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African Journal of Agricultural Research

Full Length Research Paper

Effect of oat and brachiaria intercropped with off-season maize in the grain production and biomass of green manure

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This study aims to determine the ideal time of green manures deployment and assess what kind of green manure will produce a favorable quantity of mass for the farming without interfering in the maize production. The experiment was conducted in Toledo - PR in 2013. It was designed in randomized blocks, in a factorial scheme (2 × 3 + 1) with 4 replications; the first factor is the species of intercropped coverage (*Avena strigosa* and *Brachiairia ruziziensis*), the second factor is the time of implementation of green manures intercropped with maize according to the phenological stages of the crop (VE, V4 and V8), and the single maize is the control treatment. The evaluated parameters were: Diameter of the stem base, ear insertion height, diameter of the base, middle and apex of the ear, ear length, number of grains per row and number of rows per ear, 1000 grain weight and productivity, and in the green manure the dry matter production. The results showed that the use of intercropping system did not affect maize yield, as well as the time of implementation of green manure. The more delayed the sowing of brachiaria, the lower its dry matter production; on the other hand oats showed opposite results, because the later its seeding is performed, the better are the results, presenting their normal development cycle. So the most feasible kind of green manure to be used according to the dry matter production is *B. ruziziensis* in the first sowing season (VE), being a profitable and favorable system for soil cover, without affecting maize productivity.

Key words: *Zea mays*, *Brachiaria ruziziensis*, *Avena strigosa*, crop-livestock integration.

INTRODUCTION

To be enabled technically and economically, the direct planting system (DPS) must not be focused only as an alternative method of seeding and soil management. It needs to be treated as a production system, comprising an ordered complex of agricultural practices interrelated and interdependent that include, in addition to not soil disturbance, diversified crop rotation, the use of cover crops to build and maintain stubble on the land and, more

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recently, the crop-livestock integration (Muzilli, 2000). Therefore, for the consolidation and success of the DPS, it is of the uttermost importance the crop establishment for the production of stubble, in adequate amount for soil cover, which reveals a problem in warmer regions, because of the accelerated process of decomposition (Chioderoli et al., 2010).

The soil cover crops are important components in agricultural systems, since they improve the physical, chemical and biological soil conditions. The presence of stubble on the ground reduces soil erosion and reduces weed infestation (Conte, 2007; Flores, 2008; Souza et al., 2009). Thus, it is worth to reinforce the concern in producing high amounts of stubble in order to maintain the soil protected for a longer period of time. The green manure is one of the indicated techniques used to improve soil fertility, consisting in vegetable cultivation and incorporation or not of its green mass to the soil. The choice of the most suitable green manure for each situation is very important, because the characteristics of each species of plant and its productive potential of dry matter must be known (Emater, 2002).

As the maize crop has low soil coverage levels with stubble, favoring soil degradation and reducing crop yields, other forms of coverage are being studied, such as the intercropped system of production with green manures. The intercropping is a system in which in a same area two or more species are implanted, coexisting together, for all or part of its cycle, allowing increase in productivity (Portes et al., 2003). Recently the intercropping may also be known as "mixture" of maize with other grasses, inclusive in autumn-winter (Soares et al., 2000).

The intercropping of grain-producing crops and tropical forages is possible due to the difference of time and space, in the accumulation of biomass among species (Kluthcouski and Yokoyama, 2003). According to Jakelaitis et al. (2004), the existing competition between species can make the intercropping impracticable. However, the knowledge of the species behavior, in the competition for factors of production, is of great importance for successful pasture formation in the autumn-winter period and for the satisfactory production of grain-producing crops.

As one of the most cultivated forages in the Brazilian savanna, brachiaria has been used to compose the intercropping, especially with maize, without causing damage to grain production (Ceccon et al., 2005). The maize intercropping with brachiaria allows the maintenance of maize as an economic cash crop in the off-season and the brachiaria adds coverage to the system for producing mass after the maize harvest until the time of desiccation prior to the next crop sowing (Ceccon, 2007). Being often used as green manure, oat has great importance for agriculture and cattle raising, due to its resistance to drought, low incidence of pests and diseases, low cost and high forage production (Pitol, 1988). Amado et al. (1999) observed a greater supply of nitrogen to the maize when it was preceded by oat + vetch intercrop, which promoted increase in maize yield. However, black oat has no evidence intercropping with maize, being used mostly as preceding maize crop or soybeans (Lázaro et al., 2013) which highlights the importance of the work.

The off-season maize intercropped with green manure provides great amounts of stubble for soil cover and consequently greater benefits to crops. For the intercropping becomes profitable, knowing the ideal time of sowing green manure not to interfere with the productivity of the main crop is of the uttermost importance to maximize agricultural production. Thus, this study aims to determine the ideal time to the deployment of green manures and assess what kind of green manure will produce a favorable quantity of mass to the cultivation, along without interfering in maize production.

MATERIALS AND METHODS

The experiment was conducted in 2013 on a property with direct seeding in the soybean stubble, located in Dez de Maio, a district of Toledo city- PR, latitude 24°42'28.71 "S, longitude 53°54'34.70" W, at an altitude of 504 m. The climate in the region, according to Köppen classification is Cfa, mesothermal humid subtropical, with hot summers with a tendency of rainfall concentration, with an average temperature above 22°C, winters with little frequent frosts with average temperatures below 18° C, without defined dry season. The average rainfall in the region is 1800 mm per year (Rubel and Kottek, 2010). The soil of the area used is classified as clayey eutroferric Red Latosol (Embrapa, 2012).

The experimental design adopted was in randomized blocks in a factorial design (2×3+1) with four replications. The treatments consisted of two green manures, *Avena strigosa* and *Brachiaria ruziziensis*, and three sowing seasons of green manures with the presence of a control. The size of each plot was 9×10 meters, totaling 90 m², with 2520 m² of total plots of land. The plots were composed of 10 lines of maize, with the sampling being done with the six half lines, having a useful area of 23.4 m².

The green manures were sown in predetermined stages of maize, VE (emergence of maize), V4 (four fully developed leaves) and V8 (eight fully developed leaves), being arranged in the following treatments: T1: Control (single Maize); T2: Seeding of *Avena strigosa* between rows of maize in emergency; T3: Seeding of *Avena strigosa* between rows of maize in V4 stage; T4: Seeding of *Avena strigosa* between rows of maize in V8 stadium; T5: Sowing of *Brachiaria ruziziensis* between rows of maize in emergency; T6: Sowing of *Brachiaria ruziziensis* between rows of maize in V4 stage; T7: Sowing of *Brachiaria ruziziensis* between rows of maize in V8 stadium.

The off-season hybrid maize AG 9010 YG was used, with characteristic super precocity; it can flourish before possible droughts or frosts and hence ensuring the best yield. Furthermore, it has modern plant architecture, with upright leaves and lodging resistance, this way it allows higher density and uses smaller spacing between rows, increasing the plant population (Agroceres, 2013). The used green manure plants were both *Poaceae*, being black oat (*Avena strigosa*), Embrapa 29 Garoa, with 98% of purity and 80% of viable seeds and *Brachiaria ruziziensis* cv. Ruziziensis of the company Sementes Mega 100®, with 94.9% of purity and 80% of viable seeds with sowing density of 40 viable seeds and 15 to 20 viable seeds per meter, respectively.

