from 0.03 to10 ha (mean 0.5 ha), the mean yield was 4.65 tons per hectare. Factors identified affecting farmers' adoption of sawah technology were attitude of farmers, attributes of sawah technology, access to contact farmers and household size influenced the adoption of sawah technology.

Umeh and Chukwu (2015) investigated the determinants of adoption of improved rice production technologies in Ebonyi State of Nigeria using multi-stage random and systematic sampling techniques to select a total of 240 (two hundred and forty) rice farmers from the three agricultural zones of the state. Primary data were collected with the aid of a well-structured questionnaire and interview schedule; and analyzed using both descriptive and regression analysis. Their regression result shows that variables that determine the adoption of rice technologies include gender, age, marital status, and household size.

Onumadu and Osahon (2014) investigated the socio-economic determinants of adoption of improved rice technologies by farmers in Ayamelum Local Government Area by Anambra State, Nigeria using multiple regression analysis. Their result indicates that age, gender, education, farm size, farming experience and membership of farmers' association are significant in the adoption of improved rice farming technologies.

CARD (2012) identified traditional rice-cropping problems which include the use of low quality, mixed varieties seed leading to degradation over time in quality, high cost of fertilizer and difficulty in procuring fertilizer in the appropriate amount at the appropriate time, low level of knowledge and training, lack of irrigation facilities, lack of storage facilities, poor pests and disease management, ineffective farm implements, lack of access to institutional and infrastructural support and low farm mechanization. However, according to IRRI (2015), rice production can generally be divided into seed selection, land preparation, timely planting, crop establishment, water management, nutrient management, crop health, harvesting and post harvesting operations.

METHODS USED

The study was conducted in Imo State, Nigeria. Imo State is located in southeast Nigeria. It has an estimated population of 3,934,899 people (National Population Commission, 2006). The State is made up of twenty seven Local Government Areas. Imo State lies between latitude 5°12' and 5°56' North of the Equator and between longitudes 6°38' and 7°25' east of the Greenwich Meridian. It isbordered by Abia State on the east, by the River Niger on the west, by Anambra State on the north and River State on the south. The State is located in the rainforest zone with two major seasons-the rainy and dry seasons. The area is predominately rural with agriculture (farming) as the major means of livelihood. The crops grown include rice, yam, cassava, cocoyam, maize, melon, and vegetables.

Rice is grown in three Local Government Areas and fourteen communities in Imo State, and it is widely consumed by millions of people in the State. Ideato North, Ihitte Uboma, and Oguta Local Government Areas (LGAs) are the LGAs where rice is grown in Imo State. Two-stage random sampling technique was adopted in the selection of respondents for this study. First, three communities were randomly selected from each of the LGAs where rice is cultivated in the State. Second, fifteen (15) rice farmers were randomly selected from the communities, making a total of one hundred and thirty five (135) respondents for the study. Structured questionnaire was administered to 135 selected rice farmers. Data collected were analysed using descriptive statistics and logit regression.

Logit regression models make it possible to estimate the probability of adopting an improved rice production technology, conditional on the independent variables included in the model. This takes the form:

$$Q_i = \beta_0 + \beta_i X_i \tag{1}$$

$$Li = (P_i / [1 - P_i]) = \beta_0 + \beta_i X_i \tag{2}$$

Where: P_i = is the probability that the event occurs to an individual with a given set of characteristics, X_i; β_0 = is the intercept or constant; β_i = is the vector of coefficients of the vector of covariates or coefficients, X_i; L_i = logit; $\frac{P_i}{1 - P_i}$ = odds ratio of probability of occurrence of events; X_i = Explanatory variables; Q_i = Adoption of rice technology; 1= adopt, otherwise = 0. i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10; 1 = Improved rice varieties; 2 = Improved line spacing; 3 = Planting depth; 4 = Use of agrochemicals; 5 = Fertilizer application; 6 = Mechanized harvesting; 7 = Improved nursery; 8 = Timely transplanting; 9 = Optimum seed rate; 10 = Modern rice milling; The explanatory variables are; X_1 = Age of the farmer (years); X_2 = Farm income (Naira); X_3 = Household size (Number); X_4 = Level of education (years); X_5 = Farm size (hectares); X_6 = Farming experience (years); X_7 = Membership of cooperative (1 = member; otherwise = 0); X_8 = Number of contact with extension agents (Number);
e = error term.

The parameter estimates of the binary logit model provide only the direction of the effect of the independent variables on the dependent variable, but estimates do not represent either the actual magnitude of change nor probabilities. Differentiating Equation (2) with respect to the exogenous variables provides marginal effects of the explanatory variables. The marginal effects or marginal probabilities are functions of the probability itself and measure the expected change in probability of choice (adopted or not adopted) being made with respect to a unit change in an independent variable from the mean (Greene, 2000; Deressa et al., 2008).

RESULTS AND DISCUSSION

Socioeconomic characteristics of rice farmers

Table 2 shows the socioeconomic characteristics of rice farmers interviewed. The table shows that majority (60.74%) of the rice farmers within the age bracket of 41

Table 2. Socioeconomic characteristics of the rice farmers.

Socioeconomic characteristic	Frequency	Percentage	Average
Gender			
Male	90	66.67	
Female	45	33.33	
Age (year)			
31 - 40	6	4.44	46 years
41 - 50	82	60.74	
51 - 60	37	27.41	
61 - 70	10	7.41	
Marital status			
Married	103	76.30	
Single	22	16.30	
Widowed	8	5.93	
Separated	2	1.48	
Household size (number of persons)			
1 - 6	33	9.17	
7 - 12	114	31.67	10 persons
13 - 18	191	53.06	
Educational level			
No formal education	6	4.44	
Primary	31	22.96	
Secondary	94	69.63	
Tertiary	4	2.96	
Farm size (ha)			
Less than 1	14	10.37	1.8 hectares
1 - 2	95	70.37	
2.01 - 3	20	14.82	
3.01 - 4	6	4.44	
Rice farming experience (years)			
Less than 10	6	4.44	
10 - 20	108	80.00	18 years
21 - 30	21	15.56	
Membership to cooperative			
Member	100	74.07	
Non-member	35	25.93	

to 50 years. It was then found that the mean age of farmers was 46 years. This is an indication that rice production in the area is dominated by farmers in the active age. The implication is that farmers in this age category may be more likely to handle risks involved in adopting improved technologies in rice agricultural production. This age category was in line with those Bekele (2005) referred to as economically active groups.

The table indicates that majority (66.67%) of the farmers were males. This is consistent with the findings of Dontsop-Nguezet et al. (2011) and Chekene and Chancellor (2015) who found that the majority of rice farmers in Nigeria were males. Majority (76.30%) of the farmers were married, as also observed by Kolawole et al. (2012) in their study. Married farmers are more "advantaged" in agricultural production and improved agricultural technology adoption because spouses and children of married farmers constitute the major labour force in rice production.

It was further found that the average household size of the farmers was 10 persons. This implies that rice farmers in the area have considerable family labour. This is consistent with the findings of Dontsop Nguezet et al. (2011) who found the average household size of rice

Table 3. Distribution of rice farmers according to adoption of rice production technologies.

Improved technologies	Frequency	Percentage
Improved rice varieties	99	73.33
Improved line spacing	36	26.67
Planting depth	19	14.07
Use of agrochemicals	91	67.41
Fertilizer application	106	78.52
Mechanized harvesting	20	14.81
Improved nursery	11	8.15
Timely transplanting	18	13.33
Optimum seed rate	103	86.6
Modern rice milling	49	45.4

farmers in the three major rice ecologies of Nigeria to be 10 persons. Family labour is important in rice production as it reduces the amount spent on hired labour, as opined by Garba et al. (2011).

Table 2 shows that majority (69.63%) of the rice farmers had secondary education. This implies that most rice farmers in the area completed their secondary education. Thus, the bulk of the farmers is somewhat educated and can presumably interact to generate new ideas to changing conditions in rice production. This supports the findings of Amaza and Tashikalma (2003), Kolawole et al. (2012) and Agbamu (2005) who stated that the literacy level of farmers enhances the rate of adoption of improved technology.

The average farm size of the farmers was 1.8 ha. This implies that the study area comprises mostly small-scale farmers. This agrees with Olayide (1992) that Nigerian farmers are small-scale farmers that cultivated small areas of land.

It was further found that the average rice farming experience in the area was 18 years. This implies that many of the farmers are quite “old” in rice production. Experience, they say, is the best teacher. Long farming experience is an advantage for increased rice production since it may encourage rapid adoption of improved rice technology (Obinne, 1991).

Furthermore majority (74.07%) of the rice farmers were members of cooperative societies. As posited by Rahji and Fakayode (2009), membership of association is expected to assist farmers to get easy access to credit and other production inputs.

Adoption of rice production technologies

Adoption of improved rice production technologies is presented in Table 3. The table shows that 73, 78 and 86% of the farmers adopted improved rice varieties, fertilizer application, and optimum seed rate in planting respectively. About 67% adopted agrochemicals in rice production in the area.

Factors affecting adoption of rice production technologies

The factors influencing the adoption of rice production technologies were examined using binary logistic regression models. For each rice production technology, the farmers were classified into adopters and non-adopters of such a technology. Ten binary logit regressions were carried out representing the determinants of each of the identified rice production technologies. The likelihood ratio estimates of the logit models indicated that all the Chi-square statistics were highly significant ($p < 0.001$) suggesting that the models were adequate for explaining the determinants of improved technologies in rice production. This conforms to the result of Omonona et al. (2006). The stated decision to adopt a rice production technology by the farmers was significantly associated with some of the included socioeconomic factors. The marginal effects of the logit regression results are presented in Table 4 and discussed thus:

Age of the farmers was negative across use of agrochemicals, mechanized harvesting, optimum seed rate, and modern rice milling, indicating adoption of these technologies decreased with age. This explains the negative relationship between adoption of these innovations and age. The result shows that a unit increase in the age of the farmers decreased the likelihood of using agrochemicals by 0.011 (1.1%), mechanized harvesting by 0.004 (0.4%), optimum seed rate by 0.011 (1.1%) and modern rice milling by 0.0098 (0.98%). This agrees with Adesina and Baidu-Forson (1995), that age was negatively related with probability of participation in Rice Development Projects. Contrarily age of the farmers significantly increased the uptake of improved nursery and timely transplanting. This relationship could be due to the fact that; the options here have been practised for a long period of time and are well known by older farmers than their younger counterparts. This is in line with Asante et al. (2011) and Gbetibouo

Table 4. Marginal effects of the factors affecting stated adoption of rice production technologies in Imo State.

Variable	Improved rice varieties	Improved line spacing	Planting depth	Use of agrochemicals	Fertilizer	Mechanized harvesting	Improved nursery	Timely transplanting	Optimum seed rate	Modern rice milling
Age	0.0009951(0.31)	-0.0018(-0.68)	-0.015(-1.55)	-0.011(-2.84)***	0.001(0.55)	-0.004(-2.29)**	0.110(2.17)**	0.004(2.13)**	-0.011(-3.27)***	-0.0098(-2.44)**
Income	4.14e-06(3.18)***	-4.94e-07(-0.43)	0.017(2.55)**	2.52e-06(1.69)*	3.41e-6(3.200)***	0.00003(1.94)*	0.00005(1.72)*	-5.57e-07(-1.08)	-2.25e-07(-0.25)	0.00005(4.71)**
Household size	0.0245852(2.06)**	0.023(2.27)**	0.029(2.48)**	-0.020(-1.34)	0.021(2.180)**	-0.003(-0.47)	-0.226(-1.09)	0.0001(0.03)	0.028(2.48)**	-0.003(-0.22)
Education	0.018(1.72)*	-0.010(-1.30)	4.02e-08(0.08)	0.053(3.94)***	0.018(2.090)**	0.0097(1.75)*	0.559(2.61)***	0.0096(2.02)**	0.026(2.97)***	-0.002(-0.19)
Farm size	0.106(2.17)**	0.070(1.99)**	-0.017(-3.95)***	0.121(2.23)**	0.088(2.130)**	0.050(1.89)*	-0.319(-0.45)	-0.005(-0.38)	0.082(2.33)**	0.106(1.92)*
Experience	0.007(0.47)	-0.0007(-0.06)	0.058(2.15)**	-0.013(-0.83)	-0.006(-0.50)	-0.008(-0.93)	0.991(2.19)**	0.014(1.92)*	-0.006(-0.77)	0.008(0.45)
Cooperative membership	-0.068(-0.93)	-0.0004(-0.01)	0.018(3.23)***	-0.026(-0.28)	0.104(1.78)*	0.020(0.56)	0.002(0.01)	0.004(0.16)	-0.051(-0.98)	-0.067(-0.71)
Extension	0.024(1.99)**	0.014(2.03)**	0.0101103(1.93)*	0.022(1.82)*	0.017(1.72)*	0.011(2.25)**	0.250(2.31)**	0.010(1.91)*	0.015(2.17)**	-.0061(-0.62)
Pseudo R^2	0.1575	0.1647	0.4118	0.2767	0.1776	0.3043	0.5692	0.4452	0.4858	0.2611
Likelihood Chi square	24.66***	20.81***	77.92***	46.74***	24.95***	34.47***	43.40***	47.20***	71.84***	46.19***

Values in parenthesis are z-values; ***Significant at 1% level; **Significant at 5% level; *Significant at 10% level; Field Survey (2015).

(2009) who found positive relationship between age and adoption of improved technologies. The result shows that a unit increase in the age of the farmers increased the likelihood of using improved nursery by 0.110 and timely transplanting by approximately 0.004 (0.4%).

The income of farmers surveyed had a positive and significant effect on the likelihood of adopting improved rice varieties, planting depth, use of agrochemicals, use of fertilizer, mechanized harvesting, improved nursery, and modern rice milling. Perhaps, the result is connected to the higher-income farmers are possibly less risk averse and have more access to information, a lower discount rate, a longer-term planning horizon and wealthier than less-income farmers (Franzel et al., 1999; CIMMYT, 1993). The result shows that a unit increase in the income of the farmers increased the likelihood of adopting improved rice varieties by 0.00000414 (0.000414%), planting depth by 0.017 (1.7%), agrochemicals by 0.00000252 (0.000252%), fertilizer by 0.00000341 (0.000341%), mechanical harvesting by 0.00003 (0.003%), improved nursery by 0.00005 (0.005%), and modern rice milling by 0.00005 (0.0005%). Krause et al. (1990), Immink and Alarcon (1993) and Iheke (2006) noted that lack of funds and access to credit prohibits smallholder farmers from assuming risks of financial leverage associated with the adoption of new technology.

Household size of farmers significantly increased the likelihood of adopting improved rice varieties, improved line spacing, planting depth, use of fertilizer, and optimum seed rate. This indicates that household size increases the probability of uptake of these technologies, perhaps because technologies in rice production require additional labour from the farmer, which is usually provided by his/her household members. The result shows that a unit increase in the household size of the farmers increased the likelihood of using improved varieties by 0.0245852 (2.46%), improved line spacing by 0.023 (2.3%), planting depth by 0.029 (2.9%), fertilizer by 0.021 (2.1%), and optimum seed rate by 0.028 (2.8%).

Education of the farmers was positive and significant on the likelihood of adopting improved rice varieties, agrochemicals, fertilizer, mechanized harvesting, improved nursery, timely transplanting, and optimum seed rate. This indicates the positive relationship between education and adoption of such rice production technologies. The result shows that a unit increase in the number of years spent in school by the farmers increased the likelihood of adopting improved rice varieties by 0.018 (1.8%), agrochemicals by 0.053 (5.3%), fertilizer by 0.018 (1.8%), mechanized harvesting by 0.0097 (0.97%), improved nursery by 0.559 (55.9%), timely transplanting by 0.0096 (0.96%), and optimum seed rate by 0.026 (2.6%). According to

Iheke (2010), education increases the ability of the farmers to adopt agricultural innovation and hence improve their productivity and efficiency.

Farmers' land area cultivated was positively and significantly related to the likelihood of adopting improved rice varieties, improved line spacing, agrochemicals, fertilizer, mechanized harvesting, optimum seed rate, and modern rice milling. The result shows that a unit increase in hectarage cultivated by the farmers increased the likelihood of adopting improved rice varieties by 0.106 (0.5%), improved line spacing by 0.070 (7%), agrochemicals by 0121 (12.1%), fertilizer by 0.088 (8.8%), mechanized harvesting by 0.050 (5%), optimum seed rate by 0.082 (8.2%), and modern rice milling by 0.106 (10.6%). However, farm size significantly decreased the probability of uptake of planting depth. A unit increase in the farm size decreased the likelihood of adopting the ideal planting depth for rice cultivation by 0.017 (1.7%).

Farming experience increases the probability of uptake of planting depth; improved nursery, and timely transplanting. Highly experienced farmers are likely to have more information and knowledge on rice production management practices. The result shows that a unit increase in the number of years spent in rice farming increased the likelihood of adopting ideal planting depth by 0.058 (5.8%), improved nursery by 0.991 (99.1%), and timely transplanting by 0.014 (1.4%).

Membership to cooperative societies significantly increased the probability of uptake of planting depth and fertilizer. Generally, the more farmers are involved in farmer organizations' meetings and activities, the more they will access new information about improved technologies and the more s/he will easily develop positive attitude towards the adoption of production technologies. The result shows that farmers who are actively participating in social organizations had increased likelihood of adopting ideal planting depth by 0.018 (1.8%) and fertilizer by 0.104 (10.4%).

Contact with extension agents had a positive effect across all the improved production technologies except modern rice milling indicating that extension contact increases the likelihood of adopting improved rice production technologies. Extension services serve as important source of information on agricultural production. Farmers who have significant extension contacts have better chances to be aware of various management practices that they can use to increase production. The result shows that a unit increase in the number of visits of extension agents to the farmers increased the likelihood of adopting improved rice varieties by 0.024 (2.4%), improved line spacing by 0.014 (1.9%), planting depth by 0.010 (1%), use of agrochemicals by 0.022 (2.2%%), fertilizer by 0.017 (1.7%), mechanized harvesting by 0.011 (1.1%), improved nursery by 0.250 (25%), timely transplanting by 0.010 (1%), and optimum seed rate by 0.015 (1.5%).

Conclusion

The common improved rice technologies stated as being adopted by farmers in the area include improved rice varieties, fertilizer application, agrochemicals and optimum seed rate in planting, respectively. Socioeconomic characteristics of the farmers are significantly associated with the stated adoption of the various improved rice production technologies in the area.

In view of the fact that socioeconomic factors such as farm income, cooperative membership, household size, level of education, farm size and number of contacts with extension agents are seemingly associated with stated adoption, the study recommends that programs should be designed to improve these socioeconomic characteristics of rice farmers in the area. This will go a long way as to increasing the adoption of improved technologies in the area.

Farmers should receive more training and knowledge about improved rice technologies through steady flow of information by the extension agents. Rice processing industries should be established by private organizations to encourage commercial farming to support adoption of more improved rice technologies. The high indication of adoption of the rice technologies should be used to an advantage by private rice industries who can utilize these farmers as out growers to feed their rice industries.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Macronutrient content and accumulations in different arrangements of dwarf pigeon pea intercropped with corn

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Intercropping is a technique which consists of cultivating two or more species in the same area. In these systems, planning and management should be carried out in order to avoid interspecies competition for water, light, and nutrients. This paper aimed to evaluate macronutrient content and accumulations in corn (*Zea mays* L.) intercropped with dwarf pigeon pea (*Cajanus cajan* L.) in different plant arrangements. The experimental design adopted was one of randomized blocks, with six treatments and four repetitions. The treatments consisted of different arrangements of dwarf pigeon pea intercropped with corn: corn in monoculture, dwarf pigeon pea sown in the same rows as the corn, one row of dwarf pigeon pea sown between the rows of corn, dwarf pigeon pea sown in the same rows and in a row between the corn, and dwarf pigeon pea sown in the same rows and in two rows between the corn. The following variables were evaluated: dry matter (t ha^{-1}), macronutrient content and accumulations (g kg^{-1}), total chlorophyll in the corn leaves (FCI) and grain yield of corn, as well as dry matter production (t ha^{-1}) and macronutrient content in the aerial part of the dwarf pigeon pea (g kg^{-1}). The arrangement with dwarf pigeon pea sown in the same rows and in two rows between the corn increased N content in the corn plants, in relation to the other arrangements and the corn in monoculture. Ca content and accumulations were higher in corn in monoculture and in the arrangement with dwarf pigeon peas sown in the same rows as the corn.

Key words: *Zea mays* L., *Cajanus cajan*, interspecies competition, plant nutrition.

INTRODUCTION

In recent years, there have been great advances in corn crop management, and consequently, productivity gains in the whole country (Moreira et al., 2014). It is estimated that the crop occupies 15.9 million hectares, with 67 million tons of grain being produced (CONAB, 2016). Part of the success in the production of this cereal is due to

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the high number of commercial cultivars adapted to the different regions and cultivation systems and the possibility of intercropping with other economic and/or foraging crops (Jakelaitis et al., 2005).

Intercropping consists of the simultaneous cultivation of two or more species in one agricultural area, with coexistence space and time dimensions between the cultivated plants (Pinto et al., 2013). In intercropping, knowledge about the behavior of the species with regards to their need for water, light, and nutrients is of great importance to the system's success (Pariz et al., 2011).

The favorable characteristics of corn, such as a higher rate of dry matter accumulation in the initial stages of development, the plant's tallness, and the involvement of cobs, allow harvesting to occur without interference from intercropped plants (Busato and Busato, 2011).

The dwarf pigeon pea is one of the species intercropped with corn, since lower Fabaceae dry matter production avoids competition with the cereal and does not compromise mechanized harvesting (Cortez et al., 2009). Mixing Poaceae and Fabaceae has the following advantages: higher dry matter performance, in relation to the isolated cultivation of each species; greater stimulation of N biological fixation by fabaceae, and greater efficiency in the use of water and soil nutrients, due to the exploitation of different volumes of soil by root systems with different patterns (Collier et al., 2011).

There are various questions regarding the effects of competition between jointly cultivated crops (Richart et al., 2010). For adequate species establishment and performance, the soil needs to be in good fertility conditions; the opposite will cause competition for available nutrients, affecting the development of species (Alvarenga et al., 2011). Abilities to extract nutrients from the soil and the quantities required vary not only with the species, but also with the degree of competition (Cury et al., 2012), which can vary in accordance with the competing plant population (Silva et al., 2015).