Soil correction was used with 200 kg ha^{-1} NPK formulation 08-20-20. The maize sowing was done on February 2nd, 2013 and the final population density of maize on the desired experiment was 59,000 plants ha^{-1}, with 5.3 plants m^{-1} linear, with space between rows of 0,9 m. The green manures of cover were sowed in a single row between the maize line. The control of weeds in pre-emergence was performed with the use of the herbicides glyphosate and atrazine. An application of insecticide made of imidacloprid + beta-cyfluthrin was held to control bugs in the maize at seven days after emergence (DAE). The application of nitrogen in 100 kg ha^{-1} was made when the maize crop was in V4 stage. The evaluation of the experiment occurred in the R7 stage of the maize, in other words, when the grains are already physiologically mature.

Among the evaluations, ten random plants were used within the useful area of the plot, collecting the stem base diameter data, ear insertion height, diameter of the base, middle and apex of the ear, ear length, number of kernels per row and number of rows per ear. As for the diameter of stem and ear parameters, evaluations were carried out with the aid of a digital caliper. For the parameters height of ear insertion and ear length, we used tape measure, measuring plant from the base to the ear height of stem node and measuring from base to apex of the ear, respectively. The parameters number of rows per ear and grains per row, the count was made individually.

After collecting the data from the above analysis, the harvest of the remaining useful area of the plot was held, when the maize was found in point of harvest, in other words, with 14% of humidity. Subsequently, the threshing of the material was performed, with the aid of a thresher coupled to the tractor. The threshed maize samples were submitted to weighing to determine the yield in kg ha^{-1}. Of these samples, 1000 seeds were counted to determine the weight of them. Both weight measurements were performed on precision scales.

For the green manures, it was held the collection of 2 linear meters (1.8 m²) of green plant material, since the green manures were seeded in line. These materials were added in paper bags and then taken to air forced circulation stove for drying, at a temperature of 60°C for 72 h. The samples after being drought were weighed on a precision scale and the values were transformed for kg ha^{-1} of dry matter.

The data were submitted to variance analysis and when significant, they were compared using the Tukey averages test at 5% of significance, with the help of statistical program CoStat 6.4 (Cohort Software, 2003).

RESULTS AND DISCUSSION

The qualitative components of maize: stem diameter (SD) and ear insertion height (EIH) showed no significant differences ($p > 0.05$) showing that the covers and the sowing seasons of green manure did not influence the development of maize as shown in Table 1. Table 2 shows that ear mean diameter (EMD), ear length (EL), number of rows per ear (NRE), number of grains per row (NGR) and number of grains per ear (NGE) have no significant difference ($p > 0.05$). Green manures did not interfere with the development of the plant, but through competition among plants for nutrients, water and light, the 1000 grain weight (TGW) has achieved significant results ($p < 0.05$) as the type of coverage.

Similar results were found by Tsumanuma (2004) when studying the combination of three species of brachiarias (*Brachiaria decumbens*, *Brachiaria brizantha* and *Brachiaria ruziziensis*) being sown in two seasons (V0 and V4 stage of the maize). No statistical difference were found between treatments for the following variables: Plant height; leaf area index; diameter of the stem; leaf analysis; number of grain rows; number of grains per ear; 1000 grains weight and productivity.

Gimenes et al. (2010) observed that sowing *B. brizantha* after 15 days ensured larger stem diameter, 1000 grain weight and productivity, being indifferent statistically when compared to single maize cultivation, corroborating this work, in which the intercropping becomes feasible for the maize.

According to Table 3, the productivity of maize (PROD) showed significant differences ($p < 0.05$) only in blocks, which justifies the use of randomized blocks design (RBD), as well as the number of grains per row on Table 2. Batista et al. (2011) when assessing the simultaneous cultivation in a Red Ferric Latosol between rows of maize cv. DKB 390 with four forage species (*Brachiaria brizantha* cv. Marandu, *B. decumbens* cv. Basilik, *B. ruziziensis* cv. Comum and *Panicum maximum* cv. Tanzania), found that grain yield was not affected by the presence of intercropping.

As for the dry matter production of green manure, both the type of coverage and the implementation season had an effect on it significantly ($p < 0.05$). A meaningful interaction also occurred for the type of coverage x time (Table 3). The 1000 grain weight had influence according to the type of cover used in the winter maize intercropping, where the single maize (control) had the best result and in brachiaria coverage obtained the lowest mass. The sowing of the intercrops did not show significance ($p > 0.05$) on the 1000 grain weight (Table 4). The results coincide with Spader and Vidal (2000) who found that light interference caused by the intercropped plant affect the photosynthetic rate of the maize plant; thereby reducing the amount of starch stored in the grains and therefore reducing the mass of grains. Gimenes et al. (2008) obtained a reduction of the mass of the 1000 grains weight of maize when it was intercropped with brachiaria, pointing to this reduction the competition between plants and soil and climatic conditions during this period. In the case of Table 4, the weather conditions were favorable for maize crop (Figure 1).

The productivity of off-season maize intercropped did not show any significant differences ($p > 0.05$) between treatments (Table 5). One of these facts is that the maize hybrid used in the trial has high competitiveness with other plants. The productivity results obtained are in line with Crusciol and Borghi (2007) who observe that there was not significant reduction in maize cultivation for the single maize intercropped, commenting so, that intercropping maize with brachiaria can be performed due to time and space, being different the accumulation of biomass for the species.

The sowing time of the green manures had no

Table 1. Summary of the variance analysis of the qualitative components: stem diameter (SD) and ear insertion height (EIH). Toledo – PR, 2015.

Variance factors	**M.S.**	
	SD	**EIH**
Coverage	0.008^{ns}	5.255^{ns}
Season	0.004^{ns}	2.620^{ns}
Coverage x Season	0.004^{ns}	11.745^{ns}
Blocks	0.017 ^{ns}	31.594^{ns}
Average	cm	
	2.089	84.222
CV (%)	6.339	4.457

^{ns}, Non-significant.

Table 2. Summary of the variance analysis for the production components: Ear mean diameter (EMD), ear length (EL), number of rows per ear (NRE), number of grains per row (NGR), number of grains per ear (NGE) and thousand grain weight (TGW). Toledo – PR, 2015.

Variance factors	**M.S.**					
	EMD	**EL**	**NRE**	**NGR**	**NGE**	**TGW**
Coverage	0.017^{ns}	0.113 ^{ns}	0.463^{ns}	0.066^{ns}	672.335^{ns}	1,034.43*
Season	0.001^{ns}	0.005^{ns}	0.063^{ns}	0.303^{ns}	246.923^{ns}	25.926^{ns}
Coverage x Season	0.003^{ns}	0.105^{ns}	0.127^{ns}	1.027^{ns}	346.065^{ns}	35.516^{ns}
Blocks	2.79 ^{ns}	0.239^{ns}	0.341^{ns}	9.194*	884.925^{ns}	17.046^{ns}
Average	cm		n°		g	
	4.464	16.144	14.667	30.658	449.574	312.596
CV (%)	2.411	4.643	3.851	4.890	6.487	4.061

^{ns}, Non-significant; *, significant at 5%.

Table 3. Summary of variance analysis for grain productivity (PROD) and dry matter production of the intercropped covers (DM). Toledo – PR, 2015.

Variance factors	**M.S.**	
	PROD	**DM**
Coverage	123,473.320^{ns}	30,173,333.000*
Season	68,645.055 ^{ns}	4,154,533.300*
Coverage x Season	25,804.374^{ns}	6,547,866.7*
Blocks	279,214.910*	482,785.190 ^{ns}
Average	Kg ha^{-1}	
	5,480.836	1,300.000
CV (%)	4.733	34.161

^{ns}, Non-significant; *, significant at 5%.

significant influence ($p < 0.05$) on maize productivity, since its development is slower compared to maize's (Table 5). Even in the simultaneous sowing of both crops, the maize, for being a large-sized plant and with accelerated growth, excels in the light of the forage; in this way, maize productivity is not affected.

Batista et al. (2011) conclude that by having a slow growth, brachiaria even germinating along with maize cannot compete for water, light and nutrients and its development stagnates. The authors also relate that the forage only back receiving lot of light and water when the maize mature, which makes the dried leaves reduce shading and prevent the ingress of water. Pequeno (2006) conducted a similar experiment, using five arrangements of brachiaria sowing intercropped with maize, getting no significant results between treatments

Table 4. Thousand grain weight results (TGW) of the off-season maize intercropped with different green coverage at different times of deployment of the intercrop (phenological stages of maize). Toledo – PR, 2015.

Variance factors		**TGW (g)**
Coverage	Control	322.1[a]
	Oat	312.2[ab]
	Brachiaria	303.4[b]
Season	VE	314.3[a]
	V4	312.0[a]
	V8	311.5[a]
MSD		12.9

Averages followed by the same letter in the column, do not differ significantly at 5% in the Tukey test.

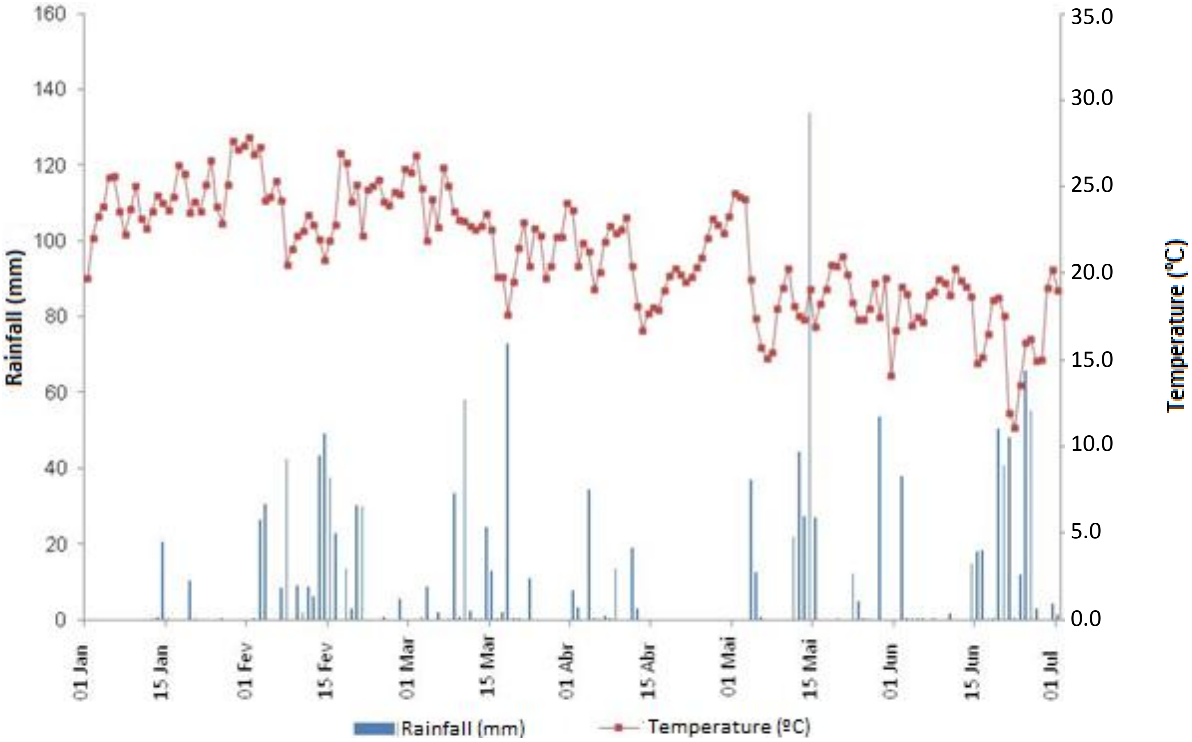

Figure 1. Weather conditions (Rainfall and Temperature) of the experimental period in 2013. Toledo - PR, 2015. Source: Weather Station from PUCPR - Campus Toledo.

($p > 0.05$), concluding economically that simultaneous sowing of brachiaria with maize is the most recommended, because it reduces the operating system in cultivation, thereby reducing costs.

Disagreeing with the results, Gimenes et al. (2008) obtained better production results in single maize compared to intercropped maize, but with acceptable loss levels. This proves the viability of maize intercropped system with forages for the low and medium population density, 10 and 15 plants per linear meter, respectively. Chioderoli et al. (2010) also achieved significant production results, both for the time of implementation of green manures and also for the type of coverage, concluding with their experiment that the most indicated green manure is *B. ruziziensis* sown at the time of the maize coverage (V4).

The dry matter produced by green manure had significant results ($p < 0.05$) as for the type of coverage and the time of their sowing (Table 6). The coverage that achieved greater dry matter production in conjunction

Table 5. Grain production of off-season maize (PROD) intercropped with different green coverage at different times of deployment of the intercrop (phonological stages of maize). Toledo – PR, 2015.

Variance factors		**PROD (kg ha^{-1})**
	Control	5,594.1^{a}
Coverage	Oat	5,398.4^{a}
	Brachiaria	5,449.9^{a}
	VE	5,525.6^{a}
Season	V4	5,449.9^{a}
	V8	5,567.0^{a}
MSD		264.5

Averages followed by the same letter in the column, do not differ significantly at 5% in the Tukey test.

Table 6. Dry matter production of oat and brachiaria depending on the sowing season. Toledo – PR, 2015.

Interaction		**Season**			**MSD**
		VE	**V4**	**V8**	
		Kg ha^{-1}			
	Control	0^{bA}	0^{bA}	0 ^{b}A	0
Coverage	Oat	580^{bB}	760^{bB}	1,160 ^{aA}	185.2
	Brachiaria	5,100^{aA}	3,110^{aB}	990 ^{aC}	1,412.0
MSD		946.2	1,473.5	351.6	

Averages followed by the same letters, lowercase in the columns and uppercase in the lines, do not differ between each other by Tukey test at 5% probability.

with the sowing time was brachiaria in VE stage of the maize. As for the sowing season, it can be observed that the maize had direct influence on the development of green manures, especially regarding the intercepted light intensity. Thus, the later the seeding is performed, in other words, the maize crop in a more advanced stage, the lower the brightness that the green manure will receive and obtaining smaller plant development and consequently, smaller amounts of biomass. Thereby, the sowing of green manure in VE's stage of maize showed better biomass production responses of brachiaria. These values are opposed to the culture of the oat, because the more delayed its implementation, it is found closer to its sowing, and consequently shows higher vegetative development.

The use of brachiaria intercropped with maize has shown good results, not reducing the production of maize grain and getting a good soil cover with dry matter of brachiaria as reported by Ceccon (2008). The same author also states that the presence of grasses does not affect the maize production, among them *B. ruziziensis* has stood out by presenting decumbent growth habit, the highest closure between lines and better soil cover.