Thus, the need arises for studies to be conducted regarding the nutritional dynamic in intercropping with the aim of finding more efficient techniques to minimize competition for nutrients (Viera et al., 2013). Competition can be minimized with the adoption of cultivation practices such as spatial arrangement and defining plant populations (Oliveira Filho et al., 2016).

In light of this, the aim of this paper was to evaluate the macronutrient content and accumulations in corn intercropped with dwarf pigeon pea in different plant arrangements.

MATERIALS AND METHODS

Site location and characterization

The study was conducted from December 2014 to July 2015, in an experimental area in the municipality of Araras – SP, at the geographical coordinates 22°17'56.9'' S and 47°22'53.80'' W, and at an altitude of 701 m. The location's soil is classified as Dystrophic Red Latosol (Oxisol), of a clayey texture, with the following chemical features in the 0.0 to 0.20 m layer: pH (in $CaCl_2$) = 5.5; P = 16.5 mg dm^{-3}; K = 4.1 $mmol_c$ dm^{-3}; Ca = 28.5 $mmol_c$ dm^{-3}; Mg = 10.0 $mmol_c$ dm^{-3}; H $^+$ Al = 22.0 $mmol_c$ dm^{-3}; soil organic matter = 23.5 g kg^{-1} and base saturation (V) = 65.5%. The region's climate is of the Cwa mesothermic type, according to the Köppen classification, characterized by hot and humid summers and dry winters. In Table 1, the climatic conditions observed during the course of the experiment are summarized.

Treatments and experimental design

The soil was prepared with a disk plough followed by a leveler. The experimental design adopted was one of randomized blocks with four repetitions. The treatments consisted of dwarf pigeon pea in different arrangements intercropped with corn: CM, corn monoculture; PR, dwarf pigeon pea in the same row as the corn (10 pigeon pea plants m^{-2}); P1B, one row of dwarf pigeon pea sown between the rows of corn (10 pigeon pea plants m^{-2}); P2B, two rows of dwarf pigeon peas sown between the rows of corn (20 pigeon pea plants m^{-2}); PR1B, dwarf pigeon pea sown in the same rows as the corn and in a row between them (20 pigeon pea plants m^{-2}); and PR2B, dwarf pigeon pea sown in the same rows as the corn and in two rows between them (30 pigeon pea plants m^{-2}).

Field establishment

The experimental plot was formed of five rows of corn, with 0.90 m spaces between them, and six seeds were sown per meter, aiming for a population of 50,000 corn plants per hectare, after thinning. The dwarf pigeon pea was sown in a density of 10 seeds per meter, in the same rows as the corn and between them, as in the treatments. The corn and dwarf pigeon pea were sown on 12/17/2014. The three central rows of corn in each plot were considered for the evaluation. The corn cultivar used was Al-Avaré.

Weed control was carried out manually in two periods, the first 20 days after the emergence of corn (DAE) (V4-V5 stage) and the second 48 days after the emergence of corn (V9-V10 stage). For fertilizing, 800 kg of dry organic compound was used, equivalent to 13 t ha^{-1}, and distributed homogeneously over the soil beside the planting row. The organic compound used in the study presented: pH (in H_2O) = 8.0; C = 131.0 g kg^{-1}; N = 13.0 g kg^{-1}; P = 13.65 mg dm^{-3}; K = 13.44 mg dm^{-3}; Ca = 0.19 $cmol_c$ dm^{-3}; Mg = 0.35 $cmol_c$ dm^{-3}; S = 0.49 $cmol_c$ dm^{-3}; Cu = 69.2 mg kg^{-1}; Fe = 561.4 mg kg^{-1}; Mn = 511.2 mg kg^{-1}; Zn = 766 mg kg^{-1}; organic matter = 22.58% and humidity = 37.40%.

Parameters evaluated

The following variables were evaluated: corn leaf dry matter (t ha^{-1}), 85 days after crop emergence, corn leaf macronutrient content and accumulations (g kg^{-1}), total chlorophyll content in the corn leaves (FCI), and dry matter production (t ha^{-1}) and macronutrient content in the aerial part of the dwarf pigeon pea (g kg^{-1}).

To calculate corn leaf dry matter, three plants per plot were collected randomly. The plants were separated into foliar limbs and stalks. For the dwarf pigeon pea, a wooden template was used measuring 0.25 × 0.25 m. The material collected was conditioned in paper bags and dried in a forced air circulation oven at 65°C, and when it reached constant mass, it was weighed. The green manure samples removed for dry matter evaluation were used to determine the nutrient content.

The corn leaf macronutrient content was determined by collecting the leaf opposite and below the upper cob in female flowering in all of the treatments (Cantarella et al., 1996). 10 leaves were collected

Table 1. Climate data observed during the months in which the experiment was conducted, Araras, SP, 2014/2015.

Months	Radiation MJ m^{-2}		Precipitation mm		Temperature ºC		
	Total	Average	Total	Average	Mín	Max	Average
Dec./2014	631.9	20.4	218.6	7.0	18.4	31.0	24.7
Jan./2015	691.3	22.3	121.8	3.9	19.9	33.3	26.6
Feb./2015	557.6	19.9	245.4	8.7	18.6	30.7	24.6
Mar./2015	513.4	16.6	173.4	5.6	18.1	28.7	23.4
Apr./2015	544.4	18.1	11.2	0.4	16.2	29.9	23.1
May/2015	405.2	13.1	67.0	2.2	14.1	25.8	20.0
Jun./2015	404.0	13.0	26.2	0.9	13.6	25.3	19.5
Jul./2015	355.4	11.5	12.1	0.4	13.8	24.9	19.3

Natural Resources and Environmental Protection Department/*UFSCAR*, Araras, SP. MJ·m^{-2} = mega joules per square meter; mm = millimeters; ºC = degrees Celsius.

per plot, at 85 DAE, and after excluding the central ridge, these were dried in a forced air ventilation oven at a temperature of 65°C for 48 h.

The corn and dwarf pigeon pea samples were ground in a Willey type grinder and submitted for analyses of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) content, according to the methodology described by Malavolta et al. (1997). The corn leaf macronutrient accumulation was obtained by multiplying the level of each nutrient by the leaf dry matter.

To determine the chlorophyll content, a ClorofiLOG® (model CFL 1030) portable chlorophyllometer was used. The measurements were expressed in dimensional units called Falker Chlorophyll Index (FCI). The readings were taken in the central third part of the limb of the last expanded leaf, in ten plants (four readings per plant) in the useful area of the plots. The chlorophyll evaluation was carried out in three periods, the first 20 days after corn emergence (DAE) (V4-V5 stage), the second 48 days after corn emergence (V9-V10 stage), and the third 85 days after emergence (R3-R4 stage).

To interpret the corn leaf macronutrient contents, the deviation from optimal percentage (DOP) method was used, as proposed by Montañés et al. (1993). This method is defined as the standard deviation in the concentration of an element in relation to the optimal level taken as a reference value. It is obtained using the following formula:

$$DOP = [(C \times 100/Cref) - 100]$$

In which C is the concentration of the nutrient in the dry matter from the sample and Cref is the optimal concentration of the nutrient in dry matter.

The values that are considered optimal for corn cultivation were proposed by Cantarella et al. (1996). As the adequate macronutrient levels for the crop are mentioned in adequate value ranges, the lowest value in the range for each macronutrient was considered.

The DOP indices were interpreted as follows: the absolute values (without sign) indicate the importance or severity of the deficiency or excess of the nutrient. The negative values indicate a situation of macronutrient deficiency; the positive values reflect situations of excess: and the indices equal to zero indicate optimal macronutrient values (Damián-Nava et al., 2006).

The yield of corn grains was also evaluated. The harvest was performed manually, removing all the spikes contained in the useful area of each plot. The moisture content of the grains was determined at 13%, yielding the productivity depending on the mass of grains harvested in each plot (t ha^{-1}).

Statistical analysis

Executing the DOP indices, the results obtained were submitted for variance analysis (F test) and the averages compared using the Tukey test, with a 5% probability. To process the statistical analyses, the Assistat software was used (Silva and Azevedo, 2016).

RESULTS AND DISCUSSION

For corn leaf dry mass (LDM), no significant difference ($p > 0.05$) was verified between the treatments evaluated, as well as for phosphorus (P), magnesium (Mg), and sulfur (S) contents (Table 2). This result is partially consistent with those obtained by Heinrichs et al. (2002), who in evaluating the production and nutritional state of corn intercropped with green manure for two years, did not verify any difference for P, Mg, and S contents in the first year of study.

Regarding corn leaf N content, there was a significant difference ($p < 0.05$) between the treatments (Table 2). The PR2B arrangement was higher than the rest, which did not differ between each other. The greater number of dwarf pigeon pea plants in the PR2B treatment probably caused a greater amount of nitrogen, which could have favored absorption by the corn plants. An increase in nitrogen availability is accompanied by a positive response in N content in the leaves (Nascimento et al., 2012).

According to Barcellos et al. (2008), the transfer of N from the fabaceae to the corn may have occurred under and/or over the soil surface, directly or indirectly, whether via the excretion of nitrogenated compounds, via the decomposition of roots and nodules, via the connection between mycorrhizae of the Poaceae roots and those of the Fabaceae, via fauna action in the soil over Fabaceae

Table 2. Leaf dry matter (LDM) and average macronutrient contents in corn crops intercropped with dwarf pigeon pea in different plant arrangements. Araras, SP, 2014/2015.

Treatments	LDM	N	P	K	Ca	Mg	S
	$t\ ha^{-1}$	$g\ kg^{-1}$					
CM	1.9[a]	31.9[b]	3.2[a]	9.9[ab]	34.8[a]	3.7[a]	1.2[a]
PR	2.3[a]	31.7[b]	3.2[a]	11.3[a]	23.0[a]	3.6[a]	1.1[a]
P1B	1.9[a]	31.7[b]	3.0[a]	7.7[b]	3.7[b]	2.9[a]	1.0[a]
P2B	1.8[a]	33.1[b]	3.0[a]	7.0[b]	3.5[b]	2.9[a]	1.4[a]
PR1B	1.9[a]	29.0[b]	3.0[a]	7.1[b]	3.8[b]	2.8[a]	1.8[a]
PR2B	2.2[a]	38.4[a]	3.1[a]	6.9[b]	3.2[b]	2.5[a]	1.4[a]
VC (%)	20.72	5.59	7.32	19.06	58.96	20.35	19.32

Averages followed by the same letter in the column do not differ statistically between each other using the Tukey test with a 5% probability. CM: Corn monoculture; PR: dwarf pigeon pea sown in the same row as the corn; P1B: one row of dwarf pigeon pea sown between the rows of corn: P2B: two rows of dwarf pigeon pea sown between the rows of corn; PR1B: dwarf pigeon pea sown in the same rows and in one row between the corn; and PR2B: dwarf pigeon pea sown in the same rows and in two rows between the corn. VC (%) = Variation coefficient.

roots and nodules, via the decomposition of leaves on the soil surface, via the leaching of nitrogenated compounds in the canopy, or via leaves losing ammonia, liable to absorption by the Poaceae.

The N values obtained in all of the treatments were considered to be satisfactory for corn cultivation, since they varied between 29.0 and 38.4 g kg^{-1}. That is, monoculture cultivation or intercropping with dwarf pigeon pea in different plant arrangements presented a N content within the adequate range for cultivation (27.5 to 32.5 g kg^{-1}), according to Malavolta et al. (1997). Corn behaves well in intercropping systems, and because it is an extremely demanding crop in terms of nutrients, especially N, the cereal favors intercropping with Fabaceae.

For corn K content, a significant difference ($p < 0.05$) was verified between the treatments (Table 2). PR had higher values than P1B, P2B, PR1B, and PR2B and did not differ statistically from MC. The presence of dwarf pigeon pea in the different arrangements hampered the absorption of potassium by the corn plants, except when the Fabaceae were sown only in the same row as the cereal. Probably, fabaceae can absorb K at depths greater than the area exploited by corn roots, and thus in the same row the species did not compete for the P available in the soil. Moreover, dwarf pigeon pea dry matter production in the rows of corn was lower than in the other arrangements, which may have reduced competition for the nutrient.

In this paper, the K contents observed in corn leaves were low in comparison to the values obtained by Heinrichs et al. (2002), which reached 24.7 g kg^{-1} for corn and dwarf pigeon pea intercropping.

There was a significant difference in Ca content between the treatments (Table 2). The CM and PR treatments were statistically similar and had higher values than the P1B, P2B, PR1B, and PR2B ones, which did not differ between each other. The reduction in nutrient content in plant tissue in intercropping may have been linked to the interspecies competitive interaction exercised by one species over the other (Viera et al., 2013). The low ability to compete for Ca on the part of corn in intercropping systems was already observed by other authors (Cury et al., 2012; Silva et al., 2015). Higher populations of the intercropped plant make greater soil exploitation possible, intensifying the competitive effects over the main crop (Belel et al., 2014).

In relation to the rates of deviation from the optimal percentage (DOP), excessive N and P in corn crop leaves was verified in all of the treatments, with PR2B presenting the highest DOP index for nitrogen, and the CM and PR treatments presenting the highest DOP indices for phosphorus (Table 3).

The higher DOP index for N verified in the PR2B treatment may be attributed to the higher number of dwarf pigeon pea plants in the system, increasing the amount of N via biological fixation, thus making a higher quantity of the nutrient available for the main crop. However, in biological fixation of N, Fabaceae need high quantities of phosphorus to meet the needs of the nodules (Caldas et al., 2009). Thus, in the treatments in which there is a greater number of dwarf pigeon pea plants, greater competition for P may have occurred, which could explain the lower DOP indices for phosphorus as the Fabaceae population increased (Table 3).

For K, all of the treatments presented negative indices, which indicates a deficiency in the macronutrient in the corn crop (Table 3). The potassium deficiency in all of the treatments may be related with the excessive Ca verified in the corn leaves (Table 3). Calcium presented positive indices in all of the treatments, showing good availability of the nutrient in the soil, especially in the CM and PR treatments, which presented very high indices.

The higher availability of Ca in soil causes its approximation to roots in greater quantity, and as Ca and K are absorbed by the same mechanisms in the cellular

Table 3. Deviation from optimal percentage (DOP) of macronutrients in the corn crop intercropped with dwarf pigeon pea in different plant arrangements. Araras, SP, 2014/2015.

Treatments	Deviation from optimal percentage					
	N	P	K	Ca	Mg	S
CM	+18.1	+60	-41.8	+1292	+146.7	-20
PR	+17.4	+60	-33.5	+820	+140.0	-26.7
P1B	+17.4	+50	-54.7	+48	+93.3	-33.3
P2B	+22.6	+50	-58.8	+40	+93.3	-6.7
PR1B	+7.4	+50	-58.2	+52	+86.7	+20
PR2B	+42.2	+55	-59.4	+28	+66.7	-6.7

CM: Corn monoculture; PR: dwarf pigeon pea sown in the same row as the corn; P1B: one row of dwarf pigeon pea sown between the rows of corn: P2B: two rows of dwarf pigeon pea sown between the rows of corn; PR1B: dwarf pigeon pea sown in the same rows and in one row between the corn; and PR2B: dwarf pigeon pea sown in the same rows and in two rows between the corn. DOP = [(C × 100/Cref) - 100]. C: concentration of the nutrient in the dry matter in the sample; Cref: optimal concentration of the nutrient in dry matter.

membrane, its absorption was probably preferential in relation to K (Medeiros et al., 2008). According to Bissani et al. (2006), Ca is generally the macronutrient found in greatest concentration in soils, after Iron (Fe), and as there is no specific absorption mechanism, it is generally found in exchangeable form in levels above those required by plants.

For Mg, positive indices were observed in all of the treatments (Table 3), showing an excess of the nutrient in the corn leaves. The highest Mg indices were obtained by the CM and PR treatments. Similar results were verified for foliar P. This similarity may be related to the synergism between these two macronutrients. According to Malavolta et al. (1997), absorption of P is influenced by the Mg concentration in the medium, with Mg able to carry P into the plant.

In relation to S in the corn plants, a deficiency was verified in the CM, PR, P1B, P2B, and PR2B treatments. In the PR1B, there was an excess, even though it was low, of the macronutrient (Table 3). It is worth noting that the S deficiency occurred to a greater degree in the treatments with lower dwarf pigeon pea plant numbers and in the corn monoculture. However, greater competition for S was expected in plots with higher dwarf pigeon pea populations, since for Fabaceae, sulfur is required in the nodules for symbiotic fixation of nitrogen, given that this nutrient is an element which constitutes nitrogenase, an N fixing element (Paiva and Nicodemo, 1993).

In the PR1B treatment, which was the only one that presented excessive S in the corn leaves, the lowest foliar content and lowest DOP index for N was verified (Tables 2 and 3). From this result, it can be inferred that in the treatment less fixation of N occurred via biological means. Thus, there was less absorption of S by the dwarf pigeon pea, allowing for greater use of the macronutrient on the part of the corn plants.

Concerning the nutrient accumulations in the corn leaves, no significant differences ($p > 0.05$) were verified between the treatments for N, P, Mg, and S (Table 4).

This result can be attributed to the absence of a significant difference for dry matter in corn leaves (Table 2). Indeed, according to Moreira et al. (2014), variations in foliar nutrient accumulations are due to variations in dry matter production by corn plants.

For K and Ca accumulations, significant differences ($p < 0.05$) were verified between the treatments adopted (Table 4). In relation to K, the PR treatment had higher values than the P1B, P2B, PR1B, and PR2B arrangements, and did not differ from the corn monoculture. For Ca, the PR arrangement and the corn monoculture were statistically equal, and had higher values than the other arrangements, which did not differ between each other. This result is related with the foliar content of these nutrients in both treatments (Table 2). Despite no statistical difference having been observed for corn leaf dry mass, the CM and PR treatments had much higher values than the other arrangements in the intercropping with regards to K and Ca content, which was reflected in the greater accumulation of these macronutrients in the corn leaf dry mass.

For the Falker chlorophyll index, no significant difference ($p > 0.05$) was verified between the treatments studied in any of the evaluation periods (Table 5).

There was no significant difference ($p > 0.05$) between the treatments for dry mass of the aerial part of the dwarf pigeon pea, as well as for the N, K, Ca, and K content of the Fabaceae (Table 6).

In relation to the P in the aerial part of the dwarf pigeon pea, a significant difference ($p < 0.05$) was verified between the treatments (Table 6). The P1B had higher values than the PR, and did not differ statistically from the PRB, PR1B, and PR2B. From this result, it can be inferred that the dwarf pigeon pea presented a greater ability to compete for this nutrient. This occurs due to the fact that Fabaceae roots, as well as being differentiated and deep, exude organic acids, especially citric ones, which act in solubilizing the P linked to the Ca, which

Table 4. Accumulation of macronutrients in corn intercropped with dwarf pigeon pea in different plant arrangements, Araras, SP, 2014/2015.

Treatments	N	P	K	Ca	Mg	S
	kg ha^{-1}					
CM	63.3^{a}	6.5^{a}	20.1^{ab}	69.0^{a}	7.3^{a}	2.3^{a}
PR	73.8^{a}	7.6^{a}	25.9^{a}	49.1^{a}	8.1^{a}	2.6^{a}
P1B	61.2^{a}	5.8^{a}	14.8^{b}	7.2^{b}	5.6^{a}	2.0^{a}
P2B	60.9^{a}	5.5^{a}	12.8^{b}	6.4^{b}	5.2^{a}	2.6^{a}
PR1B	56.2^{a}	5.9^{a}	13.8^{b}	7.5^{b}	5.5^{a}	3.5^{a}
PR2B	85.3^{a}	6.9^{a}	15.3^{b}	7.2^{b}	5.5^{a}	3.2^{a}
VC (%)	21.23	21.21	23.30	54.69	23.29	21.01

Averages followed by the same letter in the column do not differ statistically between each other using the Tukey test with a 5% probability. CM: Corn monoculture; PR: dwarf pigeon pea sown in the same row as the corn; P1B: one row of dwarf pigeon pea sown between the rows of corn: P2B: two rows of dwarf pigeon pea sown between the rows of corn; PR1B: dwarf pigeon pea sown in the same rows and in one row between the corn; and PR2B: dwarf pigeon pea sown in the same rows and in two rows between the corn. VC (%) = Variation coefficient.

Table 5. Average content of chlorophyll in the leaves of corn depending on consortium with dwarf pigeon pea in different arrangements of plants. Araras, SP, 2014/2015.

Treatments	Foliar Chlorophyll		
	20 DAE	48 DAE	85 DAE
	FCI		
CM	50.4^{a}	52.9^{a}	55.0^{a}
PR	51.5^{a}	52.6^{a}	57.9^{a}
P1B	51.4^{a}	54.4^{a}	56.5^{a}
P2B	50.1^{a}	51.8^{a}	57.7^{a}
PR1B	47.6^{a}	52.1^{a}	54.9^{a}
PR2B	48.2^{a}	50.9^{a}	56.4^{a}
VC (%)	6.64	3.46	6.35

Averages followed by the same letter in the column do not differ statistically between each other using the Tukey test with a 5% probability. CM: corn monoculture; PR: dwarf pigeon pea sown in the same row as the corn; P1B: one row of dwarf pigeon pea sown between the rows of corn: P2B: two rows of dwarf pigeon pea sown between the rows of corn; PR1B: dwarf pigeon pea sown in the same rows and in one row between the corn; and PR2B: dwarf pigeon pea sown in the same rows and in two rows between the corn. DAE = Days after emergence; FCI = Falker Chlorophyll Index; VC (%) = Variation coefficient.

favors the absorption of this macronutrient (Ae et al., 1990).

The values verified in this study were lower than those obtained by Ferrari Neto et al. (2011), in dwarf pigeon pea and millet intercropping systems. In the PR1B and PR2B treatments, the P content was higher than that observed by Heinrichs et al. (2005), in the simultaneous intercropping of corn and dwarf pigeon pea, the other treatments presented lower values, although they were very close to those verified by the authors (Table 6).