Corroborating the results of this experiment, Resende (2008) conducted experiments with different population densities of brachiaria and noted that there were not very different results between the densities. This probably occurred due to large plastic capacity of this species in terms of vegetative growth, having low population but with greater number of tillers, offsetting the average density.

Richart et al. (2010) observed the different dry matter production responses of *B. ruziziensis* sown at different times intercropped with corn, obtaining values similar to those obtained in this experiment. The authors report that there was a declining production curve as the later sowing, in other words, simultaneous seeding resulted in higher dry matter production. Borghi et al. (2007) noted that the sowing time of brachiaria influences its dry matter production, and they explain this fact through the competition caused by maize with brachiaria. This occurs due to the interception of light radiation, which promotes physiological changes in the plant, as the photosynthetic metabolism. Thus, the plan anticipates its development cycle, reducing the production of leaves, stems and sheaths.

The oat has no evidence intercropping with maize, being used mostly as preceding crop to maize or soybeans (Lázaro et al., 2013). This is due to the fact that oat is very influenced by maize and also the planting of this species along with maize or even the V8 stage of it, is out of its sowing season. Thereby, oat will reduce its vegetative cycle and then start the reproduction and consequently, biomass production will be lower. The production of dry matter varied according to implementation time, as found by Pequeno (2006) with a difference of production between the seasons, which suggests the planting of cover crops to maize simultaneously, reducing the number of agricultural operations and, above all, achieving higher dry matter production.

Therefore, the later was the sowing of brachiaria, the lower was the production and such results corroborate Tsumanuma (2004), pointing out that late sowing affects in a bad way the initial development and the accumulation of dry matter by brachiaria, caused by water competition rate, nutrients and light, in which maize has high efficiency.

Conclusion

According to the results obtained through this study, it can be concluded that there was no interference in maize yield as for the intercropping with the covers, being a viable practice to the farmer. The coverage best suited for intercropping with maize is brachiaria sown V0 stage, because it presents a greater dry matter production at the end, providing a greater soil cover and a lower cost of production. As for the green coverage sowing season, both of them caused no decrease in productivity of maize; therefore, the first sowing season is the most profitable, because it provided greater development of brachiaria, resulting in a higher production of biomass and lower production costs.

Conflict of Interest

The authors have not declared any conflict of interest.

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Soil survey and soil classification of the Koupendri catchment in Benin, West Africa

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Lack of detailed soil data has been a major constraint to hydrological modeling and making of agronomic decisions in the Koupendri Catchment. A soil survey was carried out to characterize and classify the soils of the 11.8 km^2 catchment using Soil and Terrain (SOTER) approach. The soils were classified using the soil taxonomy (USDA) and the world reference base for soil resources (WRB) classification systems. The soil map produced at a scale of 1:25000 using FAO/UNESCO legend showed five distinct soil types. The dominant soil type - Dystric Plinthosols - covered about 55% of the area and supports few crop productions but make plantation agriculture almost impossible. The soils are slightly acidic to alkaline, predominantly silty to clayey in texture with good to imperfect drainage, low permeability and high bulk density that impedes root growth. The poor soil organic carbon content, total nitrogen, available phosphorus, cation exchange capacity, base saturation and other basic exchangeable cations with moderately leached horizons indicated low-moderate fertility status of less weathered soils. The soils belong to three major soil orders: Ultisols, Inceptisols and Alfisols (USDA), and reference soil groups: Plinthosols, Cambisols, Luvisols and Gleysols (WRB). The WRB gave a better and detailed soil classification compared to USDA, and thus should be used in subsequent classification of soils in the region.

Key words: Soil and terrain (SOTER), ultisols, alfisols, inceptisols, plinthosols, cambisols, luvisols, gleysols.

INTRODUCTION

Soil is a basic natural resource with widespread utilization ranging from agriculture, forestry, and other engineering and environmental purposes such as hydrological modeling. The importance of soil data for sound environmental and natural resource management has been reported (McKenzie et al., 2000). Besides being a storage reservoir and source of water supply, soil protects groundwater supplies by buffering and transforming pollutants. It is said that many of the current environmental, social, economic, geologic, and human

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health issues such as heavy metal poison can be better addressed if soils are considered important and paid due attention (Howitt et al., 2009; Brevik, 2013; McBratney et al., 2014 cited in Brevik et al., 2014). Recently, there is an increasing global demand for soil data and information for environmental monitoring due to global warming impact on water resources. An understanding of nature, properties, dynamics, distributions and functions of the soil as part of landscapes and ecosystem is paramount especially to prevent its continuous degradation and ensure its continuous and sustainable utilization. In land evaluation, wise decisions on land use and effective management of soils for improved agronomic productivity require an understanding of soil distribution patterns (McBratney et al., 2000). This important data most times is non-existent and sometimes available at a small scale too coarse and difficult to use for accurate modeling of hydrological processes. This is particularly true for most West African catchments including Koupendri catchment in north western Benin, where the impact of climate change is expected to be pronounced. For instance, the existing data on soil types and supporting maps for the catchment were those produced by the erstwhile ORSTOM at the scale of 1:200.000, 1:250.000 and 1:500.000 and date back to the colonial period.

Reliable soil data is a prerequisite for hydrological and environmental modeling, as well as for the design of appropriate land-use systems and soil management practices. This will help to arrest further degradation and rehabilitate the potentials of degraded soils, as well as for a better understanding of the environment (FAO, 2006a). Such reliable soil information is obtained through examination and description of the soil in the field. Most soil surveys result in the preparation of a soil map alongside a soil or scientific report which gives the inventory of the soils found in the area, their geographic distribution, physical and chemical characteristics, and climate and land use together with interpretations comparing different land use.

Thorough soil description serves as the basis for soil classification and site evaluation as well as for interpretations on the genesis and environmental functions of the soil (FAO, 2006a). Thus, the aim of this study is to make a detailed soil survey of the Koupendri catchment aimed at providing basic soil data appropriate for hydrological modeling, and for making recommendations and decisions on the present and future use of the land for planners, agronomists, and other engineering uses/purposes.

Objectives of the study

1. To characterize and classify the soils using appropriate soil classification systems.
2. To develop a detailed soil map of Koupendri catchment.
3. Make recommendations that ensure sustainable management of soil and water resources.

Description of the study area

The study was conducted on 11.8 km^2 area of Koupendri catchment - a part of Volta basin located north-west of Benin (Figure 1). The geology of north western Benin is made up of the Precambrian Voltaian (Faure and Volkoff, 1996). The catchment can be characterized as an undulating pediplain relief overlying a Precambrian crystalline basement. According to ORSTOM, fersialitic and ferralitic soils are dominant often with gravelly or plinthic horizons. The catchment is located on latitude 1° 05'55'' to 1°14'54'' N and longitudes 10°44'12'' to 10°55'48''E, and has a relatively flat physiography with a mean slope of 0.4%, and height above sea level of 220 m. It has a population density of 60 persons/km^2. It has a unimodal rainfall distribution pattern with distinct wet (rainy) and dry seasons. The rainy season lasts for about five months, from May to September while the dry season lasts for seven months, from October to April. Annual rainfall varies between 900 and 1200 mm, with a yearly mean of 920 mm. During the rainy season, temperature varies between 25 and 30°C, with a relative humidity that can reach up to 97% in August. Between March and April, the temperature reaches a maximum of between 42 and 45°C. The relative humidity throughout the season is between 25 and 55%. The catchment is located within the Northern (dry) sudanian region according to the vegetation zone classification of Benin by Wezel and Böcker (2000). The Sudanian vegetation is dominated by grassland and trees/shrubs of low density. The major land use is agriculture which focuses on grain crops such as maize, sorghum, rice etc., tuber crops such as yam, oil and cash crops such as cotton, and pastoralism (livestock production). Only a small amount of land is suitable for agriculture, livestock, and for dwellings in the Volta Basin of Benin due to poor nutrient status of the soil and limited availability of water. Despite these constraints, agricultural activities are rapidly expanding due to population growth, migration and accessibility.

As a result, competition exists over these finite resources resulting to over-exploitation and further degradation of these resources. The significant demographic pressure experienced in the region put more pressure on land resources, and thus hinders economic development in the region.

FIELD METHODS

Field observations were made using toposequence method with clinometer during reconnaissance survey of Koupendri catchment. Transects were positioned at an interval of 250 m both along tracks or roads across the catchment. With the help of the global positioning system (GPS), about 200 observations points by auger

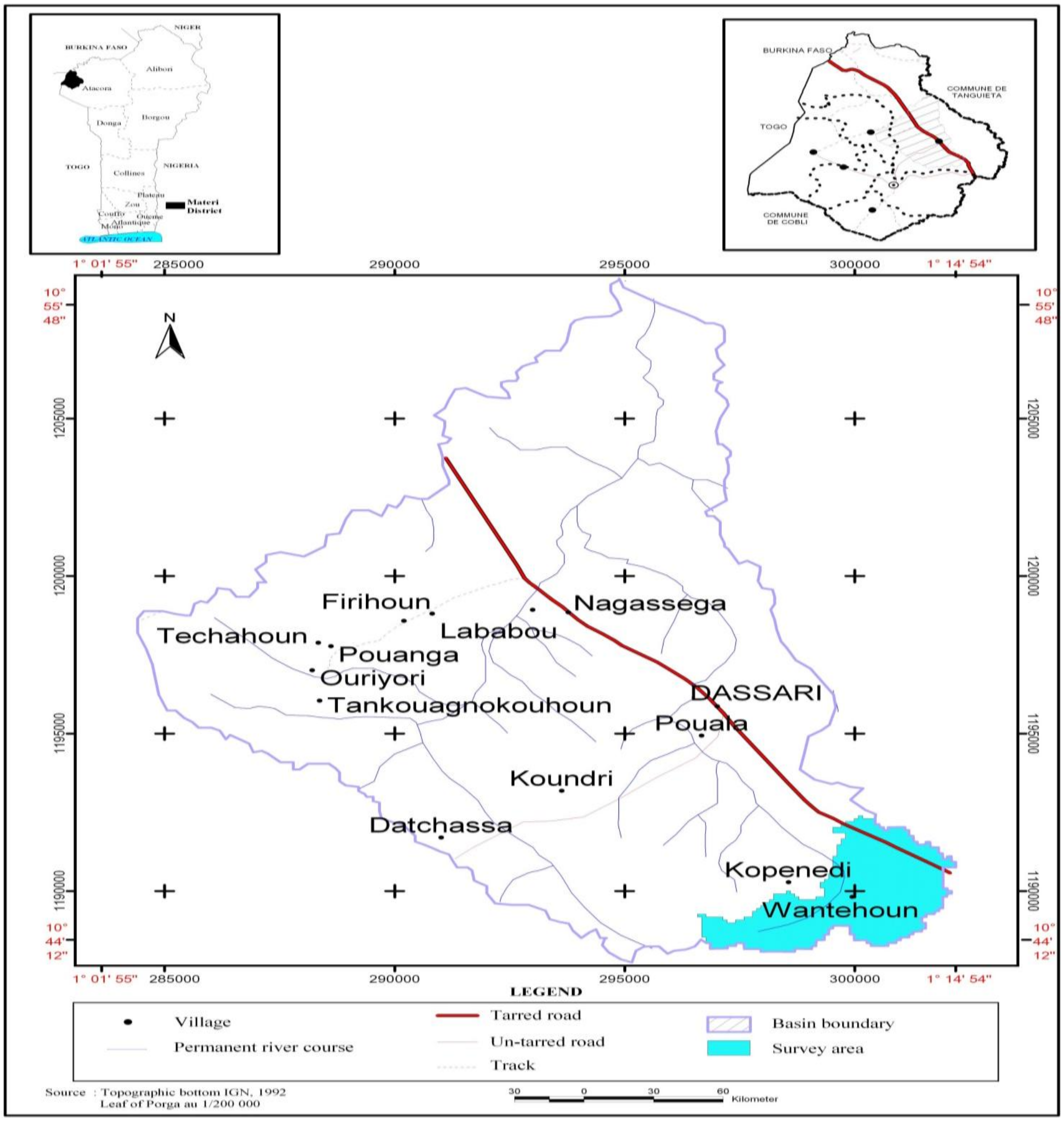


Figure 1. Location of Koupendri catchment in the Dassari catchment in Benin.

drillings at 250 m interval and ten (10) profile pits were done in the catchment (Figure 2).

The soil mapping of the location was carried out using Soil and Terrain (Soil and Terrain (SOTER)) approach (Igué, 2000; Weller, 2002) with the idea that land in which terrain and soil occur incorporates processes and systems of interrelationships between physical and biological phenomena evolving through time. Soil profile description was made based on the guidelines for soil profile description (FAO, 1990, 2006a). The profiles were sampled for determination of both physical and chemical properties of the soil. The results of the soil analysis were used for the classification and characterization of the soil.

The description, classification and characterization of the soil were done based on the Guidelines for Soil Description (FAO, 2006a), Field Book for Describing and Sampling Soils (Schoeneberger et al., 2002), Keys to Soil Taxonomy (USDA Soil Survey Staff, 2010) and the third edition of the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014), and correlated with the FAO/UNESCO legend and French classification system (CPCS, 1967).

Laboratory analysis/methods

The particle size distribution of the < 2 mm size fraction of soil samples were determined using the hydrometer method described by Gee and Or (2002). Bulk density was determined by core method as described by Blake and Hartge (1986), and Anderson and Ingram (1993). Organic carbon (C) was determined on the air dried, 2 mm sieved samples according to the Nelson and Summer (1982) method. The organic matter content (OM) was obtained by multiplying values of organic carbon by a factor of 1.724. The pH value was determined potentiometrically using a pH meter in a soil: liquid ratio of 1:2.5 suspensions of soil in 0.1N KCl and distilled water (McLean, 1982).