There was a significant difference ($p < 0.05$) between the treatments for S content (Table 6). The P2B intercropping presented a lower average in comparison to PR, and did not differ statistically from the other arrangements. This result shows that the dwarf pigeon pea plants competed more with the corn for this nutrient. It is important to highlight that the S content was lower in the treatment in which the pigeon pea accumulated more dry matter (Table 6). Therefore, the reduction in absorption of the nutrient could be attributed to possible interspecies competition.

The levels obtained in the study are below those verified by other authors in intercropping systems (Heinrichs et al., 2005; Ferrari Neto et al., 2011). The low S content in the aerial part of the dwarf pigeon pea may be related to the reduced availability of this nutrient in the soil. This was a factor that also caused its deficiency in the corn plants, according to the DOP indices (Table 2).

For grain yield, significant difference was found among treatments (Figure 1). The maize in a consortium with seedlings seeded on the line and two lines in the interline (PR2B) was superior to maize in monoculture and to

Table 6. Dry matter in the aerial part and average macronutrient content for dwarf pigeon pea in different plant arrangements intercropped with corn, Araras, SP, 2014/2015.

Treatments	DMAP	N	P	K	Ca	Mg	S
	$t\ ha^{-1}$	$g\ kg^{-1}$					
PR	0.9^{a}	38.8^{a}	1.0^{b}	15.9^{a}	7.6^{a}	2.4^{a}	0.24^{a}
P1B	0.7^{a}	32.2^{a}	1.7^{a}	14.2^{a}	7.8^{a}	2.2^{a}	0.18^{ab}
P2B	1.8^{a}	29.0^{a}	1.2^{ab}	16.4^{a}	8.3^{a}	2.5^{a}	0.15^{b}
PR1B	0.8^{a}	33.5^{a}	1.5^{ab}	16.1^{a}	8.4^{a}	2.3^{a}	0.16^{ab}
PR2B	1.2^{a}	28.4^{a}	1.5^{ab}	14.1^{a}	8.7^{a}	2.6^{a}	0.20^{ab}
VC (%)	22.62	15.59	19.06	14.59	17.94	12.58	18.71

Averages followed by the same letter in the column do not differ statistically between each other using the Tukey test with a 5% probability. PR: Dwarf pigeon pea sown in the same row as the corn; P1B: one row of dwarf pigeon pea sown between the rows of corn: P2B: two rows of dwarf pigeon pea sown between the rows of corn; PR1B: dwarf pigeon pea sown in the same rows and in one row between the corn; and PR2B: dwarf pigeon pea sown in the same rows and in two rows between the corn. VC (%) = Variation coefficient.

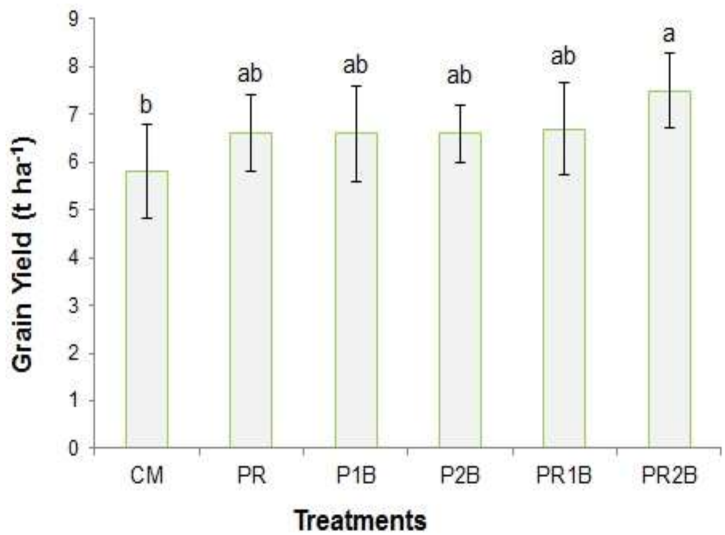

Figure 1. Corn grain yield depending on the consortium with pigeon pea in different plant arrangements, Araras, SP, 2014/2015.

other plant arrangements, which did not differ among each other.

This result corroborates in part with those obtained by Rao and Mathuva (2000), who verified higher yield of corn intercropped with pigeon pea compared to corn in monoculture, reaching 24% increase in the intercropping system.

The superiority of PR2B in relation to the other treatments can be attributed to a larger population of pigeon pea plants in the system, increasing the N uptake through biological fixation, benefiting the nutrient absorption by maize plants. This occurrence can be confirmed by the higher N content observed in maize leaves (Table 2) and higher DOP index for N (Table 3) in the PR2B system. In addition, the larger population of green manure may have contributed to the maintenance of soil moisture and greater organic matter addition in the system, improving soil nutrient cycling (Arantes et al., 2016), resulting in increased corn grain yield.

Conclusion

The different dwarf pigeon pea arrangements did not have any influence on P, Mg, and S absorption by the corn plants. When sown in rows between corn and/or in greater plant populations, Fabaceae compete more for K and Ca.

The arrangement with larger population of pigeon pea plants provided increase in corn leaf N content as well as grain yield of the crop.

The accumulations of macronutrients in corn were negatively affected by the different dwarf pigeon pea arrangements in the intercropping, with the exception of Ca, which was favored in the corn monoculture and in the arrangement with dwarf pigeon pea sown in the same row as the Poaceae.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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The sowing density on oat productivity indicators

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The sowing density adjustment in oatcan maximize the productivity expression.The aim of this study is to define the behavior of productivity expression of biomass, grains, straw andharvest indexthrough increasing sowing density in the main biotype cultivated in Southern Brazil. It proposesthe possibility of indicating higher sowing density to the productivity maximization of biomass and grains.With the densityadjusted to the grain productivity to simulate the reflexes on the biological and straw productivity and harvest index compared to recommendeddensity, considering high and reduced tillering cultivars in different succession systems.The study was carried out in 2013, 2014 and 2015 in randomized blockdesign with four replications in a 4 × 2 factorial scheme, for sowing density (100, 200, 300, 600 and 900 m^{-2}) and oat cultivars (Brisasul and URS Taura), respectively, in the corn/oat and soybean/oat succession system.With the increase in sowing density, the biological and straw productivity evidence alinear behavior and the grain productivity and harvest index ofquadratic behavior, regardless of the cultivar,agricultural year and succession system. It is possible to indicate a higher sowing density to the biomass and grain productivity maximization with sowing density close to 500 seeds m^{-2} in the main succession systems.In high and reduced tillering cultivars, the adjusted density compared tothe recommended increasedthe biological and straw productivity, regardless of agricultural year and succession systems.

Key words: *Avena sativa*, succession system, weather condition, regression.

INTRODUCTION

White oat (*Avenasativa L.*) is acknowledgedas a grain producer withnutritional quality for human and animal feeding (Garcia et al., 2012; Hawerroth et al., 2015). In Southern Brazil, it is an alternative to wheat for the winterfarming, evidencing in recent years accentuated growth in the cultivated area, mainly, due to use of the

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grains for commercialization and production of adequate haystacks for the direct sowing system (Hartwig et al., 2007; Mantai et al., 2015).

The expression of productivity potential of the white oat is associated to management techniques, viz, the plants population, nutrients availability, phytosanitary control and others (Silva et al., 2012; Mantai et al., 2015). The productivity variation by the plants population is associated with the genotype potential to produce fertile tillers as the sowing density directly influences the number of ears and/or panicles produced by area (Valério et al., 2009; Castro et al., 2012). Moreover, the fast coverage of the soil by the canopy adjustment may favor the best use of light and nutrients, providing more effective control inthe evolution of the species considered invaders (Fleck et al., 2009; Lamego et al., 2013). The high variation of productivity is also associated with the large variability of cultivation conditions, the agricultural year being the major contribution factor (Storck et al., 2014; Arenhardt et al., 2015). Therefore, years of favorable and unfavorable weather can change the efficiency of the use of natural resources and management technologies on the vegetable productivity (Mantai et al., 2015; Arenhardtet al., 2015).

The continuous genetic improvement of oats has been significantly modifying the plant architecture, reducing height, cycle, leaf area, among other characteristics (Silva et al., 2012; Romitti et al., 2016). Therefore, they are alterations which may modify the cultivars responseto the plants population, mainly when seeking an increment onthe productivity of oats biomass and grains on the current standard biotype of short-cycle and reduced height cultivated in a commercial scale in Brazil. Studies carried out by Abreu et al. (2005) and Silva et al. (2012) revealed that the increase of the plant population of white oat resulted in an increased crop growth rate and biomass productivity per unitarea. Santi et al. (2016) observed increased productivity of lupine biomass by increasing sowing density. The total biomass productivity also denominated biological productivity is directly linked to the photosynthesis and breathing processes in the vegetative and reproductive phases (Demétrio et al., 2012; Silva et al., 2015). Thus, harvest index (grain productivity divided by biological productivity) is an important parameter in determining the efficiency with which the photo assimilates are converted in straw and grain (Silva et al., 2011, 2015).

The technical recommendations of oat sowing (CBPA, 2006) have been suggesting 200 to 300 viable seeds m^{-2}, indications based on research from a plant biotype with different characteristics of the one which is currently used in production systems. This fact raised the hypothesis that the plant population above the recommended plant population may provide more effective gainson the increment of straw and grain productivity in the main biotype of oat cultivated in Southern Brazil. These conditions maybe better understood when considering cultivars of high and reduced tillering evaluated in different conditions of agricultural year and in succession system with high and reduced residual N release.

The aim of this study was to define the productivity expression behavior of the biomass, grains, straw and harvest index through increasing sowing density in the main biotype grown in Southern Brazil. It proposes the possibility of indicating a higher sowing density to the productivity maximization of the biomass and grains. With the density adjustedto the grain productivity to simulate the reflexes on the biological productivity, straw and harvest index compared to recommended plant density, considering high and reduced tillering in different agricultural years and in different succession systems.

MATERIALS AND METHODS

The experimentwas conducted in the field during 2013, 2014 and 2015 in Augusto Pestana town, RS state, Brazil (28° 26' 30'' South latitude and 54° 00' 58'' West longitude). The soil of the experimental area is classified as Distrofic Red Latosol Typical and the climate of the region, according to Köppen classification, is Cfa type, witha hot summer without a dry season. In the study, ten days before sowing, a soil analysis was performed at the local and identified the following chemical characteristics: (i) corn/oat system (pH = 6.5, P = 34.4 mg dm^{-3}, K = 262 mg dm^{-3}, Organic matter = 3.5%, Al = 0.0 cmolc dm^{-3}, Ca = 6.6 cmolc dm^{-3}, and Mg = 3.4 cmolc dm^{-3}) and (ii) soybean/oat system (pH = 6.2, P = 33.9 mg dm^{-3}, K = 200 mg dm^{-3}, Organic matter = 3.4%, Al = 0.0 cmolc dm^{-3}, Ca = 6.5 cmolc dm^{-3}, and Mg = 2.5 cmolc dm^{-3}).

In all the three years, sowing was done in the second fortnight of May with seeder-fertilizer at a row spacing of 0.20 m. During the experimentation, tebuconazole fungicide (trade name FOLICUR® CE)was applied at the dosage of 0.75 L ha^{-1}.Weed control was carried out with metsulfuron-methyl herbicide (trade name ALLY®at a dose of 4 g ha^{-1}) and additional manual weeding whenever necessary.10 kg ha^{-1}(except in the standard experiment unit), 60 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1} were applied at the time of sowingfor productivity expectancy of 3 t $ha^{-1}$and rest of N to complement an expectancy of 3 t ha^{-1} wasappliedin coverage on the phenological stage of fourth leaf expanded.

The studies were carried out in the main succession systems used in southern Brazil for oats, involving soil coverage with vegetable residue of high and reduced carbon/nitrogen ratio, in corn/oat and soybean/oat succession systems, respectively. In each succession system, two experiments were conducted, one to quantify the biological biomass and the other aiming exclusively at grain productivity estimation. In all experiments, the experimental design was randomized blocks with four repetitions, in a 4×2 factorial scheme to four sowing density (100, 300, 600 and 900 viable seeds m^{-2}) and two oat cultivars (Brisasul and URS Taura). The indicated oat cultivars represent current genotypes with biotype desired in commercial farming in Brazil, with similarity regarding the cycle (early), height (reduced) and lodging (moderately resistant), however, distinguished in the capacity of production tillering (Brisasul = high; URS Taura = reduced).

The grain productivity was obtained by cutting three central rows of each plot at the time of harvesting with grain moisture around 22.0%. The plants were threshed with a stationary harvester and directed to the laboratory for correction grain moisture to 13.0% and weighing to estimate grain productivity (GP, kg ha^{-1}). In experiments aiming to quantify the biological productivity, the harvest of the plant material was done close to the ground from the moment ofphysiological maturity of grains in the collection of a linear meter of the three central rows of each plot. The green biomass samples were directed to forced-air oven at a temperatureof 65°C, until it reached constant weight for the estimation of biological productivity (BP, kg ha^{-1}). Straw productivity (SP, kg ha^{-1}) was determined by subtraction BP – GP and the harvest index (HI, kg kg^{-1}) by the division GP/BP..

In meeting the assumption of homogeneity and normality by Bartlet and Liliefors test was carried out at variance analysis for detection of the main effects and of interaction. The values of the general average of grain production for the intendedexpectancyof 3 t ha^{-1}, according to soil MO and succession system, along with temperature information and rainfall were usedfor ranking the agricultural year asfavorable year (FY), acceptable year (AY) and unfavorable year (UY).The adjustment of second-degree equations ($GP= a \pm bx \pm cx^2$) was performed for the estimation of the sowing ideal density ($D = - b/2c$) directed to maximum grain productivity. Equations that describe the behavior of biological productivity, of straw productivity and harvest index, as a form of simulation of expression these variables from the sowing ideal dose based on the maximum grain productivity were obtained. Genes computational program was used for the determination.

RESULTS AND DISCUSSION

In Figure 1, in the application moment of N-fertilizer in 2014, the averages of maximum temperature were higher (±27°C) as compared to 2015 and 2013. The nitrogen applied in coverage in 2014 was followed by rainfall volume greater than 50 mm, volume also observed close to harvest. These facts justify the smaller productivity obtained in this year (Table 1), due to a loss of nutrients byleaching and losses by excess of rainfall during maturation, characterizing it as an unfavorable year (UY). In 2015, the maximum temperature near to application of N-fertilizer was the lowest (±12°C) as compared to other years. In the fertilizing moment, the soil presented adequate humidity due to the rain accumulation from previous days (Figure 1). The high rain volume during the cycle provided periods of less sunlightwhich reduced the photosyntheticefficiency by the plant. Therefore, the average of grain productivity in Table 1, justifies a reasonable productivity, characterizing 2015 as an acceptable year (AY) of cultivation.In 2013, the maximum temperature obtained in the application moment of N-fertilizer was around 20°C. The nutrient supply occurred under favorable conditions of soil moisture (Figure 1). In this agricultural year, although the total rainfall volume wasthe smallest, the adequate distribution of rainfall during the cycle (Figure 1) was decisive in the highest average productivity of grains (Table 1). It stands out that the established dose of N-Fertilizer exceeded the desired expectation of 3 t ha^{-1} characterizing 2013 as a favorable year (FY) for cultivation.

Battisti et al. (2013) asserted that the rainfall is the meteorological variable that mostly affects the productivity in relation to the temperature, sunshine and solar radiation. Arenhardt et al. (2015) emphasized that the condition of the cultivation year of wheat is predominantly defined by distribution and volume of rainfall. The temperature, sunlight and solar radiation also influence the productivity (Souza et al., 2013). The temperature acts as a catalyst of the biological process, reason why the plants require the minimum and maximum temperature for normality of the physiological activity (Tonin et al., 2014). In oat, the favorable weather is described as that with milder temperatures and quality of solar radiation in favoring the tillering and grain filling. Besides, without occurrence of rain in high amount and intensity, but which favors adequate soil moisture (Castro et al., 2012).

In Table 2, regardless of oat cultivar, agricultural year and succession system, the increment of sowing density in relation to the grain productivity presented quadratic behavior. The parameters of inclination (cx^2) were effective in validating these equation in the estimated of adjusted density. Therefore, in conditions of unfavorable year (2014) and acceptable year to the cultivation in soybean/oats system, the adjusted sowing to the higher production expression of grains was between 500 and 570 seeds m^{-2}, regardless of oat cultivar.It is highlighted that in these years, the adjusted density of seeds provided increment in the grain productivity in relation the recommended density (250 seeds m^{-2}). In the favorable year of cultivation (2013), the adjusted density was close to 410 and 420 seeds m^{-2}. In these conditions, the differences between adjusted and recommended density did not present change in grain productivity (Table 2). In general, in the soybean/oats system, independently of year and oat cultivar, the optimal density of sowing was 500 seeds m^{-2}, increasing the elaboration of grains in comparison to the density of recommendation in more than 260 kg ha^{-1}. The results presented in soybean/oats system revealed that in unfavorable and acceptable year to cultivation, the use of more elevated seed sowing promotes effective benefits in the grain productivity. In the year 2013 (FY), although the amount of seeds in the adjusted sowing is lower than values obtained in 2014 (UY) and 2015 (AY), in 2013there was necessity of superior amount of seeds than the recommendation, however, not evidencing differences in grain productivity expression.Possibly, the favoring of agricultural year had contributed in the larger productivity and development of fertile tillers compensating the use of smaller amount of seeds.

In the corn/oats (Table 2), regardless of agricultural year condition and cultivar, the adjusted density of seeds presented values higher than 500 seeds m^{-2}. The use of adjusted density also presented increment of grain productivity higher than the recommendation. Results obtained in acceptable year to the oat cultivation (2015)stand out, when the adjusted density increased the grain productivity in more of 485 and 600 kg ha^{-1} in the URS-Taura and Brisasul cultivars, respectively in comparison with recommended sowing density. In general, regardless of year and cultivar, the adjusted density in corn/oats system was of 550 seeds m^{-2}, increasing the grainproductivity in more than 300 kg ha^{-1} in relation to the recommended sowing density. In this growing conditions, lower release of N-residual (corn/oats system), the use of

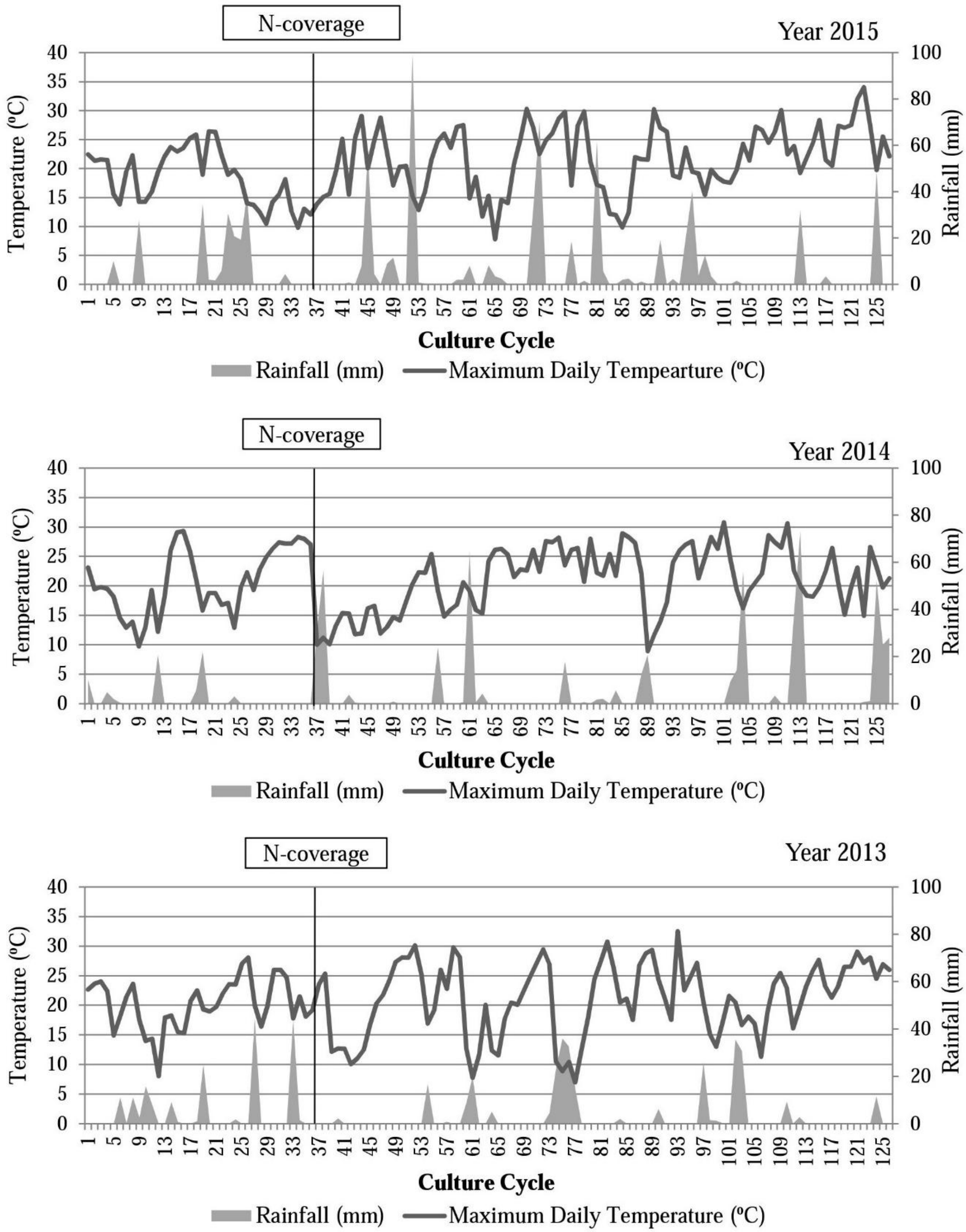

Figure 1. Rainfall and maximum temperature in the cycle of oat cultivation.

higher densities was found to be more effective on grain productivity when compared with the soybean/oats system. Therefore, the type of residual coverage indicates interference in the adjustment of sowing density

Table 1. Temperature and rainfall in cultivation months and means of grain productivity.

Month	Temperature (°C)			Rainfall (mm)		$GP_{\bar{x}}$ (kg ha^{-1})	Class
	Minimum	Maximum	Average	Average 25 years*	Occurred		
				2015			
May	10,5	22.7	16.6	149.7	100.5		
June	7.9	18.4	13.1	162.5	191		
July	8.3	19.2	13.7	135.1	200.8		
August	9.3	20.4	14.8	138.2	223.8	2983^{b}	AY
September	9.5	23.7	16.6	167.4	46.5		
October	12.2	25.1	18.6	156.5	211.3		
Total	-	-	-	909.4	973.9		
				2014			
May	11.1	24.5	17.8	149.7	20.3		
June	9.3	19.7	14.5	162.5	59.4		
July	7.4	17.5	12.4	135.1	176.6		
August	12.9	23.4	18.1	138.2	61.4	2516^{c}	UY
September	12	23	17.5	167.4	194.6		
October	15	25.5	20.2	156.5	286.6		
Total	-	-	-	909.4	798.9		
				2013			
May	10	22.6	16.3	149.7	108.5		
June	8.9	20	14.5	162.5	86		
July	7	20.6	13.8	135.1	97		
August	6.6	19.8	13.2	138.2	1603	3400^{a}	FY
September	9.6	21	15.3	167.4	119.7		
October	13.2	27.1	20.2	156.5	138.8		
Total	-	-	-	909.4	712.0		

*Means rainfall from May to October from 1991 to 2015; FY: Favorable year; UY: unfavorable year; AY: acceptable year; $GP_{\bar{x}}$: mean grain productivity. Means followed by the same lowercase letter in the column do not differ statistically from one another by the Skott & Knott model at a 5% error probability.

in oat, mainly in favorable year of cultivation.

The adjustment of optimal sowing density in different cultivation conditions may benefit the change of the grain productivity plateau. The positive answersin use of higher densities were also observed in cultures as soybean, corn and wheat (Lima et al., 2008; Strieder et al., 2008; Silveira et al. 2010). In wheat, Zagonel et al. (2002) showed that higher density of plants may favor the increase of grainproductivity, to the point of identifying genotypes that were responsive to the increase of the population. Almeida et al. (2003)have already observed, in oat obsolete cultivars of middle and late cycle, amplitude of seeds density adjustedfrom 50 to 500 plants m^{-2}. The increment of the sowing density inearly cycle wheat cultivars, mainly of lower expression of tillering, presented benefits in the increase of sowing density on grain productivity (Silveira et al., 2010). Valério et al. (2008) had already been reporting that the wheat of early genotypes with reduced potential of tillering are more dependents of the correct adjustment of sowing density, suggesting values higher than those of recommendation to increase grain productivity. Silva et al. (2015) highlighted the need of changes in the recommendation of sowing density of oat seeds in the main biotype of early cycle and reduced height cultivated in Southern Brazil to increase the productivity provided, there is nolodging. The same authors highlight the benefits in farming management by greater plant coverage, bothin the more effective control of invasive species, as in the maintenance of soil moisture and erosion control, qualifying the direct sowing system to thesummer species. The use of an adequate density allows a species to develop more quickly and covers the soil more efficiently, causing less interference of the weeds (Fleck et al., 2009). In studies with oats cultivars of reduced height and cycle, it was also observed an adjusted density higher than the recommendation of 550 seeds m^{-2} (Silva et al., 2012).

Table 2. Regression equation and its parameters in estimated of grains productivity by the recommended and adjusted sowing density to the grain productivity (Y_E) in oats.

Cultivar	Equation ($GP=a\pm bx\pm cx^2$)	R²	P (cx^2)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
	Soybean/Oats system						
	2015 (AY)						
Brisasul	$2145 + 5.1881x – 4.81 \times 10^{-3}x^2$	0.94	*	250	540	3141^B	3544^A
URS-Taura	$2243 + 6.2308x – 5.48 \times 10^{-3}x^2$	0.89	*	250	570	3458^B	4014^A
	2014 (UY)						
Brisasul	$1874 + 4.4343x – 4.42 \times 10^{-3}x^2$	0.93	*	250	500	2706^B	2986^A
URS-Taura	$1947 + 5.6068x – 5.57 \times 10^{-3}x^2$	0.99	*	250	505	3001^B	3358^A
	2013 (FY)						
Brisasul	$3431 + 2.885x – 3.54 \times 10^{-3}x^2$	0.93	*	250	410	3931^A	4019^A
URS-Taura	$3031 + 1.38642x – 1.65 \times 10^{-3}x^2$	0.97	*	250	420	3274^A	3322^A
General	$2445 + 4.2886x – 4.305 \times 10^{-3}x^2$	-	*	250	500	3248^B	3513^A
	Corn/Oats system						
	2015 (AY)						
Brisasul	$1294 + 6.65352x – 5.82 \times 10^{-3}x^2$	0.99	*	250	570	2594^B	3196^A
URS-Taura	$1683 + 4.42860x – 3.68 \times 10^{-3}x^2$	0.97	*	250	600	2566^B	3051^A
	2014 (UY)						
Brisasul	$2402 + 2.96546x – 2.85 \times 10^{-3}x^2$	0.97	*	250	520	2965^B	3173^A
URS-Taura	$2135 + 3.21667x – 3.14 \times 10^{-3}x^2$	0.99	*	250	510	2743^B	2959^A
	2013 (FY)						
Brisasul	$2529 + 2.89005x – 2.76 \times 10^{-3}x^2$	0.90	*	250	525	3079^B	3286^A
URS-Taura	$2769 + 3.12254x – 2.71 \times 10^{-3}x^2$	0.99	*	250	575	3380^B	3668^A
General	$2135 + 3.87947x – 3.54 \times 10^{-3}x^2$	-	-	250	550	2884^B	3201^A

R^2: Determination coefficient; P(cx²): angular parameter that measure the significance in 5% level of error probability; GP: grain productivity; (Y_E):value of grain productivity estimated by the regression model; RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line do not differ statistically from one another by the Skott& Knott model in 5% level of error probability.

In Table 3 (biological productivity or total biomass), a linear behavior was also observed with the positive parameter of inclination and significant through the increment of the sowing density, regardless of oat cultivar, agricultural year and succession system. In the soybean/oats system, the use of the optimal density of sowing by the grain productivity in the model of linear regression of biological productivity, the favorable year to the farming (2013) evidenced the highest expression of total biomass. Also, in the general model, in soybean/oats, the density of 500 seeds m^{-2} adjusted to the higher productivity of grainsindicated an expectancy of biomass productivity of 8033 kg ha^{-1} higher than the biomass produced in comparison with the density of recommendation.

In the corn/oats system (Table 3), linear behavior was also observed.Besides that, the use of optimal density to grain productivity (Table 2) in the linear model of expression of biological productivity (Table 3) provided high values of total biomass mainly in the favorable year of farming (2013) with values higher than 9200 kg ha^{-1}.In corn/oats system, the density with 550 seeds m^{-2} adjusted to the highest grain productivity indicated an expectancy of biomass productivity of 8266 kg ha^{-1}, significantly higher than the recommended density. The increase of sowing density showed positive increment on the biological productivity, although the grain productivity evidenced quadratic behavior in defining an optimal sowing density to recommendation (Table 2). This fact raised the hypothesis that the tendency linearity obtained in the biological productivity possibly is due to the higher expression of the productivity directed to the elaboration of straw.

The density of plants per unit area is a decisive factor

Table 3. Regression equation and its parameters in estimative of biological productivity by the recommended and adjusted sowing density to the grain productivity (Y_E) in oats.

Cultivar	Equation (BP=a±bx)	R^2	P (bx)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
Soybean/Oats system							
2015 (AY)							
Brisasul	5339 + 2.72x	0.98	*	250	540	6019^B	6808^a
URS-Taura	5636 + 1.98x	0.88	*	250	570	6132^B	6766^a
2014 (UY)							
Brisasul	6286 + 3.99x	0.99	*	250	500	7283^B	8279^A
URS-Taura	6540 + 4.13x	0.99	*	250	505	7573^B	8627^A
2013 (FY)							
Brisasul	7098 + 3.71x	0.99	*	250	410	8025^B	8618^A
URS-Taura	7655 + 2.78x	0.99	*	250	420	8351^B	8823^A
General	6425 + 3.22x			250	500	7229^B	8033^A
Corn/Oats system							
2015 (AY)							
Brisasul	4196 +4.14x	0.99	*	250	570	5231^B	6556^A
URS-Taura	5404 + 4.05x	0.88	*	250	600	6417^B	7835^A
2014 (UY)							
Brisasul	6497 + 3.2x	0.97	*	250	520	7308^B	8184^A
URS-Taura	6661 + 2.89x	0.96	*	250	510	7383^B	8133^A
2013 (FY)							
Brisasul	7739 + 2.81x	0.95	*	250	525	8442^B	9214^A
URS-Taura	8749 + 1.66x	0.89	*	250	575	9163^B	9702^A
General	6541 + 3.14x	-	-	250	550	7325^B	8266^A

R^2: Determination coefficient; P(bx): angular parameter that measure the significance in 5% level of error probability; BP: biological productivity; Y_E: value of biological productivity estimated by the regression model; RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line do not differ statistically from one another by the Skott& Knott in 5% level of error probability.

in the development of a speciesseeking the maximization of the production. Therefore, besides providing a higher grain productivity, it may potentialize the biomass area^{-1} (Valério et al., 2008). Abreu et al. (2006) noted that the seed sowing periods and the cycle of oat cultivars presented significant effect in the biomass production, directly interacting in the best adjustment of population density. Fleck et al. (2009) considered that in early stages of plant development the high population favors the fast soil coverage with benefits in the protection against erosion and weed reduction. In this context, Schuch et al. (2000) discussed the importance of the fast biomass accumulation in oat, conditionstrengthened by the biomass production rate and uniformity of emergency, and the latter, directly related to the vigor of the seeds. The increment of the tiller number and/or plants per unit area indicated a strong participation in the biomass production, important aspect to increase the biological productivity (Silveira et al., 2010; Silva et al., 2015). The productivity of total biomass, also denominated biological productivity, is directly linked to the photosynthesis and respiration process in the vegetative and reproductive phases (Demétrio et al., 2012; Silva et al., 2015). Harvest index is an important parameter to determinethe efficiency with which thephoto-assimilates are converted in straw and grains (Silva et al., 2012, 2015). The increase in the plant population of white oats resulted in elevation of the growing rate of the oat and of biomass productivity per area (Abreu et al., 2006; Romitti et al., 2016). In the soybean/oats succession system, Silva et al. (2012) observed most evident increases of expression of the biological and grains productivity in relation to the corn/oats system, favored by the higher N-residual availability.

Table 4. Regression equation and its parameters in estimated of straw productivity by the recommended and adjusted sowing density to the grain productivity Y_E in oats.

Cultivar	Equation (SP=a±bx)	R²	P (bx)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
Soybean/Oats system 2015(AY)							
Brisasul	$2397 + 2.332x$	0.97	*	250	540	2980^B	3656^A
URS-Taura	$2586 + 1.162x$	0.82	*	250	570	2877^A	3248^A
2014 (UY)							
Brisasul	$3703 + 3.997x$	0.92	*	250	500	4702^B	5702^A
URS-Taura	$3698 + 4.134x$	0.93	*	250	505	4732^B	5786^A
2013 (FY)							
URS-Taura	$4354 + 3.163x$	0.97	*	250	420	5145^B	5682^A
General	$3355 + 3.124x$			250	500	4136^B	4917^A
Corn/Oats system 2015(AY)							
Brisasul	$1968 + 3.339x$	0.90	*	250	570	2803^B	3871^A
URS-Taura	$3211 + 2.814x$	0.94	*	250	600	3915^B	4899^A
2014 (UY)							
Brisasul	$3858 + 3.184x$	0.92	*	250	520	4654^B	5514^A
URS-Taura	$3737 + 3.190x$	0.90	*	250	510	4535^B	5364^A
2013 (FY)							
Brisasul	$4410 + 2.411x$	0.93	*	250	525	5013^B	5676^A
URS-Taura	$5760 + 1.649x$	0.99	*	250	575	6172^B	6708^A
General	$3824 + 2.764x$	-	-	250	550	4515^B	5344^A

R^2: Determination coefficient; P(bx): angular parameters that measure the significance in 5% level of error probability; SP: straw productivity;Y_E: value of straw productivity estimated by de regression model; RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line do not differ statistically from one another by the Skott & Knott model in 5% level of error probability.

Table 4 showed a linear behavior with positive parameter of inclination through the increment of the seeds density. In the use of the optimal density of sowing to the grain productivity in the linear regression model of the straw productivity, the use of the adjusted density showed favorability to the straw elaboration in the increment of seeds density, except in the URS Taura cultivar in acceptable year of cultivation (2015), which did not show any changes. In the general model in soybean/oat system, regardless of agricultural year and oat cultivar, the density of 500 seeds m^{-2} adjusted to the highest grain productivity, it indicated an expectancy of straw productivity of 4917 kg ha^{-1}, higher than the recommended sowing density with 4136 kg ha^{-1}, increase in almost 800 kg ha^{-1} of straw directed to the soil.

In the corn/oats system (Table 4), the favorability of expression of the straw productivity through the adjusted density was also statistically different to the recommended sowing density in all the conditions. In the general model in corn/oats system, regardless of agricultural year and oat cultivar, the density of 550 seeds m^{-2} adjusted to the highest grain productivity indicated an expectancy of straw productivity of 5344 kg ha^{-1}, higher than the density of recommendation with 4515 kg ha^{-1}, increasing in morethan 800 kg ha^{-1} of straw directed to the soil. It is possible to highlight the favorability of expression of the straw productivity in the corn/oats in comparison to the soybean/oats system, suggesting that the system of higher N-residual release (soybean/oats) promotesmore pronounced effects on grains elaboration than straw, unlikethe corn/oats system.

Studies carried out with different winter's species showed the elevated performance of the white oat in the straw productivity seeking the soil protection. The straw productivity is essential as organic residue to the succession cultures, promotes improvement of the physical and chemical quality of the soils,erosion control and soil resistance to compaction (Marchãoet al., 2007; Silva et al., 2015). The use of the black oat straw on the soil coverage reduced the infestation of invasive plants, benefitting the productivity of soybean (Fleck et al., 2009).

The elevated performance of the white oat in the straw production seeking the soil protection qualities, direct sowing system, which is directly dependent of the volume and quality of the biomass (Silva et al., 2008). Oliveira et al. (2011) commentedon the importance of detecting the genetic differences among the oat cultivars in the straw and grains production. The growth and the biomass production in the oat are stronglylinked to the nitrogen availability, index of leaf area, photoperiod, temperature, sun radiation and hydric availability (Almeida et al., 2011; Mantai et al., 2016). Therefore, the use of sustainable and low cost technologies such as the management of vegetation cover, the use of N-residual and the adjustment of the sowing density in oat may favor the straw productivity which returns to the soil on the erosion control, moisture maintenance and protection of the culture in early stage (Silva et al., 2012; Romitti et al., 2016).

In Table 5, regardless of oat cultivar, agricultural year and succession system, the increment of the sowing density on the harvest index presented quadratic behavior. In the soybean/oats system, the use of the optimal sowing density to the grain productivity in the quadratic regression model to the predictability of the harvest index indicated absence of differences between the recommended and adjusted density. However, in acceptable year of cultivation (2015), the URS Tauracultivar presented the highest expression of the harvest index with the adjusted density. In the general model, in soybean/oats system, regardless of agricultural year and oat cultivar, the adjusted and recommended seeds density did not differ on the expression of the harvest index, with an estimated value of 0.44. In the general model, in corn/oats system, no differences were observed; however, there wasa reduction of expression of this variablein this cultivation condition, with harvest index of 0.40. The results obtained suggested that the increase of the adjusted density, besides presenting the highest expression to the grain productivity (Table 2), also favored the straw productivity (Table 4) in the same proportion. Therefore, not changing the relation between straw and grains, and consequently, maintaining the expression of the harvest index between recommended and adjusted seed density. The results obtained on the harvest index, reasserted what was mentioned about the corn/oats system, through a higher expression of straw productivity than in the soybean/oats system. Therefore, a higher straw production directly decreases the expression of harvest index.

Duarte et al. (2013) considered the harvest index an identification component of peanut genotypes tolerant to water stress. In corn cultivation, the harvest index was used in the identification of agronomic performance to different climate scenarios in Central-West of Brazil (Minuzzi and Lopes, 2015). Fageria et al. (2007) commentedon the necessity of analysis of the harvest index in studies with rice, because it is closely associated with the increase of the grain productivity.Ludwig et al. (2010)used the analysis of the productivity and the harvest indexin the definition of soybean cultivars better adjusted to the period and the sowing density.Silva et al. (2015)observed a higher increment of expression of the harvest index in oat cultivation on the soybean/oats system in comparison to the corn/oats through the higher expression of the productivity directed to grains. The same authors also observed a strong plasticity of the oat cultivars to the increase of the sowing density, condition that may favor higher stability of the harvest index by the maintenance of the relation between straw and grains, condition also observed in this study.The isolated analysis of the harvest index does not allow identification of efficient managements,because, the grain productivity is also dependent on the minimum adequate expression of leaves and stems in the biomass composition (Silva et al., 2015). Schaedler et al. (2009) studying white oat cultivars of mid and late cycle obtained harvest index varying from 0.33 to 0.48.

Conclusion

In the increment of the sowing density in oats, the biological and straw productivity evidenced linear behavior and the grains productivity and the harvestindex evidenced quadratic behavior, regardless of cultivar, agricultural year and succession systems.

It is possible to indicate higher sowing density to the maximization of the biomass and grains productivity, withdensity adjusted around 500 seeds m^{-2} in the main succession systems.

In cultivars of high and reduced tillering, the adjusted density in relation to the recommended sowing density enhanced the biological and straw productivity, regardless of agricultural year and succession system.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 5. Regression equation and its parameters in estimative of harvest index by the recommended and adjusted sowing density to the grain productivity (Y_E) in oats.

Cultivar	Equation ($HI = a \pm bx \pm cx^2$)	R²	P (cx^2)	Density (s m^{-2})		Y_E	
				RC	AJ	RC	AJ
Soybean/Oats system							
2015 (AY)							
Brisasul	$0.42 + 5.50.10^{-4}x - 6.6 \times 10^{-7}x^2$	0.95	*	250	540	0.52^A	0.52^A
URS-Taura	$0.39 + 8.39.10^{-4}x - 8.5 \times 10^{-7}x^2$	0.99	*	250	570	0.55^B	0.59^A
2014 (UY)							
Brisasul	$0.30 + 3.59.10^{-4}x - 5.0 \times 10^{-7}x^2$	0.89	*	250	500	0.36^A	0.35^A
URS-Taura	$0.32 + 4.03.10^{-4}x - 5.5 \times 10^{-7}x^2$	0.99	*	250	505	0.39^A	0.38^A
2013 (FY)							
Brisasul	$0.42 + 2.55.10^{-4}x - 4.4 \times 10^{-7}x^2$	0.91	*	250	410	0.46^A	0.45^A
URS-Taura	$0.38 + 5.61.10^{-5}x - 2.0 \times 10^{-7}x^2$	0.89	*	250	420	0.38^A	0.37^A
General	$0.37 + 4.10.10^{-4}x - 5.3 \times 10^{-7}x^2$		*	250	500	0.44^A	0.44^A
Corn/Oats system							
2015 (AY)							
Brisasul	$0.35 + 7.03.10^{-4}x - 8.2 \times 10^{-7}x^2$	0.99	*	250	570	0.47^A	0.48^A
URS-Taura	$0.33 + 3.84.10^{-4}x - 4.2 \times 10^{-7}x^2$	0.99	*	250	600	0.40^A	0.41^A
2014 (UY)							
Brisasul	$0.29 + 4.79.10^{-4}x - 5.8 \times 10^{-7}x^2$	0.94	*	250	520	0.37^A	0.38^A
URS-Taura	$0.35 + 3.07.10^{-4}x - 4.6 \times 10^{-7}x^2$	0.99	*	250	510	0.40^A	0.39^A
2013 (FY)							
Brisasul	$0.36 + 2.24.10^{-4}x - 2.9 \times 10^{-7}x^2$	0.91	*	250	525	0.40^A	0.40^A
URS-Taura	$0.30 + 1.81.10^{-4}x - 2.3 \times 10^{-7}x^2$	0.98	*	250	575	0.33^A	0.33^A
General	$0.33 + 3.79.10^{-4}x - 4.6 \times 10^{-7}x^2$		*	250	550	0.40^A	0.40^A

R^2: Determination coefficient; P(cx^2): angular parameter that measure the significance in 5% level of error probability; HI: harvest index; $\mathbf{Y_E}$: value of harvest index estimated by the regression model;RC: recommended; AJ: adjusted; FY: favorable year; AY: acceptable year; UY: unfavorable year. Means followed by same capital letter in the line donot differ statistically from one another by the Skott& Knott model in 5% level of error probability.

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Full Length Research Paper

Reaction of *Coffea canephora* clones to the root knot nematode, *Meloidogyne incognita*

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In the Western Amazon, Brazil, *Coffea canephora* Pierre is the main species cultivated because it has good adaptation to the climate and soils of the region. Among the factors that limit the yield of this crop, *Meloidogyne* or root-knot nematode, caused by the root knot nematode, is an aggressive disease present in the state of Rondonia. The aim of this study was to evaluate the reaction of fifteen clones of *C. canephora*, belonging to the cultivar BRS Ouro Preto, to *Meloidogyne incognita* (Est I2). Therefore, six seedlings with six months of growth in a nursery from each one of the clones of the cultivar were transferred to pots containing a sterilized substrate in a greenhouse. Following the same design, three clonal genotypes selected from the cultivar IAC Apoatã (*C. canephora* botanical variety Robusta) served as resistant controls, and seedlings of *C. arabica* of the Obatã line and tomato (*Solanum lycopersicum*) cv. Santa Clara (20 days after germination) as susceptible controls, for a total of 120 pots. A 10 ml suspension containing 5000 eggs of *M. incognita* was inoculated on each plant, and after 150 days, they were evaluated with regards to root fresh weight (FWR), number of galls (NG), number of eggs (NE), and the nematode reproduction factor (RF = final population/initial population). Except for the clone K98M-0061, which exhibited galls (29.17), all the clones of the variety BRS Ouro Preto showed resistance at levels equivalent to those of the controls of the var. Apoatã (RF <1) and good root development. Thus, it can be concluded that the total composition of clones of the variety BRS Ouro Preto is resistant to *M. incognita* in Rondonia.

Key words: Coffee, *Meloidogyne*, plant selection.