Saturated hydraulic conductivity (ksat) was measured using the constant head permeameter method. Darcy's equation, as outlined by Young (2001) was used for the computation of Ksat.

$$Ksat = QL/(A\ T\ \Delta H) \quad (1)$$

Where Q = steady state volume of outflow from the entire soil

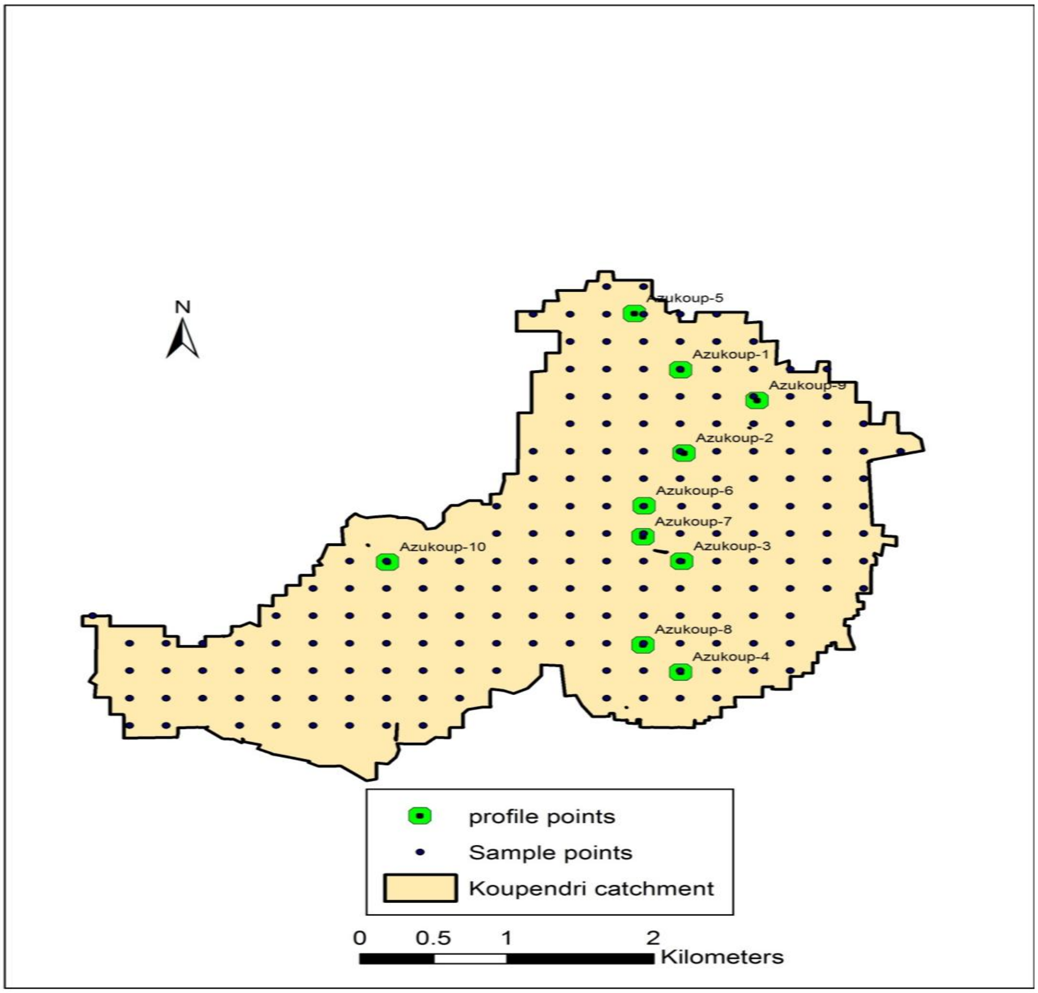


Figure 2. Map of Koupendri catchment showing auger sampling and profile points.

column (cm^3), L is the length of soil column (cm), A is the interior cross-sectional area of the soil column (cm^2), ΔH is the change in hydraulic head or the head pressure difference causing the flow (cm), T is the time of flow (sec).

Soil water retention characteristics (field capacity (0.33 bars) and wilting point (15 bars)) were determined using pressure plate extractors or apparatus (Van Reeuwijk, 2006), then Available Water Holding Capacity (AWHC) was computed from FC and PWP.

$$AWHC = FC - PWP \tag{2}$$

Total nitrogen (N) was determined by Kjeldahl method (Bremner, 1996). Available phosphorus (P) was determined using Bray II method (Bray and Kurtz, 1945). Cation exchange capacity (CEC) was determine using the method described by Lavkulich (1981) or the $BaCl_2$ compulsive exchange method by Gillman and Sumpter (1986). Exchangeable Cations (Na, K, Ca, and Mg) were extracted using ammonium acetate (NH_4OAc). The cations were read on Flame Photometer (K, Na, and Ca) and Atomic Absorption Spectrophotometer (AAS) (Mg) respectively. Soil color was determined using Munsell colour charts (Munsell Colour Company, 2000). Soil depth was determined by measuring the thickness of each soil horizon using a ruler/tape graduated in centimeters. Total porosity (%) (assumed particle density $p_s = 2.65$ kg m^{-3}), base saturation (BS), exchangeable sodium percentage (ESP) and CEC of clay were computed, using their respective equation as follows:

$$TP = \left(1 - \frac{ps}{pb}\right) x\ 100 \tag{3}$$

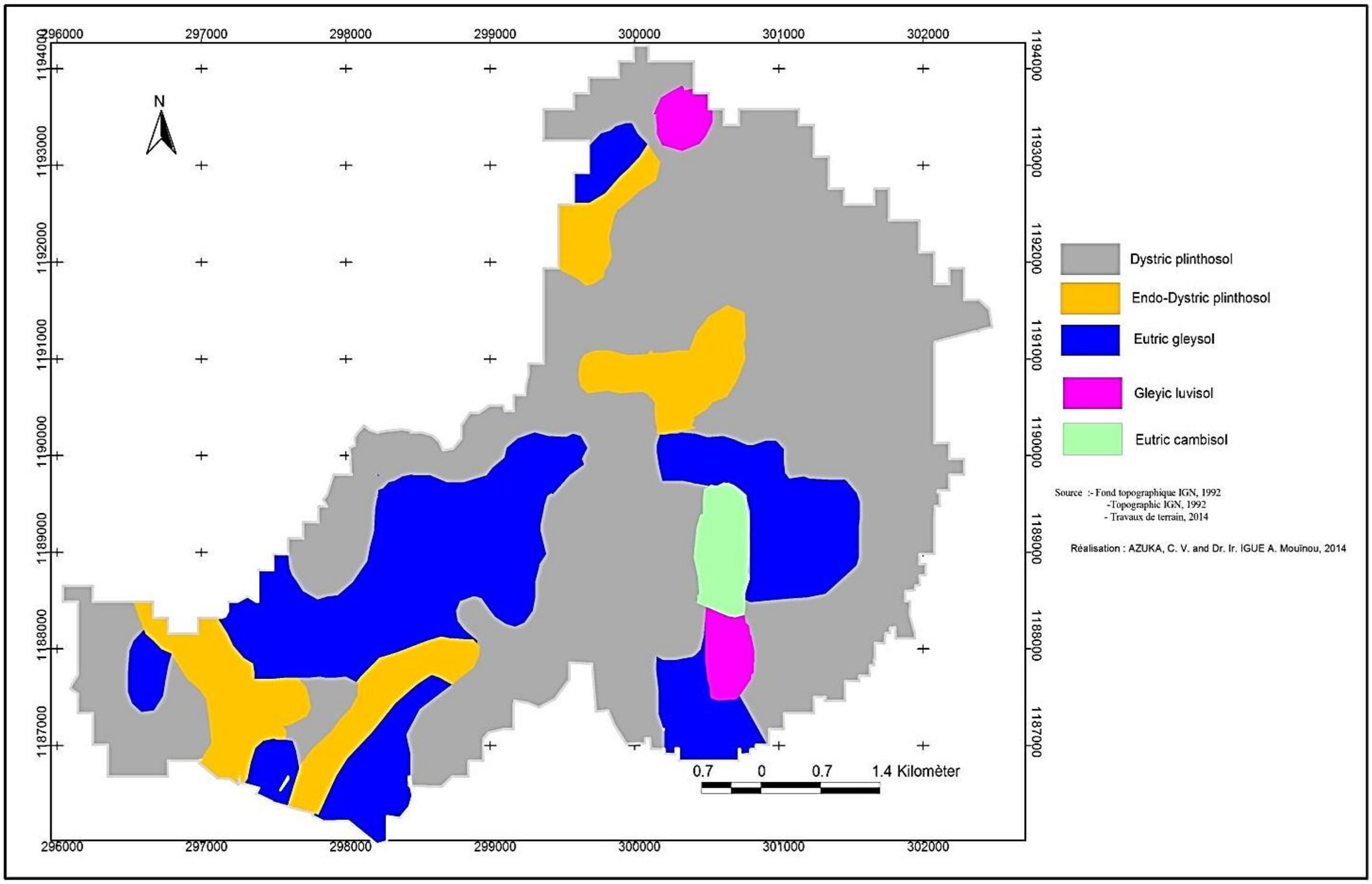
$$BS = \frac{Ca+Mg+K+Na}{CEC} x\ 100 \tag{4}$$