INTRODUCTION

Brazil is the world's largest producer and exporter of coffee (*Coffea* spp.), with a total production area of 1,942.1 thousand hectares (Conab, 2016). The state of Rondonia is the largest coffee-growing area in the North region of Brazil, and is the second largest producing state of conilon coffee (*Coffea canephora*) in Brazil, exceeded only by Espírito Santo (Conab, 2016). In addition to soil and climate conditions, other factors can limit the yield of conilon coffee, such as the occurrence of pests and diseases (Faganello, 2006). Among the diseases that damage the coffee crop, those caused by plant parasite nematodes can cause a decline of approximately 15% in world production and 20% in Brazilian production (Ito et al., 2008). Among the plant nematodes that have important economic consequences in diverse crops throughout the world, those of the genus *Meloidogyne*, also known by the generic name "root-knot nematodes", are responsible for approximately 75% of these losses (Lordello, 1984). In recent years, surveys have shown an extensive array of *Meloidogyne* spp. ability to parasitize coffee roots, and distribution of this species that differs widely from one country to another. Such species are widely distributed in coffee fields in Brazil, where they cause considerable losses and damage according to the species, the population density and the susceptibility of the cultivar (Barros et al., 2014; Contarato et al., 2014; Salgado; Rezende, 2010). Currently, 18 species have already been described as parasites in coffee fields throughout the world (Humphreys-Pereira et al., 2014). Five of them occur in Brazilian coffee fields: *Meloidogyne coffeicola* Lordello and Zamith, *Meloidogyne exigua* Goeldi, *Meloidogyne hapla* Chitwood, *Meloidogyne incognita* (Kofoid & White) Chitwood, and *Meloidogyne paranaensis* Carneiro (Salgado et al., 2015; Silva et al., 2013), and all have been classified as regulated non-quarantined pests (Brasil, 2009), that is, their spread between crop fields and regions should be impeded through prohibition of sale of contaminated seedlings.

In Brazil, *M. incognita* is considered as one of the most harmful to coffee fields because the damage it causes might not only lead to death of the plant but might expose the root system of the plants to the attack of other diseases and reduce the capacity of the plant to absorb water, leaving it more susceptible to drought, which occurs from May to September, as has been observed with regard to the occurrence of *Fusarium* wilt and *Rhizoctonia* disease in crop fields of up to two years of age in Rondonia (Vieira Júnior et al., 2015).

Although, *C. canephora* is considered more resistant to nematodes than *C. arabica* (Barbosa et al., 2014; Ito et al., 2008). Vieira Junior et al. (2008) report the occurrence and the symptoms of root-knot nematode in different municipalities of the state of Rondonia. A recent study confirmed two main species as parasites of *C. canephora* in production areas in Rondonia: *M. exigua* and *M. incognita*. Of these two, *M. incognita* has greater occurrence in all the municipalities evaluated (Vieira Júnior et al., 2015). In another study, the species *M. incognita* was also identified in a sample of coffee roots from five coffee fields in the municipalities of Cacoal (two areas), Nova Londrina, Ji-Paraná and Ouro Preto do Oeste, showing that it is one of the species associated with coffee growing in the state (Pissinati et al., 2015). Therefore, *M. incognita* is believed to be the most widespread and most important species in the state of Rondonia.

With the intention of service to regional coffee growers, Embrapa Rondonia released a synthetic cultivar in 2012 composed of 15 clones of *C. canephora*, designated as 'BRS Ouro Preto' (RNC/MAPA No. 29486). Some of the main characteristics of this cultivar are uniform maturation of fruit, lower biennial yield differences, mean yield of 70 bags/hectare of hulled coffee under medium technology conditions, large coffee beans, good beverage, and tolerance to diseases and to the main abiotic stresses- low altitude, high mean temperature and relative humidity, and medium to high water deficit (annual water deficit = 150-200 mm) (Ramalho et al., 2015). Although, the variety released offers adequate levels of resistance to rust and *Cercospora* leaf spot (Sera et al., 2007; Vieira Junior et al., 2015), a study has not yet been carried out to evaluate the reaction of the clones that make up this cultivar to the species of *Meloidogyne* present in the state.

Due to the potential of this cultivar for growing in the state of Rondonia, and the impact of the root-knot nematode on coffee growing in Rondonia, the aim of this study was to characterize the clones of the cultivar 'BRS Ouro Preto' with regard to resistance to the root-knot nematode, *M. incognita* (Est I2).

MATERIALS AND METHODS

To obtain inocula of *M. incognita*, samples of the nematode were collected from under the canopy of naturally infested plants from a coffee field in the municipality of Ji-Paraná, RO. The inoculum was then multiplied in a greenhouse by inoculating tomato plants cv. Santa Clara with egg masses derived from a single female.

With establishment of the pure sample, enzymatic characterization of the esterase profile was carried out using the electrophoresis technique (Carneiro and Almeida, 2001) in the Plant Pathology Laboratory of Embrapa Clima Temperado – Pelotas, RS. Recognition of a single pattern of esterase allowed identification of *M. incognita* (Est I2) in a pure sample. In the following step, seedlings of the fifteen clones that make up the cultivar of *C. canephora* 'BRS Ouro Preto' (K98M-0016; 0057; 0061; 0069; 0073; 0088; 0089; 0125; 0130; 0160; 0167; 0187;

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Table 1. Analysis of variance (ANOVA) on fresh weight of roots (FWR), number of galls (NG), number of eggs (NE), and reproduction factor (RF) of the nematode *M. incognita* evaluated in 15 clones of *C. canephora* (conilon) 'BRS Ouro Preto' in comparison with four controls.

SV	DF	FWR	NG[1]	NE[1]	RF
Treatment	18	4.54**	23.49**	9.89**	11.68**
Clones	14	3.44**	15.19**	2.26*	4.17**
Controls	3	9.67**	69.75**	37.57**	48.79**
Clones vs Controls	1	4.50*	4.01*	33.69**	5.60*
Residue	95				
Total	113				
$Mean_{General}$		36.76	5.39	1.78	0.36
$Mean_{Clones}$		35.78	4.64	1.86	0.37
$Mean_{Controls}$		40.46	8.17	1.48	0.30

[1]Data transformed to square root of the value. **: Significant at 1% probability.

00189; 00197; 0199) with six months of age, were transplanted to polyethylene pots (8 L capacity) containing a sterilized substrate composed of sand, vermiculite, natural soil and organic compost (1:1:1:1). Two weeks after transplanting the seedlings, extraction of eggs from the tomato plants was carried out using the Hussey and Barker (1973) technique. Each coffee plant (or pot) was inoculated separately with a 10 ml suspension containing 5,000 eggs of *M. incognita* (Est I2). Three clonal genotypes ('A1322', 'A1326', 'A1327') selected for resistance to *M. incognita* in the cultivar IAC Apoatã (*C. canephora*, botanical variety Robusta) were evaluated as resistant controls. The *C. arabica* variety Obatã IAC 1669-20 (RNC/MAPA Nº 2956) was used as a susceptible control, arising from a cross (Sarchimor x Catuaí), as well as tomato cv. Santa Clara seedlings. The coffee plants were inoculated after transplanting at six months of age and those of the tomato plant at twenty days of age.

The trials were carried out in a post-and-rafter type greenhouse, a structure with treated wood, covered with anti-UVB plastic film of 120 µ, with front ventilation and free sides at the Universidade Luterana do Brasil in the municipality of Ji-Paraná (10°51'44.36"S, 61°57'29.33"O).

At 90 days after inoculation (DAI), the tomato plants were evaluated with regards to reaction to *M. incognita* (Est I2). Evaluation of the coffee plants occurred at 150 days after the date of inoculation. For that purpose, the roots of each plant were separated from the shoots, washed, weighed, evaluated with regards to the number of galls, and processed (Hussey and Barker, 1973) for evaluation of the number of eggs and determination of the reproduction factor (RF = final population / initial population) in the different genotypes. Cultivars with RF< 1.00 were considered resistant; with RF = 0.00, immune; and with RF > 1.00, susceptible (Oostenbrink, 1966).

To assist in data interpretation, the RF values were used to classify the reaction of the coffee plants to *M. incognita* by the criteria of Seinhorst (1967), in which plants with RF<1 are considered poor hosts (PH); with RF≥1, good hosts (GH); and RF = 0, non-hosts (NH). The susceptibility of the plants was also classified following the criteria recommended by Sasser et al. (1984), in which plants whose number of galls throughout the root system is less than ten are considered resistant (R) and greater than or equal to ten as susceptible (S). To quantify the resistance response, a completely randomized design was used with six replications for each treatment (clone), considering the following model:

$$Y_{ij} = u + G_i + e_{ij}$$

Where, $Y_{ij} =$ observation of the i-th clone in the j-th replication, $u =$ overall mean, $G_i =$ effect of the i-th clone and $e_{ij} =$ random error involving the i-th clone and in the j-th replication. To test the equality hypothesis between the means of groups, the Scott-Knott test was used at 5% probability. For that purpose, a single plant (or pot) was considered an experimental unit, and each genotype was evaluated through 6 plants (or pots).

The estimates of genotypic, environmental and phenotypic variance were obtained from the least squares estimation method so as to quantify the proportion of total variance due to the effects of genotypes (clones) and environment (error) (Cruz et al., 2012). Broad-sense heritability, the coefficients of genotypic and environmental variation, and the intraclass correlation were estimated from the components of variance (Rocha et al., 2015). Broad-sense heritability measures the relative proportion between the genotypic and environmental effects in expression of the characteristics. It is considered the most important component of the estimates of genetic progress obtained from asexual propagation, which, according to Vencovsky and Barriga (1992), can be estimated by the expression:

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2}$$

Where, h^2 is broad-sense heritability, σ_g^2 is genotypic variance and σ_e^2 is environmental variance.

The coefficient of environmental variation, estimated by the ratio between the root of environmental variance and the mean of the experiment, was used to provide a measure of experimental precision. For its part, the coefficient of genetic variation, estimated by the ratio between the root of genotypic variance and the mean of the experiment was interpreted to verify the predominance of the genetic component in expression of this characteristic.

RESULTS AND DISCUSSSION

According to the F test of analysis of variance, the effects of clones, controls and of the clone × control contrast were significant at 1% probability for fresh weight of roots (FWR), number of galls (NG), number of eggs (NE) and the reproduction factor of the nematode *M. incognita* (RF) (Table 1). The significance of the effect of clones × control contrast indicates that the three clones of the *C. canephora* variety Apoatã and *C. arabica* of the Obatã line showed significant differences from the genotypes evaluated.

The coefficient of variation that weights the mean value of the experiment and the variance of the residue was interpreted to quantify the precision of the experiment (Table 2). When there is no previous knowledge of the

Table 2. Estimates of the genetic parameters of fresh weight of roots (FWR), number of galls (NG), number of eggs (NE), and the reproduction factor (RF) of the nematode *M. incognita* evaluated in 15 clones of *C. Canephora* (conilon) 'BRS Ouro Preto'.

Genetic parameters	FWR	NG	NE	RF
σ_g^2	52.76	1.23	0.04	0.01
σ_e^2	15.35	0.08	0.02	0.00
σ_p^2	37.41	1.15	0.02	0.01
h^2	70.91	93.41	55.72	75.99
$\hat{\rho}$	28.89	70.28	17.34	34.54
CV_g	17.10	61.40	11.03	26.94
CV_e	26.11	39.17	25.84	32.74
CV_g/CV_e	0.65	1.57	0.43	0.82

σ_g^2: Genotypic variance, σ_e^2: environmental variance, σ_p^2: phenotypic variance, h^2: heritability for selection based on the mean of the genotypes, $\hat{\rho}$: intraclass correlation, CV_g: coefficient of genotypic variation, CV_e: coefficient of environmental variation, CV_g/CV_e: ratio between the coefficients of genotypic and environmental variation.

difficulty of measuring a characteristic, the coefficient of variation can be classified in accordance with the criteria proposed by Pimentel-Gomes (2009), which classifies values of the coefficient of variation from 20 to 30 as associated with high data dispersion. It was observed that the estimates of the coefficient of variation were equivalent to those obtained by Ito et al. (2008) and Gonçalves et al. (1996), and due to the heterogeneity of variance, the evaluations coming from counting were transformed using the square root of the original value (Tables 1 and 2).

Cloning of plants, whether by planting of orthotropic stem cuttings or by tissue culture, allows the complete genotypic value of the individual to be exploited. The magnitudes of genotypic variance and of environmental variance indicate a predominance of the effect of genotypes on the expression of this characteristic, which is the result of the differentiated genetic expression among clones of the variety. The estimates of heritability of 0.7 for FWR, 0.93 for NG, 0.55 for NE, and 0.75 for RF indicated the predominance of the genotypic component in expression of these characteristics (Table 2).

The susceptible controls represented by the tomato cv. Santa Clara and Arabica coffee acted as good hosts (GH) for *M. incognita* at 90 DAI (tomato) and 150 DAI (Arabica coffee), leading to a high reproduction factor RF>1 (11.71 and 1.3, respectively) and high number of galls (791 and 34, respectively), confirming the pathogenicity of the inoculum of the nematode used in this experiment. The fifteen clonal genotypes of the cultivar 'BRS Ouro Preto' reacted in a resistant manner to *M. incognita* at 150 DAI, exhibiting a reproduction factor less than one (RF<1), and were classified as poor hosts (Seinhorst, 1967) (Table 3).

Nevertheless, the clone K98M-0061 had a susceptibility (S) response by the classification of Sasser et al. (1984) in relation to the number of galls produced in the roots of the coffee plant (Table 3). Moura et al. (1997) reported that the presence of galls is a symptomatological aspect of the plant resistance response, and that galls should not be considered in an isolated manner in evaluation of resistance because resistant plants can also form galls in the presence of the nematode in resistance trials. In a study carried out by Silva et al. (2006), it was also found that part of the clones considered resistant (RF<1) responded as susceptible in relation to number of galls. This fact suggests that although the nematode induced formation of galls, the parasite reproduced very little in all the clones evaluated in this study (Table 3).

In relation to the controls of Apoatã evaluated in this experiment, all were classified as non-hosts (RF=0); they did not form galls or formed only a small number, and all the genotypes responded as resistant (Table 3). Genotypes of *C. canephora* of the botanical variety Robusta Apoatã have been used as an alternative in control of root-knot nematode in the form of rootstock or otherwise. Among them, the cultivar IAC 2258 is recommended for planting in areas infested with the nematodes *M. exigua*, *M. incognita* (Kofoid & White) Chitwood and *M. paranaensis* (Andreazi et al., 2013). In areas infested by the pathogen, results were found in which the mean yield over six crop seasons of non-grafted susceptible genotypes was up to 55% less than the yield of those genotypes grafted onto IAC Apoatã 2258 (Barbosa et al., 2014). In a study performed in an area naturally infested by *M. incognita* in Paraná, Dias-Arieira et al. (2012) found that 34 months after planting, the cultivar Iapar 59 grafted onto Apoatã 2258 had 448% greater coffee bean production than the treatment with the non-grafted Iapar 59 cultivar. This study shows the effectiveness of the rootstock Apoatã in maintaining production of the scion, even in areas infested by the nematode.

In the present study, it was also observed that the clones K98M-0057and K98M-184 obtained root development (FWR= 44.48 and 52.89) similar to the Apoatã controls according to the Scott-Knott mean grouping test at 5% probability. The other clones exhibited less developed root systems, with the two lowest values of FWR being identified in clone K98M-073 and K98M-167 (Table 3). According to Sera et al. (2006), there is a possibility of success in selecting clones that have a

Table 3. Fresh weight of roots (FWR), number of galls (NG), number of eggs (NE), reproduction factor (RF), and response of clones of *C. canephora* 'BRS Ouro Preto', in comparison with three standard clones for resistance from cv. IAC Apoatã, and for susceptibility from cv. Obatã (*C. arabica*), in relation to the standard for susceptibility (tomato, *S. lycopersicum* cv. Santa Clara) to root-knot nematode *M. incognita* (Est I2) at 150 days after inoculation with 5000 eggs of the nematode/plant.

Clone	FWR[a]	NG[b]	C[1]	NE[c]	RF[d]	C[2]
K98M-0016	38.45[b]	1.50[c]	R	670[c]	0.27[c]	PH
K98M-0057	44.49[a]	2.00[c]	R	670[c]	0.19[c]	PH
K98M-0061	36.51[c]	29.17[a]	S	1000[c]	0.23[c]	PH
K98M-0069	37.87[c]	2.00[c]	R	650[c]	0.18[c]	PH
K98M-0073	22.81[d]	5.67[b]	R	1000[c]	0.33[c]	PH
K98M-0088	38.08[c]	3.50[c]	R	500[c]	0.15[c]	PH
K98M-0089	32.2[c]	5.00[b]	R	1170[c]	0.23[c]	PH
K98M-0125	37.79[b]	4.00[b]	R	1000[c]	0.20[c]	PH
K98M-0130	31.29[c]	2.50[c]	R	2000[b]	0.45[b]	PH
K98M-0160	35.28[c]	2.33[c]	R	670[c]	0.16[c]	PH
K98M-0167	24.53[d]	2.50[c]	R	500[c]	0.16[c]	PH
K98M-0184	52.9[a]	2.50[c]	R	1000[c]	0.28[c]	PH
K98M-0189	31.42[b]	1.50[c]	R	170[c]	0.00[d]	PH
K98M-0194	36.03[b]	1.33[c]	R	330[c]	0.21[c]	PH
K98M-0199	37.02[c]	2.83[c]	R	330[c]	0.11[c]	PH
C. Arabica cv. Obatã	23.13[d]	34.00[a]	S	6500[a]	1.30[a]	GH
Apoatã 1322	51.51[a]	0.83[c]	R	0[d]	0.00[d]	NH
Apoatã 1326	45.08[a]	1.17[c]	R	0[d]	0.00[d]	NH
Apoatã 1327	42.09[a]	0.67[c]	R	0[d]	0.00[d]	NH
Tomato Sta, Clara	15.66	791	S	508000	11.71	GH

[1] Response according to Sasser et al. (1984), in which R= resistant and S= susceptible; [2] Response according to Seinhorst (1967), in which NH= non-host; PH= poor host, and GH= good host; [a] fresh weight of roots; [b] number of galls; [c] number of eggs; [d] reproduction factor; Significant at 1 and 5% probability by the Scott-Knott test.

more voluminous root system, because this is a favorable characteristic for a good rootstock cultivar.

According to Pasqualotto et al. (2015), the management strategies for reducing the plant nematode population are crop-based, biological, chemical and genetic, the last of which is the most effective and economically viable. Therefore, selection of resistant clones is one of the most promising alternatives for minimizing losses caused by the nematodes in the coffee crop because it allows nematode populations to be maintained below the level of economic damage (Wangai et al., 2014). However, it is important to emphasize that generally, the levels of resistance of coffee genotypes are related to the species and/or strains of associated Meloidogyne. Sera et al. (2006) found that 24 clones of *C. canephora* exhibited a resistance response to *M. incognita* strain 1, but when exposed to *M. incognita* strain 2, only 12 clones showed resistance.

Therefore, due to the occurrence of other species of *Meloidogyne* associated with the coffee plant in the state of Rondonia, it becomes necessary to carry out new trials so as to evaluate the reaction of the cultivar BRS Ouro Preto to other nematodes. Among them, *M. exigua* is one of the most important because in surveys undertaken in the state, this species was considered as the most frequent in coffee-producing areas (Vieira Junior et al., 2015).

In addition, one of the obstacles of nematology research in agricultural crops is the absence of methodological standardization in relation to the best population density of the nematode that is able to express adequate levels of resistance/susceptibility of the genotypes, and in relation to the best date for evaluation, especially in the case of perennial crops, like coffee. Since species like *M. incognita* and *M. paranaenses* are more aggressive to the coffee plant (Ito et al., 2008), Sera et al. (2006) suggested that these nematodes should be tested with low levels of inoculum because inoculum pressure could induce a resistant plant to act as susceptible, generating misleading results. According to Machado et al. (2015), using very high initial populations of the nematode, the roots of the host plant can be severely damaged by the attack of the pathogen and there is substantial competition between the individuals for feeding sites of the host, making the reproduction factor at the end of the experiment remain below 1.0, which characterizes a resistance reaction, even in plants susceptible to the nematode (Greco and Di Vito, 2009).

In this study, a concentration of 5000 eggs/eight-liter pot was used; however, new experiments with different nematode concentrations, as well as trials in a greenhouse and in the field should be carried out to better understand the resistance response of this cultivar to the different species and strains of the root-knot nematodes that act as parasites of the coffee plant.

Conclusion

All the clones of the cultivar, BRS Ouro Preto can be considered resistant to *M. incognita* (Est I2) (RF<1) in spite of the larger number of galls observed in clone 61, indicating that this cultivar is resistant to the pathogen. The clones of Apoatã evaluated are not hosts of *M. incognita* (Est I2) and they can serve as an important tool in the control of the pathogen and in plant breeding programs aiming at resistance to this nematode. New studies with other species and strains of root-knot nematode under different environmental conditions should be carried out to quantify the resistance response of this variety.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment of the performance of informal women entrepreneurs in Enugu State, south east Nigeria

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A simple theoretical model of informal women co-operatives micro credit societies' participation in providing access to credit to informal women entrepreneurs was used to explain their coping strategies under liquidity constraints. A total of 432 questionnaires were administered to informal women entrepreneurs from September 2013 to January, 2014 for primary data collection in Enugu State, south east Nigeria. Also, a total of 60 questionnaires were administered to the managers of informal women co-operatives micro credit societies during the same period for primary data collection. Data were analyzed with descriptive and simple linear regression model. The results portrayed the informal women entrepreneurs in the light of economic operators who depended on agriculture and allied activities for their sustenance. Their operations were characterized by poor resource situations resulting from lack of access to credit, which obviously necessitated the need for involvement in organizing informal-women-co-operative micro-credit society. Their organizational structure and operational procedure allowed for optimization of efficient management and use of funds. The respondents were mostly credit worthy, thus debunking the belief that the poor misuse credit. There was a high level of awareness among the creditors concerning the performance, creditability, promptness and reliability of the women's cooperatives. The informal women's cooperatives are still highly dependent on the NG/Os for their operations and all the credits disbursed are from NGOs. Quantitative analysis showed that: Credit repaid was statistically significant and positively related to the amount of credit disbursed. The regression analysis showed that repayment was related to savings generated by the informal women's groups. Total loan repaid was found to be statistically significant with positive coefficient of (0.8) and R^2 value of 0.79. Thus the informal women's co-operatives have increased the volumes of savings of their clients as well as the volume of credit available to their clients. Thus government should provide incentives to informal-women-entrepreneurs by linking formal micro-finance institution with organized informal women's micro credit societies for sustainable rural micro-finance programmes in Nigeria.

Key words: Informal-women-entrepreneurs, micro-finance, co-operatives, Nigeria.

INTRODUCTION

Micro Small and Medium Enterprises (MSMEs) is a core element in fostering economic growth, employment and poverty alleviation NBS, SMEDAN (2010). However, access to and costs of finance are reported to be severe problems for Micro Small and Medium Enterprises (MSMEs) in developing countries (Vossenberg, 2013). Generally, MSMEs face higher transaction costs than larger enterprises in obtaining short term credit to finance working capital (Kessy, 2009; Hashi and Toci, 2010). In addition, information asymmetries have continued to restrict the flow of finance to MSMEs in developing countries (Binswanger and Rosenzweig, 1986; Stiglitz and Weiss, 1981). Nigeria as a developing country has attempted to meet the financial needs of entrepreneurs at the MSME levels, through adoption of varied methods, especially through state led and main stream formal micro finance institution like the National Poverty Eradication Program (NAPEP), Community Banks (CBS), Peoples Bank (PBs), Family Economic Advancement Programs (FEAPs) etc (Opata and Nweze, 2009). One key problem of such institutions was they were not designed to function as true financial intermediaries that mobilize deposits to make loans, they had no obligation to operate under financial viability constraints, neither were they driven by commercial financial performance criteria. Several factors, including the chronic dependency on government funds, lack of competition, bureaucratic obstacles and limited accountability contributed to bring about bad loans, extremely inefficient operations, loan recovery problems, political patronage and eventual collapse or un-sustainability of their credit facilities (Yaron, 1992).

Availability of microfinance derivatives has been viewed as a critical element in the development of women's MSMEs in Nigeria (Kessy, 2009; Hashi and Toci, 2010). However, the above institutions were known to be biased against women (Ogunleye, 2005; Vossenberg, 2013). Thus the enterprises owned by women were small in size, have limited prospects for profitability and fail to provide collateral for obtaining loans (Vossenberg, 2013). Following years of disappointing experiences with this approach in Nigeria, policy makers and development practitioners have been searching for new and more sustainable models of rural credit. In 2005, a Microfinance Policy, which provides a regulatory and supervisory framework, was initiated by the Nigerian government in order to enhance the flow of financial services to micro, small and medium enterprises in the country (MSMEs) (Central Bank of Nigeria, 2005) and this was to be implemented through the private sector. This policy document was subsequently reviewed in 2007 and 2011 and 2013 (CBN, 2012, 2014). Despite the introduction of new finance policy by central bank of Nigeria and the subsequent revision of the document in 2007, 2011, and 2013, key problems continued to be a road block in empowerment of female entrepreneurs of MSMEs in the country. This includes poor credit penetration, issue of collateral, complex application procedures, asymmetric information, and deprivation of the right of land inheritance which can be used as collateral in the process of obtaining loans. Furthermore, the absence of well developed financial markets makes it difficult for MSMEs especially women's enterprise to grow to their optimal size (Okoro, 2007; Coleman and Robb, 2009; Klapper and Parker, 2010; Peprah, 2012; Fapohunda, 2013).

Various agencies including: Nigerian Federal Ministry of Women Affairs and Development, Enugu State Ministry of Women Affairs and Development and, Microfinance Banks who are interested in economic empowerment of women for increasing their access and control over economic resources and opportunities were all interested in scientific evidence on access to finance by informal women entrepreneurs. This is because informal women entrepreneurs, in particular, find it difficult to borrow from banks because most do not have bank accounts, have no collateral, and do not know the procedures for accessing bank loans (Okorie, 1998). Thus the informal women co-operative microfinance providers still remain the only source of funds available to informal women entrepreneurs who have not been able to access the formal sector microfinance institutions. This has serious implications for sustainability of the system. Integration of informal women co-operative microfinance society with the formal sector microfinance institution will serve as a vital source of income and solvency required in informal business activities carried out by informal women entrepreneurs. This is needed especially for the growth of agricultural productivity and food security as these women are engaged in production as well as commodity value chain. They target production as well as post harvest handling. Their performance leads to poverty reduction, through asset creation associated with a series of loan financed investments, higher income that will help women to better perform their reproductive roles as brokers of health, nutritional, and educational status of other household members. To ensure that machineries for financial inclusion are put in place, a study of this nature is also required in Africa with Nigeria as a case study. This scrutinized the performance of informal women co-operative micro finance society in financial intermediation. It is in view of this that this study analyzed the dynamics of credit accessibility to women entrepreneurs through informal women's cooperative micro finance societies in Nigeria. Specifically the study described: (i) the socio-economic characteristics of informal women entrepreneurs and their involvement in informal women's cooperative MFIs credit and savings activities; (2) analyzed the performance of informal women's cooperative microfinance societies in terms of the amount of credit disbursed, amount of savings generated and number of clients reached; and described

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the operational procedures, sustainability and linkages of selected informal women's cooperative microfinance societies.

MATERIALS AND METHODS

Study area

The study area was Enugu State, south eastern Nigeria which is 512 km away from capital, Abuja. The study was conducted from September, 2013 to September, 2014. The state lies approximately between longitudes 6° 53^1 and 7° 55^1 East of the Greenwich meridian and latitudes 5^{0}56^1 and 7^0 05^1 North of the equator (Anyadike, 2002). The State occupies an area of about 8,022.95 km^2 (Enugu State Agricultural Development Programme, [ENADEP] 2008) with a population of about 3,257,298 people consisting of 1,624,202 male and 1,633,096 females (Nigerian News, 2007). A multistage sampling technique was employed. First, three agricultural zones: Enugu Zone, Agwu Zone and Nsukka Zone were randomly selected from the six agricultural zones. Second, two local government areas (LGA) were randomly selected from each of the three agricultural zones to give a sample of six local government areas. Third, ten informal women co-operative micro finance societies were purposively selected from each LGA, making a total of 60 informal women co-operative micro finance societies. Fourth, a total of 432 clients were selected from the 60 informal women co-operatives for the study.

Data collection instrument

Data were obtained from primary sources using structured questionnaire and focus group discussions. Information were sought on age, sex, occupation, educational level, family size, income borrowing experience, credit repayment, number of clients reached, amount of credit disbursed, total savings generated. Focus Group Discussion was carried out in the central place in each of the six local government areas (LGA). Each group for the discussions comprises of the managers and secretary of each group making a total of twenty participants in each of the six LGA selected.

Data analysis

Descriptive and inferential analytical methods were used to realize the objectives of this research. Descriptive statistics such as mean, frequency distribution were used to describe the socioeconomic characteristics of the clients and managers of the informal women cooperative micro finance societies. Multiple regression model analysis was used to determine the performance of informal women co-operatives society in terms of amount of savings mobilized (TSG), amount of credit (loan) disbursed (TALODI) and number of clients reached (N. CL. R.) and to test the null hypotheses. If the F-calculated > F-tabulated at 0.05 level of significance, we reject the null hypotheses and accept the alternative.

Model

Multiple regression model analysis was used in three different ways:

(i) Determinants of performance in terms of the amount of savings generated (TSG2013)
The model is implicitly specified as follows:

Y = f (LEV.ED.M + YR.EX.M + IRAT.C13+ TALODI13 + TALORE13 + U)

Where: Y= Volume of savings Generated (TSG13) ($); LEV.ED.M = Level of Education of mangers (years of formal education). YR.EX.MA =Years of Experience of Managers (years); IRAT.C13 = Amount of Interest Charged per $ 1000 ($); TALORE13= Total Credit Repaid ($); TALODI13 = Total Credit Disbursed ($)
μ= error term

(ii) Determine the performance in terms of the volume of credit disbursed (TALODI13)
The model is implicitly specified as follows:

Z =f (LEV.ED.M + YR.EX.MA+ TALORE13+ IRAT.C13+ TSG13)

Where: Z = Volume of credit disbursed ($); LEV.ED.M = Level of Education of mangers (years of formal education). YR.EX.MA = Years of Experience of Managers (years); IRAT.C13 = Amount of Interest Charged per N 1000 ($); TALORE13 = Total credit repaid ($); TSG13 = Total Savings Generated ($)

μ = error term

(iii) Determinants of performance in terms of the clients reached (N. CL. R.). The model is implicitly specified as follows:

Y = f (LEV.ED.M + YR.EX.MA+ TCRFD13+ IRAT.C13+ TSG13 + TALORE13) + U

Where: Z = Number of clients reached (N. CL.R.); LEV.ED.M = Level of Education of mangers (years of formal education). YR.EX.MA = Years of Experience of Managers (years); TCRFD13 = Credit Received from donor agencies ($); IRT.C13 = Amount of Interest Charged per N 1000 ($); TSG2013 = Total Savings Mobilized ($); TALORE13 = Total Credit Repaid ($); U = Error term.

The participants were duly informed about the need to obtain scientific evidence of what their activities with respect to credit administration to enable implementation of policy that could help them to access credit.

RESULTS

People–related variables influence access and use of credit. Here we focus on personal characteristics that shape performance of women groups in credit administration to entrepreneurs (Table 1). Age, household size, educational level, major occupation and size of credit received. Table 1 show that the age distribution of the respondents was skewed towards the upper age group of 40 and above. About 33.8% of the subjects had never been to school while the rest attended primary 40.3%, secondary 19.4% and tertiary 6.5% levels of education. During the peak periods of farm operations, from May to July all the clients were involved in one farm operation or the other while agribusiness was a minor occupation. After the peak period most managers and other members of informal women co-operatives clients usually engaged in gathering of farm products for consumers. About 40.3% reported that they were full time marketers in post-harvest agribusiness including

Table 1. Summary of socio-economic characteristics of respondents (N=432).

Variables	Frequency	Percentage
Age (years)		
<30	24	5.6
31 - 40	116	26.8
41-50	203	47.7
51-60	86	19.9
Household size		
1-4	40	9.3
5-8	246	56
9-12	136	32.9
13-16	6	1.4
Above 16	2	0.4
Education in (years)		
No formal	146	33.8
Primary	174	40.3
Secondary	84	19.4
Tertiary	28	6.5
Major occupation		
Agribusiness	146	33.8
Cropping/livestock	74	40.3
Cropping	84	19.4
Teaching	28	6.5
Size of credit received (₦)		
20,000 - 29,999	10	4.6
30000 - 39,999	93	43.1
40,000 - 49,999	2	0.9
50000 - 59,999	61	28.2
60,000 - 99,999	12	5.6
100,000 - 199, 999	17	7.9
200,000 - 400,000	21	9.7

Source: Field survey, 2015.

distribution of fish, tomatoes, yam, cocoyam, processing of palm fruits, cashew nuts, melon etc mainly produced by other farmers. The respondents cultivated between one and two hectares of land. The size of credit received by rural women varied from N20,000 to N400, 000 mainly for marketing activities. They were able to repay 99.9% of loan obtained from NGOs as a result of using peer pressure for collateral. If any member defaults the whole group will be forced to pay for such clients. Thus the members must be aware of the reputation of each of their clients and that each uses her loan in marketing to avoid default. Based on World Bank classification, all the study participants earned low income with less than $1045 (480,700 naira) per annum (World Bank, 2014).

The model indicates that the explanatory (independent) variables included in the model accounted for 79% of the variation in the performance of informal women's cooperatives MFIs in terms of the total amount of savings generated. Credit repaid, total loan disbursed (TALODI) and year of experience of managers (YR.EX.MA) were significant factors that enhanced savings generated. Level of education of managers (LEV.ED.MA) and interest rate charge (IRAT.C) were negatively related and were not statistically significant with the total savings generated (Table 2).

The selected equation (linear form) provided a good estimate of the socio-economic factors that determine the volume of credit disbursed. This is because the adjusted (R^2) was 84%. This shows that the explanatory variable included in the model was able to explain 84% of the variation in the performance of informal women cooperatives in term of the amount of loan disbursed. An examination of the individual determinants showed that total loan repaid (TALORE) was also statistically significant at 5% probability levels with the regression coefficient of 0.49 with the total loan disbursed. This implies that an additional dollar of loan repaid will raise the total loan disbursed by 49% (Table 3).

Table 2. Coefficients of linear regression equation on total savings generated (TSG).

Model	Unstandardized coefficients	Unstandardized coefficient std error	Standardised coefficients Beta	T	Sig.
Constant	-177307	126580.6		-1.401	0.172
LEV.ED.M	-9630.216	11496.597	-.076	-0.838	0.409
YR.EX.M	62596.285	20453.666	0.305	3.060	0.005*
IRAT.C	-101.546	446.964	-0.022	-0.227	0.822
TALODI	3.969E-02	0.016	0.43	2.256	0.002*
TALORE	9.816E-02	0.019	0.850	5.047	0.000*

*Significant at 5% level of significant. R^2 = 79, F ratio = 22.301. Source: Field survey, 2015.

Table 3. Coefficients of linear regression equation on total credit disbursed (TALODI).

Model	Unstandardized coefficients	Unstandardized coefficient std error	Standardised coefficients Beta	T	Sig.
Constant	-248754	574830.5		-0.433	0.668
LEV.ED.M	228599.1	238165.7	0.210	-0.960	0.345
YR.EX.M	-139011	289323.7	-0.096	-0.480	0.634
IRAT.C	-52840.5	300395.0	-0.023	-0.176	0.862
TSG	4.532	1.296	0.524	3.498	0.001*
TALORE	0.395	0.092	0.490	4.295	0.000*

*significant at 5%, R^2 = 83.9%, F ratio = 31.182. Source: Field survey, 2015.

Table 4. Coefficients of linear regression equation on number of clients reached (N.CL.R.).

Model	Unstandardized coefficients	Unstandardized coefficient std error	Standardised coefficients Beta	T	Sig.
Constant	279.961	127.616		2.194	0.036
LEV.ED.M	18.749	11.359	0.87	1.651	0.110
YR.EX.M	10.427	22.888	0.030	0.456	0.652
TCRFD	1.629E-04	0.000	0.827	6.306	0.000*
IRAT.C	-1.083	0.437	-0.135	-2.479	0.019
TSG	5.110E-04	0.000	0.300	2.866	0.008**
TALORE	-250E-05	-000	-0.158	-1.646	0.111

*significant at 5% level of significant, **significant at 10% level of significant, R^2 = 0.93, F ratio = 66.981. Source: Field survey, 2015.

Table 4 showed that the coefficient of multiple determination (R^2) = 0.93 was high. The model indicates that the explanatory (independent) variables included in the model accounted for 93% of the variation in the performance of informal women's cooperatives, in terms of the number of clients reached.

Examination of individual explanatory variables showed that only one of the explanatory variables was significant at 0.05 or 5% probability level (TCRFD). One other factor was significant at 10% which is outside the accepted level of significant for this study. Also two other factors were positively related but not significant explanatory variable while the last two were negative explanatory variables.

F – calculated = 22.301 and theoretical value of F at 5% level of significance is 2.50. Thus, F- calculated > F-tabulated at 0.05 level of significance. This implies that the independent variables have contributed to the performance of informal women cooperatives in terms total saving generated and that the variables included in the model were able to explain the models of TSG. Hence, we reject the null hypothesis and accept the alternative that informal women's cooperative MFIs have significantly increased the volume of savings of their beneficiaries.

The overall regression equation was significant at the 5% probability level, as the F statistics of, 22.301 was greater than the critical F- value 2.50 and the R^2 = 79%. This implies that those explanatory variables included in the model contributed significantly to the performance of informal women cooperatives. Thus, based on the fact that the F – statistic was significant, at 5% level, it was accepted that socio-economic characteristics of informal women's cooperatives MFIs have significant relationship with their volume of savings. Therefore, hypothesis "iii' (there is no significant relationship between socio-economic determinants of savings and volumes of savings generated by informal women's cooperatives), was rejected.

Test of hypothesis ii

The F- calculated recorded 31.182 and the theoretical value of F at 5% level of significance is 2.50 Thus, F-calculated > F- tabulated at 0.05 level of significance. This implies that the explanatory variables included in the model contributed significantly to the performance of women cooperatives. Hence we reject the null hypothesis and accept the alternative that informal women's cooperative MFIs have significantly increased the volume of credit available to their clients. The overall regression equation was not significant at 5% level as the F statistic 31.182 was more than the critical F–value 2.50 and R^2 =83.9%. This implies that the explanatory variables included in the model contributed significantly to the performance of informal women cooperatives. The null hypothesis of no significant relationship between socioeconomic determinants of credit disbursed and volume of credit disbursed was rejected.

The operational procedures, sustainability and linkages of selected informal women's cooperative microfinance societies

The result of focus group discussion, observation and interviews shows that managers and members of the informal women co-operative micro finance were from rural community of Enugu state. They consisted of members who obtain loan from Non-Governmental Organization and extend it to their members for income generating activities. Their close relation in terms of belonging to the same social groups made it easy for obtaining information about the potential members since joint liability and group cohesion, served as collateral for the group members to obtain micro credit from NGOs. The intending beneficiaries and members of informal women cooperatives must be physically fit to carry out income generating activities such as processing and marketing of agricultural products. Amount of business investment ranged from 20,000 naira to 400, 000. About 95% of the money used for the business was from informal women co-operatives. Member must be of good behaviour and must attend weekly meetings. It was observed that the financial transaction hinges on social cohesion, trust and mutual dependence. The participants have numerous social, ethnic and economic relations with each other as a result of which women's co-operative MFIs face little problems of information asymmetry, transaction cost and moral hazard. Information asymmetry is handled at a relatively low cost than formal credit scheme by exploiting locally available information about the reputation, indebtedness and wealth of the prospective borrower, through repeated social and economic interactions. Loan repayment is ensured through sanctions, peer pressure and personalized relationships that may threaten the long term utility and reputation of the delinquent or defaulted borrower.

Member of informal women co-operatives were also involved in generating savings from their members. There are two types of savings for women's cooperatives that are linked up to NALT NUSH. These are mandatory savings and voluntary savings of any amount which could be withdrawn at will. The mandatory savings is usually N 100 per week for all loan beneficiaries. This savings can only be withdrawn during withdrawal of membership of women's cooperatives. The interest rate of 3 to 5% was credited to all savers annually, to measure up with what obtains in the banking sector. Those that were linked up to other NGOs were only involved in mandatory savings of 10% of the amount of loan. Though credit was administered individually to members in a group, there was collective responsibility on the part of the entire women's group members to ensure that all members paid their loans. A client decides when to withdraw from membership. A member of women's cooperative linked up to NGOs is mandated to save every week or month depending on the specific NGOs. This can be withdrawn by a client when she wishes to withdraw her membership from the NGO. Clients are normally allowed to obtain loan from most of these NGOs for a maximum of 5 years after which the person will have saved reasonable amount to use her own capital for the business. The interest payable in NALT-NUSHO was 32% per annum while that of DEC was 30% per annum and 23% for CIDJAP. Those that belong to NAPEP and CSA paid only 8 and 14% respectively. The total amount of the loan given to a client was added to the annual service charge of 32, 30 and 23% and divided into 44 weekly install mental repayments or 10 annual install mental repayment in case of DEC. For instance, a woman that got N100,000 loan would have to pay N32,000 interest. This means that a total of 132000 divided into 44 weekly installments would bring about the loan repayment of N3000 per week, N100 savings and a total of N3100/week would be paid by a client for 44 weeks. For a woman in DEC with 100,000 naira loan, she will pay an interest of N40,000 and 140,000 will be divided into 10 installments repayment of 14,000 every month. The repayment rate for women's groups that were linked up to most of these NGOs was about 99%. The default was mainly due to death of members due to their efficient management of funds.

There is considerable flexibility in the organization of women's cooperative associations. By their nature, such associations are not formed on a standard form of organization but are guided by their objectives and philosophy of mutual interest, self-help through cooperation, mutual benefit and democratic control. The educational and occupational background of participants necessitates the adoption of a simple form of organization capable of easy understanding and management. This work has also indicated high levels of NGOs participation in funding the informal women's cooperative in microfinance activities. However their interest rate is relatively higher than those of National Poverty Eradication Programme. The interest rate of NAPEP and CSD are between 5 and 8% while that of NGOs is between 23 and 40%. Development Education Commission (DEC), NALT United Self Help Organization (NALT NUSHO), Catholic Institute of Development Justice and Peace (CIDJAP), and National Poverty Eradication Program (NAPEP) were the major source of fund for the informal women co-operatives. However DEC was the topmost NGO and gives loan to women groups in all the local government of the state while CIDJAP and NALT-NUSHO served women groups in all the local government in Nsukka zone. NAPEP and CSA only served very few informal women groups with credit.