$$ESP = \frac{Exchangeable\ Na}{CEC}\ x\ 100 \tag{5}$$

RESULTS AND DISCUSSION

Soil map of Koupendri catchment

The soil map of Koupendri catchment was produced using both field observable features and analytical results based on Soil and Terrain (SOTER) approach. Soil and Terrain (SOTER) approach was originally designed for small scale mapping at 1: 1,000,000 considering terrain-soil attribute relationships.



Source :- Fond topographique IGN, 1992
-Topographic IGN, 1992
- Travaux de terrain, 2014

Réalisation : AZUKA, C. V. and Dr. Ir. IGUE A. Mouïnou, 2014

Figure 3. Distribution of soils in Koupendri catchment (FAO) at a scale of 1:25000.

However, at larger scales of 1:100,000 and beyond, only the soil attributes are retained with little or no terrain attributes. These soil attributes obtained from about 200 auger drilling points spaced at 250 m intervals were projected on the map of the catchment. Soils with similar attributes based on field observable features and analytical results were grouped together and mapped using expert knowledge. The soil map of this study was produced at the scale of 1:25,000 showing mainly the soil attributes using the FAO/Unesco soil map legend. The soil map showed that Plinthosols are the dominant soil type in the catchment. Plinthosols which are characteristic of strongly weathered soils (FAO, 1988) consist more than 55% of the catchment soils compared to other soil types; Gleysols, Luvisols and Cambisols (Figure 3).

Soil description and characteristics of Koupendri catchment

The soil colour (moist, dry) value and chroma varied with depth ranging from dark brown 10 YR mostly at the A-horizon to reddish brown 7 YR and yellow 2 YR at the sub-surface horizon except at few horizon (AZUKOUP-4 and AZUKOUP-5) with uniform reddish brown 7 YR throughout the horizons (Table 1). The increase in soil color from dark brown 10 YR to reddish brown 7 YR could be attributed to the oxidation of iron oxides responsible for the reddish colour in subsoil horizons (Buol et al., 2003) and to a lesser extent, the decrease in SOC with depth. The poor variability in the soil colour hue, value and chroma is an indication of the presence of soil moisture caused by a high water table due to a shallow aquifer. The presence of mottles in some subsoil layers confirms that the soils have moderate to poor drainage conditions.

The soil structure of the surface horizons of the soil profiles were mostly massive and compact with varying size of weak peds except at AZUKOUP-3 that has cubic and platy structure at the surface (Table 1). The subsurface horizons were massive and compact with few exception having either platy, prismatic, angular blocky or blocky structure. The consistence (dry) of both surface and subsurface horizons ranged from friable through hard to very hard. The gravel content of the soils increases

Table 1. Koupendri catchment characteristics and soil description.

	Depth (cm)	Color		Structure	HB	Cons.	CF	BA
		Moist	Dry				(%)	
AZUKOUP-1								
Ap$_{c}$	0-20	10YR5/3	10YR7/2	MC	Dis	F	20	High
Bt$_{nc}$	20-30	7.5YR4/6	7.5YR5/6	MC	Dis	vh	60	Low
AZUKOUP-2								
A$_{c}$	0-15	10YR4/2	10YR5/2	MC	Dis	F	10	Low
Bt$_{nc1}$	15-47	7.5YR5/3	7.5YR5/6	BL/AB	Gr	F	15	Low
Bt$_{nc2}$	47-80	7.5YR8/2	7.5YR8/6	MC	Dis	F	10	Low
AZUKOUP-3								
A$_{gh}$	0-12	10YR3/2	10YR7/1	Cu/Pl	Gr	Vh	-	High
Bt$_{gn}$	12-30	7.5YR3/2	7.5YR8/1	Pri/Pl	Dis	Vh/C	-	Medium
Bt$_{gcn}$	30-60	10YR4/3	10YR7/2	M/Pl/C	Gr	Vh	15	Low
Bt$_{gc2n}$	60-100	2.5Y7/2	2.5Y6/2	M/Pl/C	Gr	Vh	15	Low
AZUKOUP-4								
A	0-12	7.5YR3/2	7.5 YR7/1	M/C	Dis	Vh	-	High
AB$_{g}$	12-35	7.5YR4/2	7.5YR6/2	M/C	Dis	Vh	-	Low
Bt$_{g}$	35-58	10YR4/3	10YR8/1	AB/C	Dis	Vh	-	Low
Bt$_{gc}$	58-120	2.5Y4/4	2.5Y7/6	BL/C	Dis	Vh	10	Low
AZUKOUP-5								
A	0-20	7.5YR5/3	7.5 YR7/2	M/C	Dis	F	-	High
Bt$_{ng}$	20-56	10YR5/3	10YR7/6	AB	Gr	F	-	Low
BC$_{ng}$	56-100	10YR4/2	7.5YR8/1	AB	Gr	F	-	Medium
AZUKOUP-6								
A$_{gn}$	0-20	7.5YR3/2	7.5 YR7/1	M/C	Dis	F	-	High
Bt$_{ng}$	20-32	7.5YR7/1	7.5YR8/2	M/C	Dis	S	-	Low
Bt$_{ngc}$	32-55	7.5YR7/1	7.5YR8/1	M/C	Gr	S	30	Low
AZUKOUP-7								
A$_{gc}$	0-17	7.5YR4/2	7.5 YR7/1	AB	Gr	F	5	High
Bt$_{gc1}$	17-42	7.5YR5/2	7.5YR6/1	AB	Gr	F	10	Medium
Bt$_{gc2}$	42-100	7.5YR5/1	7.5YR6/1	M/C	Gr	S	15	Low
AZUKOUP-8								
A$_{c}$	0-12	10YR4/2	10YR5/2	AB	Dis	F	20	Medium
Bt$_{c}$	12-40	7.5YR4/6	7.5YR58	M/C	Dis	Vh	50	Low
AZUKOUP-9								
A$_{c}$	0-20	7.5YR3/2	7.5YR7/1	M/C	Dis	F	40	High
Bt$_{c}$	20-52	7.5YR5/6	7.5YR7/8	M/C	Dis	Vh	60	Low
AZUKOUP-10								
A$_{c}$	0-15	10YR5/3	10YR7/2	M/C	Dis	F	45	High
Bt$_{c1}$	15-32	10YR3/3	10YR5/2	AB	Dis	F	50	Medium
Bt$_{c2}$	32-60	2.5YR4/4	2.5YR6/1	AB	Dis	S	60	Low

A= A-horizon, c=concretions or nodules, B= B-horizon, h=accumulation of organic matter, V= occurrence of plinthite, Vm= Hardened plinthite (hardpan, iron stone, petroferric or skeletic), g= stagnic conditions, t=illuvial accumulation of silicate clay, n=pedogenetic accumulation of exchangeable sodium, p = ploughing, HB = horizon boundary, cons. = consistence, CF = coarse fraction, BA = biologic activity, M/C = massive/compact, BL = blocky, AB = angular blocky, Pl = platy, Gr = gradual, Dis = distinct, F = friable, Vh = very hard, S = sticky, Cu = cubic, Pri = prismatic.

with depth and ranges from 10 % to more than 60%.