DISCUSSION

The informal women's cooperation has grown because rural women are constrained to source for themselves with credit which the government fails to provide, The main feature of such financial intermediation is that the local people identify their needs themselves and link up with NGOs which were in turn sponsored by donor agencies such as Community Development Foundation (CDF) or United Nation Development Program micro credit (UNDP-Nigeria) to meet such needs. Credit repaid by informal women's cooperatives was statistically significant and positively related with the coefficient of 0.85 to the amount of savings mobilized. The positive influence of these variables is consistent with a priori expectations. Clients were afraid of not being labelled as not being creditworthy because of the social stigma attached to such label in the area. There is also penalty charge for not repaying loan as at when due as this encourages members to attend meetings promptly and to pay their loan. Total loan disbursed was also found to be statistically significant with the total savings generated with the regression coefficient of 0.43 to the amount of savings generated. This means that an additional naira of loan obtained by clients will raise savings generated by 0.43%. Thus more credit to clients in the study area will increase their productive and savings capacity as they are yet to attain their optimal credit utilization capacity. The positive influence of this variable also conforms to the theoretical expectations. This is because savings generated by members of informal women co-operatives was 10% of the total loan disbursed so one will expect that the high the amount of loan the higher the total savings generated. This again calls for linkages with developmental agencies without which rural women cannot be self-sufficient in micro finance. Thus the repayment by clients in the study area will increase the ability of NGOs to give more loans to informal women co-operatives for disbursement. This is consistent with the *a priori* expectation since informal women's cooperative must repay their previous loan before they can qualify for obtaining another loan from NGOs. The total savings generated (TSG) was also found to be statistically significant at 5% probability levels with regression coefficient of 0.52 with the total amount of funds disbursed. Total credit received from donors (TCRFD) was statistically significant with positive coefficient of 0.83 factors at 5% level of significant with the number of clients reached. This implies that for every one client reached by informal women cooperative the total credit received from donors accounted for 83% of the variation. This is consistent with the theoretical explanation since more clients only joined to women groups to enable her obtain fund for marketing. An increase in funding by donor agencies make more fund available for targeting and mobilizing clients. The total savings generated has a positive coefficient of 0.30 with the number of clients reached. Amount of interest charged (IRAT.C), and total loan repaid (TALORD) were found to be statistically insignificant and negatively related with clients' outreach. This suggests that increase in interest rate and repayment of loan will scare many clients away. The LEV.ED.M and YR. EX. M were found to be positive but statistically insignificant with the number of clients reached. The result of this study is similar to the work done by (Opata and Nweze, 2009) in an aspect which showed statistical relationship between loan disbursed and repaid by women micro entrepreneurs. The results of previous study also showed that they are faced with internal constraints, socio-cultural constraints, and weak policy support as major constraints and barriers militating against women micro entrepreneurs from accessing micro credit. It is also in agreement with the work done by (Otoo, 2012) which show that women are strong entrepreneurs, borrowers and change agents through Women's small and medium enterprises (WSMEs).

Governments and policy makers must realize that although the growth of tiny enterprises has resulted largely from the lack of alternative employment opportunities, they are often viable undertakings which make an important contribution to the economic survival of the poor. As such, governments should encourage the establishment of more micro-enterprises in the form of small-scale cottage and other agro-based industries. Governments must also recognize that these undertakings need to be supported by better access to institutional finance. Micro-finance institutions (MFIs) should carry out business analyses of the practical business needs of their customers so as to be able to encourage more access to credit for the women entrepreneurs. This would facilitate their potential contributions to the development of economic activity in the private sector, as well as the sustainability of the informal sector as it begins to align with the formal sector.

CONCLUSION

The following conclusions are derived from this study which was designed to analyze the drivers of the performance of informal women's cooperative micro credit society in third world countries. The socio-economic background of women has portrayed them as economic operators who depended on agriculture and allied activities for their sustenance. In the same vein, women's access to formal micro-credit is a clear indication of their participation in informal micro finance societies. Although the road to gender equality and poverty alleviation is rough and challenging, this study has shown that informal women's cooperative MFIs have played a key role in addressing issues of poverty alleviation and gender inequality. Nevertheless, although a lot of significant impacts have been made by these organizations, they are still highly dependent on the NGOs for operation. This implies that for these associations to be relied upon in far-reaching gender equality and poverty reduction, their potentials need to be developed through training and further involvement in productive activities. Since this study shows that women repaid 100% of micro-credit loan given to them, efforts should be made to incorporate their models into other women-based rural development project that require capital project. Also apropos in this regard is the suggestion to assimilate informal women's cooperative MFIs into federal government's overall rural banking policy. This will go a long way towards reducing the problems of high dependency on NGOs for funds. In most cases, therefore, and similar to recent research in the Ghanaian context (Otoo, 2012) micro-credit from MFIs and formal banks is considered a last resort in the credit options hierarchy. The potential economic benefits of sustainable microfinance in Nigeria are compelling, and its potential effects on the development process cannot be understated. This calls for a holistic approach to facilitating the development of the microfinance sub-sector thereby unleashing its potential for accelerated growth and development.

RECOMMENDATIONS

Governments and policy makers must realize that although the growth of tiny enterprises has resulted largely from the lack of alternative employment opportunities, they are often viable undertakings which make an important contribution to the economic survival of the poor. As such, governments should encourage the establishment of more micro-enterprises in the form of small-scale cottage and other agro-based industries. Governments must also recognize that these undertakings need to be supported by better access to institutional finance. Government Micro-finance institutions (MFIs) should carry out business analyses of the practical business needs of their customers especially those belonging to the informal women microfinance institution so as to be able to formulate better and more appropriate policy for linking them to the formal microfinance institution.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Sequential sampling for evaluation of caterpillars, small and large in soybean

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Among the main limitations of grain yield in soybean are the insect pests, especially the defoliating caterpillars. It is necessary to reveal and quantify these insects for proper decision-making according to pre-established control levels. So, for the implementation of appropriate management of these soybean insect pests, there is a necessity to establish a sampling plan that will allow an effective, reliable and less time consuming estimation of the population density of pests. This work aims to establish a sequential sampling plan for small and large caterpillars in soybean in accordance with the sequential test of probability rates. Data was collected for two growing seasons (2010/2011 and 2012/2013). The number of small caterpillars (<1.5 cm) and large (>1.5 cm) of the species *Anticarsia gemmatalis* (Hübner, 1818), *Chrysodeixis includens* (Walker, 1857) and *Spodoptera eridania* (Cramer, 1872) was estimated using the vertical cloth-to-beat in a grid of 154 sample points marked with a 20 × 20 m spacing in an area of 6.16 ha of soybean. The distribution of small and large caterpillars in soybean is aggregated. According to the sequential sampling plan, the number of maximum samples, for the decision making of the control or not of caterpillars in soybean is 30 samples units.

Key words: Pest management, sampling plan, vertical cloth-to-beat, spatial distribution.

INTRODUCTION

The productivity of soybean can be affected by several factors, among these the defoliating caterpillars (*Anticarsia gemmatalis, Chrysodeixis includens* and *Spodoptera eridania*) become important constraints. These insect pests feed both limbo and leaf veins and can cause defoliation up to 100%, leading to losses in grain yield (Hoffmann-Campo et al., 2012).

It is extremely important to quantify population of this insect pest, so that decisions are taken properly, based on pre-established levels of control. In soybean, the recommended level of control is 20 large caterpillars (≥1.5 cm) per square meter (Reunião da Pesquisa da Soja na Região Sul, 2014). Therefore, it is necessary to know fast and efficient sampling methods, so that the

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control is executed at the exact moment when the population level reaches the level of control (Fernandes et al., 2002). Choosing the best method is dependent on factors such as the phenological stage of the crop, the target pest in question, the accuracy and precision required for sampling, ease of use, time and cost of performing it (Wade et al., 2006).

The vertical cloth-to-beat method was the most efficient in comparison with cloth-of-beat methods and large cloth-to-beat in several studies (Guedes et al., 2006; Kuss et al., 2007; Stürmer et al., 2012). These samples can be optimized using the sequential sampling plan, which presents itself to be more reliable and faster because it is based on a variable number of samples depending on the size of the sampled population (Kogan and Herzog, 1980).

For the correct development of sequential sampling plans, three basic requirements are required; (1) a probability function is obtained that describes the distribution of insect counts; (2) the level of economic damage (NDE) or threshold in the form of two critical densities, so that the level of damage occurs as soon as the population density exceeds a previously established upper limit and does not occur when the population remains below the limit defined bottom; (3) we select maximum levels of probability of making errors in the decision on population densities, that is, probabilities of α and β to predict a non-prejudicial population as being prejudicial (α = type I error), and the probability of diagnosing a density prejudicial as being non-prejudicial (β = type II error) (Ruesink and Kogan, 1975). Sequential sampling plans are constructed based on Wald's sequential probability ratio test (1945). In order to establish the use of this method of evaluation, it is necessary to know the spatial distribution of insect pests in the culture (Giles et al., 2000).

Therefore, this study aims to implement a sequential sampling plan for the evaluation of small and large caterpillars in soybean.

MATERIALS AND METHODS

The experiments were conducted in an area of 6.16 ha in the Federal University of Santa Maria in Santa Maria, Rio Grande do Sul State which lies at an latitude 29° 42'24 "S; longitude 53°48'42 "W; and altitude, 95 m, in two growing seasons (2010/2011 and 2012/2013). In the first year, the soybean cultivar BMX Potencia RR, of indeterminate growth habit and semi-early maturity group, it was sown on October 29, 2010, in rows spaced 0.5 m, with 25 m plant density. In the second crop, the soybean cultivar used was Nidera A 6411 RG, a determined growth habit and semi-early maturity group, sown on December 10, 2012, in rows spaced 0.43 m, with a plant density of 16 plants per square meter. In both years, fertilization, control of weeds and diseases were conducted according to the technical recommendations for the crop (Reunião da Pesquisa da Soja na Região Sul, 2014). In the year 2010/2011, methomyl was applied (107 g active ingredient ha^{-1}) to control caterpillars on February 3, 2011, on the basis that defoliation had reached the level of control (Reunião da Pesquisa da Soja na Região Sul, 2014). In the year 2012/2013, the pest control was not necessary because the control levels were not achieved. In both crop years, it was marked on the area a grid of 154 sampling points spaced 20 × 20 m. In each of these, 154 points were counted, the number of small (<1.5 cm) and large (>1.5 cm) caterpillars of the species *A. gemmatalis* (Hübner, 1818), *C. includens* (Walker, 1857) and *S. eridania* (Cramer, 1872).

At the end, the total number of small caterpillars and the total number of large caterpillars were recorded through the vertical cloth-of-beat sampling (Figure 1), 14 phenological stages of soybean (V7, V9, V11, R1 R2, R3, R4, R5.1, R5.3, R5.5, R6, R7.1, R7.3 and R8.2) on the 2010/2011 season, and 8 stages for the year 2012/2013 (R2, R4, R5.1, R5.2, R5.5, R6, R7.1 and R7.3) using the scale proposed by Ritchie et al. (1982). The sampling method and the manner of collection are described subsequently.

Vertical cloth-to-beat, consisting of a wooden stick at the top end and a polychloride polyvinyl tube (100 mm), cut in half lengthwise, the lower end, connected by a white cloth with 1 m of length and height-adjustable to the height of soybean plants. The polychloride polyvinyl tube served as a gutter to collect insect pests. To collect the insects, the cloth was placed vertically between the lines of the crop and only one row of plants were shaken against the surface of the cloth. This procedure was conducted by 2 m of soybean line in order to sample the area of 1 m^2.

Each of the 2,156 collections of 1 m^2 formed by the combination of 154 points × 14 phenological stages in the year 2010/2011 and 1,232 collections formed by the combination of 154 points × 8 phenological stages in the year 2012/2013 accounted for the number of caterpillars (small, large and total). Statistical analysis was performed with the help of MINITAB 17 software and Office Excel application.

To verify the degree of aggregation of small and large caterpillars, dispersion indexes described subsequently were used.

Dispersion indexes

Reason variance/average, called dispersion index, is the most common of the indexes used. It is given by the variance/mean relation ($I = s^2/m$). According to Rabinovich (1980), it is a measure of the deviation of an arrangement of the conditions of randomness. Values equal to the unit indicate dispersion at random, values lower than the unity indicate regular or uniform distribution, and significantly higher values that the unit indicate aggregate spatial distribution. The limitations of this index are the influence of sample size on the amount of sampled individuals, affecting the aggregations (Krebs, 1999).

K exponent of negative binomial distribution

The estimated values of K are obtained by two methods, the first method of the moments:

$$k = \frac{m^2}{s^2 - m}$$

and by the method of maximum verossimilitude:

$$N \ln\left(1 + \frac{\hat{m}}{\hat{k}}\right) = \sum_{i=1}^{nc} \left(\frac{A(x_i)}{\hat{k} + x_i}\right)$$

where N = number of sampling units, A(x) = sum of the frequencies of the values higher than x and xi = number of subjects sampled by point. Negative values indicate uniform distribution, low and positive values (k<2), highly aggregated arrangement, values ranging from

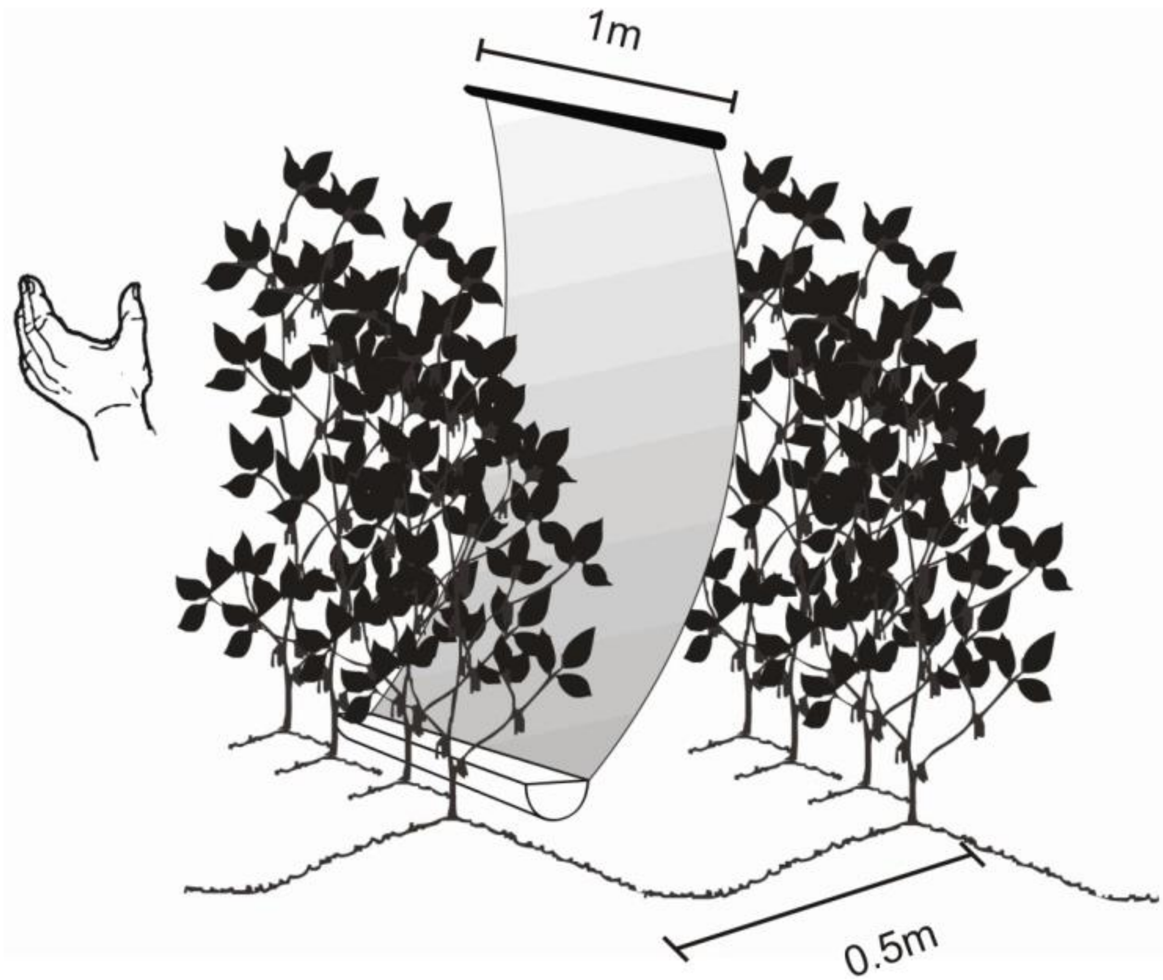

Figure 1. Representation of the vertical cloth-to-beat used in sampling caterpillars, small and large, in soybean (Stürmer et al., 2012).

two to eight indicate moderate aggregation and values greater than eight randomized distribution (Elliott, 1979).

Probabilistic models for the study of spatial distribution of pests

Poisson distribution is also known as random distribution, with variance equal to the average (m = s2). The formulas for calculating the series are given by:

$$P(0) = e^{-\hat{m}}$$

and

$$P(x) = \frac{\hat{m}}{x}.P(x-1)$$

where x = 1,2,3 ...; e = base of the natural logarithm (e = 2.718282 ...); P (x) = probability of finding × individuals in a sampling unit; and m = sample mean.

Negative binomial distribution shows greater variance than the average (s^2>m), namely, aggregate distribution and has two parameters, the mean (m) and the exponent k (k> 0). The odds are calculated by the formulas:

$$P(0) = (1-\frac{\hat{m}}{\hat{k}})^{-\hat{k}}$$

$$P(x) = \frac{\hat{k}+x-1}{x}.(\frac{\hat{m}}{\hat{m}+\hat{k}}).P(x-1)$$

for x = 1, 2, 3, ..., where P (x) = probability of finding a sampling unit containing × individuals, sample mean, estimate of the negative binomial exponent k, obtained by the method of moments.

Sequential sampling is the next step which was the establishment of a sequential sampling plan for small and large caterpillars in soybean. The plan is based on the sequential test of likelihood ratio (TSRP) proposed by Wald (1945). The plan aims to test with the lowest expected number of samples, the hypotheses H0 and H1. H0 indicates that the population is below the safety level, while the H1 hypothesis is that the population is above the level of control. Thus, H0 rejection, or the acceptance of H1, may indicate the need for application of insect control methods, and accepting H0 indicates the non-application (Barbosa, 1992). For preparation of the sequential sampling plan of caterpillars, the level of control of 20 caterpillars/m² was adopted and a safety level of 10 caterpillars/m². Using the errors of type I and type II, the values α = β = 0.10.

The required decision lines for the rest were built. The top line brings the number of individuals needed to achieve the proposed level of control, the lower decision line indicates the total number of organisms stating that the population is below the safety level and does not require the adoption of any measure of control.

For the operating characteristic curve and expected medium size for the sample, the evaluation of the test TSRP does not need determination of the Operating Curve CO(p) and the Curve of the Expected Size of Sampling units Ep(n). The Operating Characteristic Curve CO(p) is a graphical representation of the operational characteristic function, providing the probability that sampling is finished, not recommending the control to a certain degree of crop infestation. This indicates the probability of adopting a right or wrong decision on a certain level of infestation. The Curve of the Expected Size of Sampling Units Ep(n) represents the average number of observations/samplings required for decision making. According to Young and Young (1998), the functions for the determination of both curves at any type of distribution is described as:

$$CO(p) = \frac{\frac{(1-\beta)^h - 1}{\alpha}}{\frac{(1-\beta)}{\alpha} - \frac{(\beta)^h}{1-\alpha}}$$

$$E_p(n) = \frac{CO(p)(h_0 - h_1) + h_1}{p - S}$$

where p = average number of individuals; h = auxiliary dependent variable of p; α = type I error; β = type II error; H0 = hypothesis H0; H1 = hypothesis H1.

RESULTS AND DISCUSSION

The dispersion index of the reason of the variance/mean (I) showed values greater than the unity for small caterpillars in the 2010/2011 season, the 11 initial assessments, that is, in all stages with a mean different from zero, indicating aggregate distribution (Table 1). As for the estimation of K by the moments method (K mom) in five of the phenological stages (V7, V9, R5.1, R5.3 and R6), values were low and positive, called highly aggregated dispersion. In other evaluations, were found individuals (V11, R1, R2, R3, R4 and R5.1), the values found ranged between 2 and 8, which indicates aggregate distribution. In the three remaining assessments (R7.1, R7.3 and R8.2) individuals were found in the area. The number of small and large caterpillars was not collected in the area, in the 2010/2011 season, for the last three stages evaluated, mainly due to insecticide application and the competition for food.

Only in V7 values were negative showing uniform distribution. In other stages, the index ratio variance/mean values were higher than one. To estimate K by the method of moments in the stages V9, V11, R2 and R5.5 values obtained are found between 0 and 2, in the other five stages, values denoted moderately aggregate distribution (2 <k <8).

Similar results were observed by Stecca (2011), when the spatiotemporal distribution of defoliating caterpillars of soybean was analyzed, concluding that they present gregarious behavior, due to its population growth. Fernandes et al. (2003) found in the cotton crop, for *Spodoptera frugiperda*, also aggregate distribution, that is, adjusting for the negative binomial distribution. These results confirm those found by Moura (2012), where the spatial distribution and the sequential sampling plan of *C. includens* in different soybean seeding systems was evaluated.

Thus, it is understood that the distribution of large and small caterpillars in the 2010/2011 season adjusts to the distributions that describe this arrangement, as the negative binomial distribution. These results go against Maruyama et al. (2002), which show that, generally, the distribution of insects in the field is given in aggregate form.

For the index of variance/mean ratio for the number of small caterpillars in the 2012/13 crop, the values were higher than one in all of the soybean stages which denotes aggregate population distribution.

For the analysis of the k index of the moments, in three phenological stages of the culture (R6, R7.1 and R7.3) K values are between 0 and 2, which denotes a highly aggregated distribution. In the other stages the values showed a moderately aggregate distribution.

For the number of large caterpillars in the season 2012/2013, the $I = S^2/m$ index presented values indicating the aggregate distribution in the first 6 phenological stages (R2, R4, R5.1, R5.2, R5.5 and R6). In the others (R7.1 and R7.3) the values were smaller than 1 (uniform distribution). For the estimation of K by the moments method, the results were similar. In stages R7.1 and R7.3, negative values were found. In R4, R5.1 and R6 values were between 0 and 2 (highly aggregated); R2 and R5.2, the indices showed a moderately aggregate distribution. In R5.5, the value presented was greater than 8, denoting a random distribution.

Adjustment tests for small caterpillars in the 2010/2011 season showed that in three phenological stages there was a fit to the negative binomial distribution, and in none was a fit to the Poisson distribution. Demonstrating that the population of small caterpillars tend to have an aggregate distribution. As for large caterpillars of the 14 sampled phenological stages, in six, there was a fit to the negative binomial distribution showing no significant values. Adjusting just one to the Poisson distribution, demonstrating also that the distribution of large caterpillars this season, occurs as aggregate (Table 2).

For 2012/2013 harvest, relative to the number of small caterpillars in the area, no adjustment in any of the

Table 1. Mean, variance and dispersion indices for the number of small and large caterpillars.

		Season 2010/2011							
		Small caterpillars				Large caterpillars			
Indexes		m	S²	I = S²/m	K mom	m	S²	I = S²/m	K mom
Sampling Season	V7	0.2532	0.3472	1.3710	0.6825	0.0519	0.0496	0.9542	-1.1354
	V9	0.8312	1.4354	1.7269	1.1434	0.1883	0.2061	1.0947	1.9894
	V11	2.5584	5.8299	2.2787	2.0008	1.0909	2.1224	1.9455	1.1537
	R1	5.1104	12.1381	2.3752	3.7162	1.0844	1.6595	1.5303	2.0449
	R2	9.0455	35.3639	3.9096	3.1089	3.2922	10.2082	3.1007	1.5672
	R3	26.5130	158.7221	5.9866	5.3169	10.0130	51.7776	5.1710	2.4006
	R4	24.3312	123.8177	5.0889	5.9506	25.5260	131.3490	5.1457	6.1572
	R5.1	4.5195	10.8787	2.4071	3.2120	4.5390	10.7207	2.3619	3.3327
	R5.3	2.1364	8.8506	4.1428	0.6798	1.7273	2.9055	1.6821	2.5321
	R5.5	1.4351	3.3193	2.3130	1.0930	0.5909	0.9492	1.6063	0.9746
	R6	0.5130	1.2841	2.5033	0.3412	0.1039	0.1068	1.0278	3.7403
	R7.1	0	0	-	-	0	0	-	-
	R7.3	0	0	-	-	0	0	-	-
	R8.2	0	0	-	-	0	0	-	-
		Season 2012/2013							
Sampling Season	R2	2.3117	3.9414	1.7050	3.2790	3.5195	8.0290	2.2813	2.7468
	R4	5.9156	10.7314	1.8141	7.2665	1.4156	3.1334	2.2135	1.1666
	R5.1	6.5519	26.7587	4.0841	2.1244	3.0909	13.4688	4.3576	0.9206
	R5.2	4.1883	9.9316	2.3713	3.0543	1.3442	1.7958	1.3360	4.0003
	R5.5	1.6688	2.8765	1.7237	2.3060	0.5325	0.5643	1.0598	8.9071
	R6	0.5584	1.1240	2.0128	0.5514	0.1234	0.1873	1.5181	0.2382
	R7.1	1.0779	2.4383	2.2621	0.8541	0.0325	0.0316	0.9739	-1.2419
	R7.3	0.4675	0.7081	1.5145	0.9087	0.0714	0.0668	0.9346	-1.0929

m - sampling mean; S² - variance; I – variance/mean ration K mom - k estimation by the method of moments.

Table 2. Chi-square test results (χ^2) for adjusting the Poisson and negative binomial distributions, for the number of large and small.

		2010/2011 Season			
Stage	Sampling stage	Poisson		Negative Binomial	
		χ^2	GL	χ^2	GL
Small caterpillars	V7	-	-	22.04677*	3
	V9	17.2964*	2	162.9631*	6
	V11	79.1846*	6	34.7255*	11
	R1	93.6846*	9	26.8771*	15
	R2	266.56*	12	73.6158*	24
	R3	790.880*	11	54.4815^{ns}	47
	R4	561.175*	11	58.0907^{ns}	43
	R5.1	87.1134*	8	16.9580^{ns}	15
	R5.3	177.672*	5	5376.7214*	12
	R5.5	59.7105*	4	65.2473*	9
	R6	34.2815*	2	596.5029*	7
	R7.1	-	-	-	-
	R7.3	-	-	-	-
	R8.2	-	-	-	-
Large caterpillars	V7	-	-	0.2707^{ns}	1

Table 2. Contd.

V9	0.07^{ns}	1	3.7976^{ns}	3
V11	51.93*	3	30.1082*	7
R1	11.7258*	3	8.9343^{ns}	5
R2	93.2229*	7	394.155*	15
R3	246.943*	7	199.8869*	28
R4	492.742*	11	67.0357*	44
R5.1	81.777*	8	25.3457^{ns}	16
R5.3	21.0309*	4	12.2190^{ns}	8
R5.5	15.3693*	2	41.9777*	5
R6	0.07738*	1	0.06472^{ns}	2
R7.1	-	-	-	-
R7.3	-	-	-	-
R8.2	-	-	-	-

χ = Chi-Square statistics test; GL: Chi-Square degrees of freedom; *Significant at a 5% probability; ^{ns}Non-Significant at a 5% probability.

Table 3. Chi-Square test results (χ^2) for adjusting the Poisson and negative binomial distributions, the number of large and small caterpillars.

Stage	Sampling Stage	2012/2013 Season			
		Poisson		Binomial Negativa	
		χ^2	GL	χ^2	GL
Small caterpillars	R2	32.1367*	5	22.7616*	9
	R4	64.0598*	10	17.9859^{ns}	15
	R5.1	96.220*	10	1.7×10^8*	16
	R5.2	79.5813*	8	85.4421*	13
	R5.5	37.3942*	4	23.2786*	8
	R6	40.5273*	2	134.2888*	6
	R7.1	56.9278*	3	386.7366*	7
	R7.3	6.3761*	1	253.3033*	4
Large caterpillars	R2	139.905*	7	49.9388*	12
	R4	14.8944*	3	7.21842^{ns}	6
	R5.1	307.330*	6	3043.452*	15
	R5.2	9.8291*	3	2.9547^{ns}	6
	R5.5	0.20820^{ns}	2	1.0397^{ns}	4
	R6	-	-	388.4375*	2
	R7.1	-	-	0.0970^{ns}	1
	R7.3	-	-	0.4962^{ns}	1

χ^2 = Chi-Square Statistycal test; GL: Chi-Square degrees of freedom; *Significant at a 5% probability; ^{ns}Non-Significant at a 5% probability.

stages with the Poisson distribution happened, and only in R4 to the negative binomial distribution, demonstrating a population random distribution, which can be explained by the smaller population in the area. For the population of large caterpillars, there was adjustment in five samples for negative binomial distribution and only R5.5 for Poisson distribution (Table 3).

These results demonstrate that for both small and large caterpillars, the population distribution of these pests tends to be aggregated, as described by Moura (2012) in a study of *C. includens* in different soybean planting systems.

With the adhesion test showing that the number of large and small caterpillars in seasons 2010/2011 and 2012/2013 had a more satisfactory adjustment to the negative binomial distribution, fits this model with a K_{common} which is the representative of all evaluations, therefore the values obtained are shown in Table 4.

From the K_{common} index, sequential sampling plans were constituted for large and small caterpillars in season

Table 4. K_{common} indices for small and large caterpillars in the 2010/2011 and 2012/2013 season.

Index	Season 2010/2011		Season 2012/2013	
	Small caterpillars	Large caterpillars	Small caterpillars	Large caterpillar
Kcommon	4.801852452	4.300367607	2.986652923	1.500572399

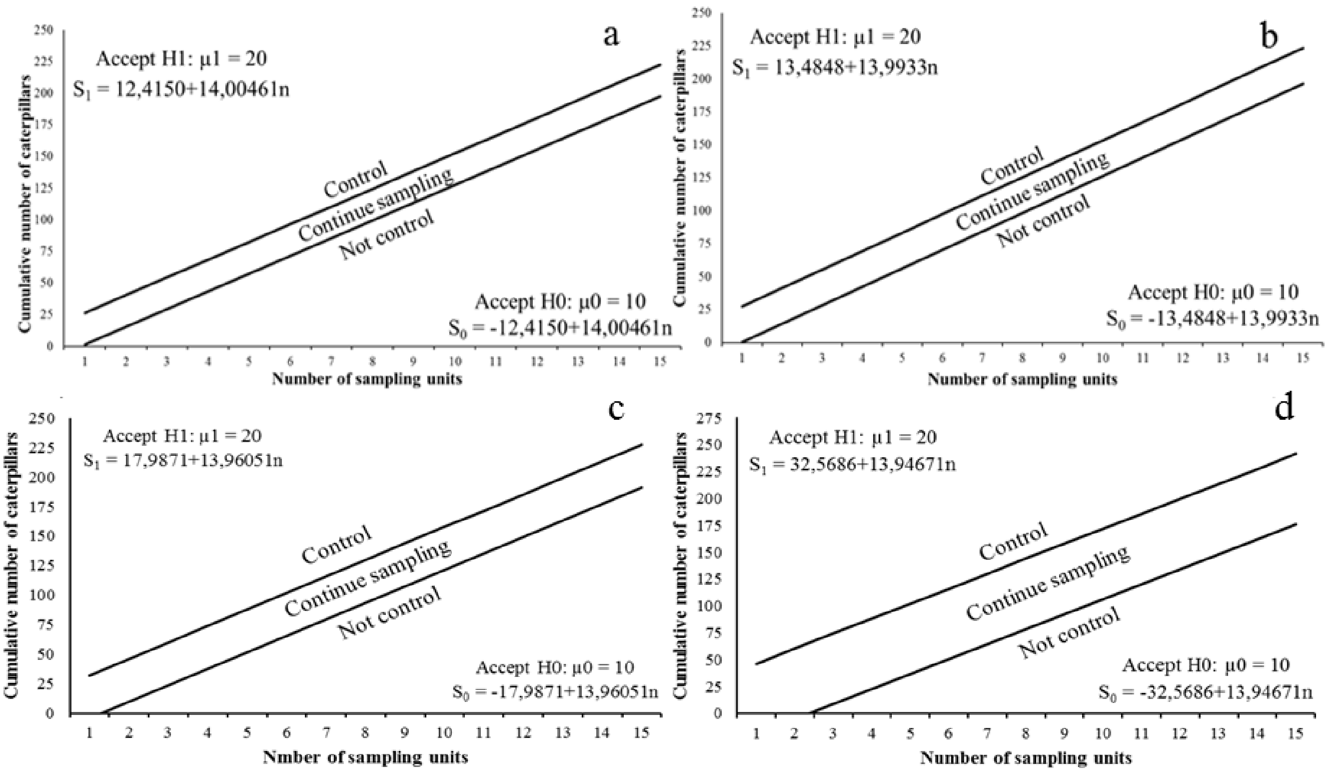

Figure 2. Decision lines of the sequential sampling plan for the number of small caterpillars (a) and large caterpillars (b) collected by vertical cloth-to-beat method at 154 sampling points in 14 growth stages, based on the negative binomial distribution, 2010/2011 harvest. Decision lines of the sequential sampling plan for the number of small caterpillars (c) and large caterpillars (d) collected by vertical cloth-to-beat method at 154 sampling points in 8 phenological stages, based on the negative binomial distribution, 2012/2013 harvest..

2010/2011 and 2012/2013 in graphical form (Figure 2). The top line brings the number of insects required for the control of caterpillars, rejecting H0, the bottom line accepts H0, requiring no control.

From these graphs field sheets are obtained Tables 5, 6, 7, and 8, which facilitate the sequential sampling field work. For each value of n, the value of S, found by S1 and S0 functions was is calculated. The second column of the table represents the lower limit of the graph, that is, the points S0, and the last column represents the points obtained through S1.

The field procedure is performed in the following manner, the area in question is covered, so that random sampling of large and small caterpillars is done, after counting at each sampling point, this number is accumulated, thus being compared with the limits in the field sheet, in a manner that you control or not the insect pests. If the total accumulated value is greater than the upper limit, it accepts H1, sampling stops and control is done. If the number of insects is less than S0 line, H0 is accepted, rejecting H1, sampling stops and the control is not done in the area. When the accumulated value does not exceed any of the decision lines, staying between them, sampling continues until the expected maximum number of caterpillars, both large and small for the decision making. New sampling taking place after one week, when the survey is biweekly, or after 4 days when the survey is weekly (Gallo et al., 2002). It is recommended that the minimum number of 6 samples to start the control or not of the insect pest in question, according to recommendations of Embrapa (2016).

The characteristic operating curve (CO) is the

Table 5. Field sheet for small caterpillars sampling in soybean using the vertical cloth-to-beat 2010/2011 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	2	-	26
2	16	-	40
3	30	-	54
4	44	-	68
5	58	-	82
6	72	-	96
7	86	-	110
8	100	-	124
9	114	-	138
10	128	-	152
11	142	-	166
12	156	-	180
13	170	-	194
14	184	-	208
15	198	-	222
16	212	-	236
17	226	-	250
18	240	-	264
19	254	-	279
20	268	-	293

Table 6. Field sheet for sampling of large caterpillars in soybean using the vertical cloth-of-beat 2010/2011 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	1	-	27
2	15	-	41
3	28	-	55
4	42	-	69
5	56	-	83
6	70	-	97
7	84	-	111
8	98	-	125
9	112	-	139
10	126	-	153
11	140	-	167
12	154	-	181
13	168	-	195
14	182	-	209
15	196	-	223
16	210	-	237
17	224	-	251
18	238	-	265
19	252	-	279
20	266	-	293

probability of completion of sampling, so that there is no control of the target insects for degree of infestation.

Figure 3 represent the CO(m) for small and large caterpillars in the 2011/2012 and the 2012/2013 season.

Table 7. Field sheet for small caterpillars sampling in soybean using the vertical cloth-of-beat 2012/2013 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	ND	-	32
2	10	-	46
3	24	-	60
4	38	-	74
5	52	-	88
6	66	-	102
7	80	-	116
8	94	-	130
9	108	-	144
10	122	-	158
11	136	-	172
12	150	-	186
13	163	-	199
14	177	-	213
15	191	-	227
16	205	-	241
17	219	-	255
18	233	-	269
19	247	-	283
20	261	-	297

ND: Not determined

Table 8. Field sheet for sampling of large caterpillars in soybean using the vertical cloth-of-beat 2012/2013 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	ND	-	46
2	ND	-	60
3	9	-	74
4	23	-	88
5	37	-	102
6	51	-	116
7	65	-	130
8	79	-	144
9	93	-	158
10	107	-	172
11	121	-	186
12	134	-	200
13	148	-	213
14	162	-	227
15	176	-	241
16	190	-	255
17	204	-	269
18	218	-	283
19	232	-	297
20	246	-	311

ND: Not determined

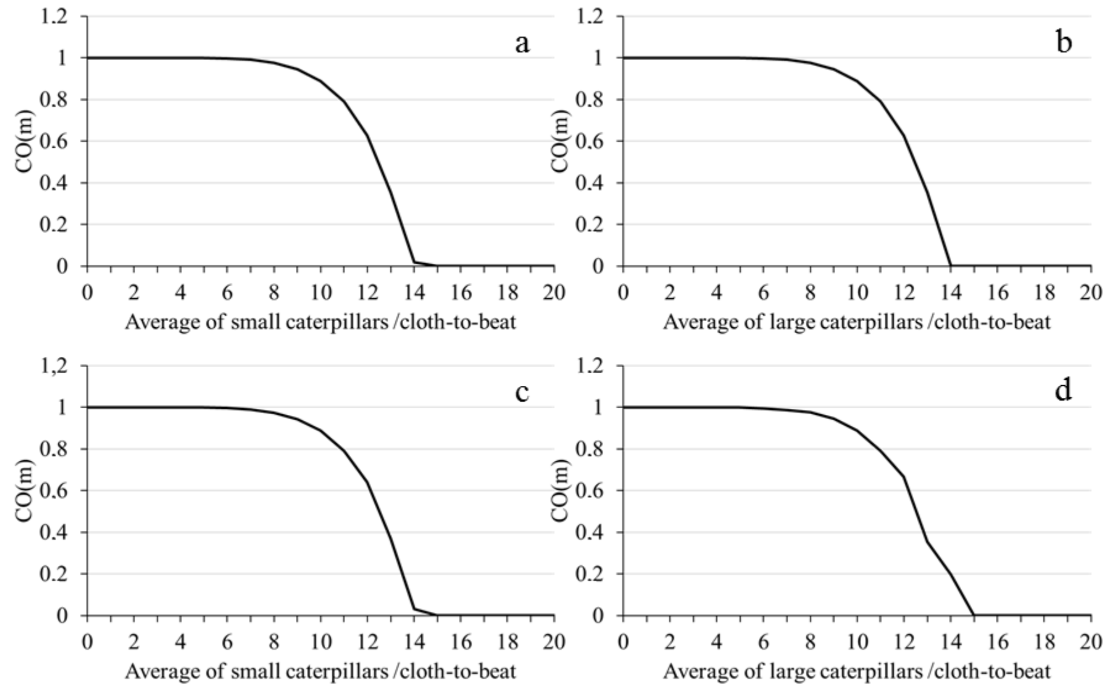

Figure 3. Characteristic operating curve CO(m) of the sequential sampling plan for small caterpillars (a) and large caterpillars (b) collected by vertical cloth-to-beat method at 154 sampling points in 14 growth stages, 2010/2011 harvest. Characteristic operating curve CO(m) of the sequential sampling plan for small caterpillars (c) and large caterpillars (d) collected by vertical cloth-to-beat method at 154 sampling points in 8 phenological stages, 2012/2013 harvest.

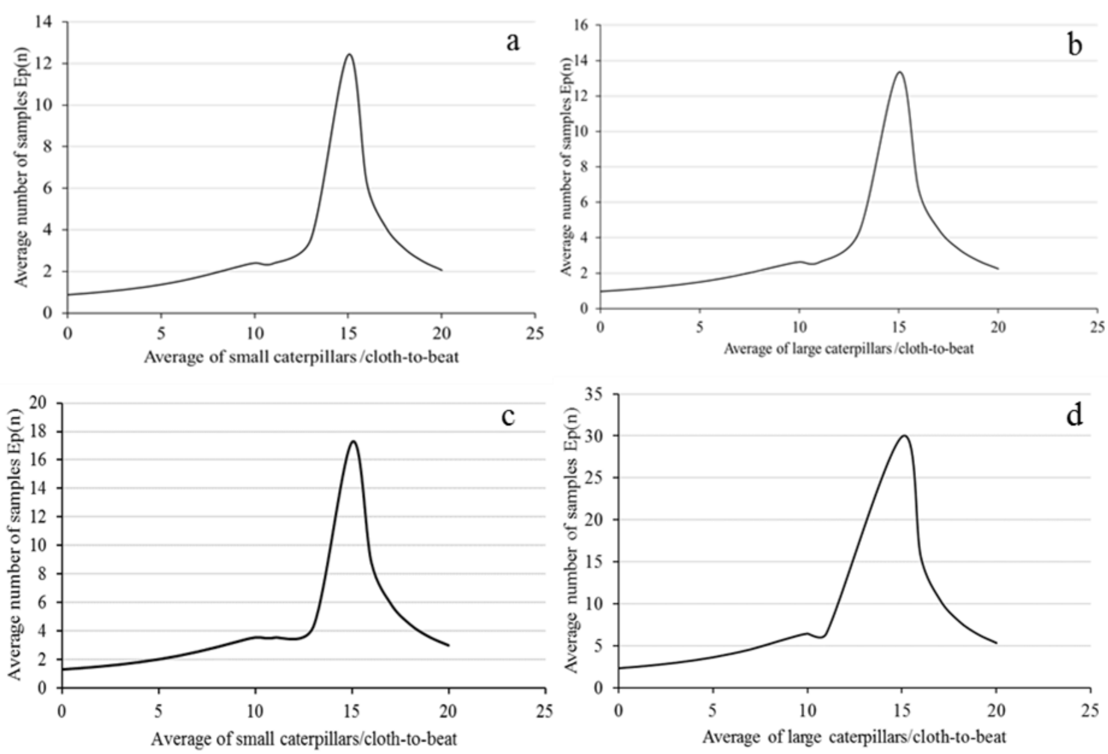

Figure 4. Curve of the expected size of the sample units Ep(n) of the Test of the Sequential of the Likelihood Ratio for the number of small caterpillars (a) and large caterpillars (b) in soybean in the 2010/2011 season. Curve of the expected size of the sample units Ep(n) of the Test of the Sequential of the Likelihood Ratio for the number of small caterpillars (c) and large caterpillars (d) in soybean in the 2012/2013 season.

The results for the Expected Number of Sampling Units Ep (n) for small caterpillars in the 2010/2011 season (Figure 4a) indicate that for an average infestation of 15 caterpillars/vertical cloth-to-beat, the maximum number of samples to be performed is 13. As for large caterpillars in soybean in the 2010/2011 season (Figure 4b), the maximum number of samples is close to 14. Figure 4c indicates that for the number of small caterpillars in the 2012/2013 season, the maximum sampling would be 17, for large caterpillars in the same season (Figure 4d), the maximum number is 30, both with an average infestation of 15 caterpillars/vertical cloth-to-beat.

As the distribution of defoliating caterpillars of soybean is given in an aggregate manner, plans can be used efficiently and effectively for the different caterpillar sizes, as well as for the total population of caterpillars in the area, regardless of species.

It is recommended that the sequential sampling plan is used in order to meet the standards of Integrated Pest Management (IPM) in uniform stands with regard to planting, cultivating, topography, soil type, management, cultural practices, among others.

Conclusion

The distribution of small and large caterpillars in soybean tends to be aggregated, regardless of population density. Four sequential sampling plans for small and large caterpillars were built in two growing seasons, based on the negative binomial distribution. For the evaluation of caterpillars in the soybean crop, a number of samples for decision making, ranging from at least 6 sample units, up to a maximum of 30, should be used for determined and indeterminate growth cultivars.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Appendix A - Description of soybean growth stages

I	Vegetative Phase
VC	From emergency to open cotyledons.
V1	First node; open unifoliolate leaves.
V2	Second node; first open trefoil.
V3	Third node, second open trefoil. Vn Nth (last) node with open trefoil, before flowering.

II	Reproductive Phase (observation on the main stem)
R1	Beginning of flowering up to 50% of plants with a flower.
R2	Full flowering. Most racemes with open flowers.
R3	End of flowering. Pods up to 1.5 cm in length.
R4	Most of the pods in the upper third with 2-4 cm, with no noticeable grain.
R5.1	Grains perceptible to touch 10% of graining.
R5.2	Most pods graining 10 to 25%.
R5.3	Most pods between 25 and 50% of graining.
R5.4	Most pods between 50 and 75% of graining.
R5.5	Most pods between 75 and 100% graining.
R6	Pods with graining 100% and green leaves.
R7.1	Beginning to 50% yellowing leaves and pods.
R7.2	Between 51 and 75% yellow leaves and pods.
R7.3	More than 76% of leaves and yellow pod.
R8.1	Home to 50% defoliation.
R8.2	More than 50% of pre-harvest defoliation.
R9	Crop maturation point.

Fonte: Ritchie, S.W. et al. How a soybean plant develops. Ames: Iowa State University of Science And Technology Cooperative Extension Service. Special Report, 53, mar. 1982. (Adaptado por J. T. Yorinori (1996)).


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