Soil textural characteristics

The clay content increased with increasing depth throughout the profiles except at AZUKOUP-4 and AZUKOUP-5 where it is irregular resulting to abrupt textural change (Table 2). The sand content decreased with increasing depth throughout the profiles while the silt content was irregular with increasing depth. The topsoils

Table 2. Soil textural properties of Koupendri soils.

Horizon	Depth (cm)	Fine S (%)	Coarse S (%)	Total S (%)	Silt (%)	Clay (%)	Gravel	TC	siltsilt/clay
AZUKOUP-1									
Ap$_{c}$	0-20	32.00	20.00	52	40	8	30.79	SL	5.0
Bt$_{nc}$	20-30	22.73	25.43	48	35	17	64.07	L	2.1
AZUKOUP-2									
A$_{c}$	0-15	27.70	29.30	57	34	9	14.42	SL	3.8
Bt$_{nc1}$	15-47	19.02	17.98	37	36	27	17.25	L	1.3
Bt$_{nc2}$	47-80	19.53	11.87	31	42	27	15.2	L	1.6
AZUKOUP-3									
A$_{gh}$	0-12	14.94	9.36	24	59	17	10.2	SiL	3.5
Bt$_{gn}$	12-30	12.65	8.15	20	57	23	15.04	SiL	2.5
Bt$_{gcn}$	30-60	11.97	10.73	22	47	31	12.61	CL	1.5
Bt$_{gc2n}$	60-100	7.08	17.88	24	39	37	22 .88	CL	1.1
AZUKOUP-4									
A	0-12	20.45	22.55	43	49	8	10.84	L	6.1
AB$_{g}$	12-35	21.00	20.00	*41*	50	9	10.94	SiL	5.6
Bt$_{g}$	35-58	21.96	18.04	40	42	8	16.93	L	5.3
Bt$_{gc}$	58-120	16.00	18.00	34	38	28	12.62	CL	1.4
AZUKOUP-5									
A	0-20	22.39	33.61	56	36	8	11.21	SL	4.5
Bt$_{ng}$	20-56	15.93	26.07	42	44	14	11.15	L	3.1
BC$_{ng}$	56-100	21.69	33.31	55	36	9	10.51	SL	4
AZUKOUP-6									
A$_{gn}$	0-20	25.22	26.78	52	41	7	9.16	SL	5.9
Bt$_{ng}$	20-32	12.08	16.00	28	41	31	16.79	CL	1.3
Bt$_{ngc}$	32-55	4.57	11.43	16	29	55	35.91	C	0.5
AZUKOUP-7									
A$_{gc}$	0-17	12.90	13.10	26	62	12	12.58	SiL	5.2
Bt$_{gc1}$	17-42	6.08	11.08	17	51	32	16.03	SiCL	1.6
Bt$_{gc2}$	42-100	5.92	16.08	23	41	36	22.75	CL	1.1
AZUKOUP-8									
A$_{c}$	0-12	22.65	21.35	44	46	10	10.19	L	4.6
Bt$_{c}$	12-40	15.00	20.00	35	47	18	22.86	L	2.6
AZUKOUP-9									
A$_{c}$	0-20	14.59	50.41	65	27	8	53.34	SL	3.4
Bt$_{c}$	20-52	13.00	36.00	49	31	20	55.12	L	1.6
AZUKOUP-10									
A$_{c}$	0-15	24.00	35.00	59	26	15	52.93	SL	1.7
Bt$_{c1}$	15-32	12.79	32.21	45	24	31	64.94	SCL	0.8
Bt$_{c2}$	32-60	6.19	16.81	23	26	51	58.08	C	0.5

L = Loam, SiL = Silty Loam, SL = Sandy Loam, SCL = Sandy Clay Loam, SiCL = Silty Clay Loam, CL = Clay Loam, C = Clay, S = sand, TC = textural class, S = sand.

were mostly sandy loam with few silty loam and loam.

The silt/clay ratio and the degree of degradation they reflect are shown in Table 2. Generally, the silt/clay ratio decreased with depth throughout the profiles contrary to variation in clay contents. The highest value (6.1) was obtained in the A-horizon of AZUKOUP-4 while the least value (0.5) was obtained at the B-horizon of AZUKOUP-6 and AZUKOUP_10 respectively.

The gravel content of the soils increases with depth in most horizons with mixture of increase and decrease in gravel contents in few horizons (Table 2). The gravel content ranges from 9% in the A-horizon (A$_{gn}$) of

Table 3. Soil physical/ hydraulic properties of Koupendri catchment.

Horizon	Depth (cm)	BD (gcm^{-3})	Ksat (cmd^{-1})	Por (%)	pF 2.5	pF 4.2	AWC
AZUKOUP-1							
Ap$_{c}$	0-20	1.50	27.71	43.27	21.46	11.38	10.1
Bt$_{nc}$	20-30	1.70	26.16	35.85	17.66	9.36	8.3
AZUKOUP-2							
A$_{c}$	0-15	1.57	46.93	40.71	22.45	11.85	10.6
Bt$_{nc1}$	15-47	1.56	26.11	41.27	28.36	15.03	13.3
Bt$_{nc2}$	47-80	1.58	6.63	40.52	31.91	16.91	15.0
AZUKOUP-3							
A$_{gh}$	0-12	1.74	22.94	34.33	20.11	10.33	9.78
Bt$_{gn}$	12-30	1.86	5.97	29.81	19.07	10.09	8.98
Bt$_{gcn}$	30-60	1.87	2.32	29.43	20.32	10.76	9.56
Bt$_{gc2n}$	60-100	1.88	1.68	29.06	21.45	11.47	9.98
AZUKOUP-4							
A	0-12	1.63	20.01	38.58	11.03	5.85	5.18
AB$_{g}$	12-35	1.54	15.78	41.46	18.53	9.82	8.71
Bt$_{g}$	35-58	1.57	8.4	40.59	17.43	9.05	8.38
Bt$_{gc}$	58-120	1.78	7.16	32.73	20.53	10.88	9.65
AZUKOUP-5							
A	0-20	1.62	60.25	39.00	21.42	11.36	10.07
Bt$_{ng}$	20-56	1.73	70.96	44.01	16.73	8.87	7.86
BC$_{ng}$	56-100	1.69	21.57	36.69	15.22	8.065	7.16
AZUKOUP-6							
A$_{gn}$	0-20	1.57	11.18	40.81	17.70	9.38	8.32
Bt$_{ng}$	20-32	1.68	5.97	36.77	30.41	16.12	14.29
Bt$_{ngc}$	32-55	1.59	21.4	39.94	28.44	15.08	13.37
AZUKOUP-7							
A$_{gc}$	0-17	1.56	20.55	41.07	21.05	11.11	9.94
Bt$_{gc1}$	17-42	1.42	39.83	46.34	31.73	16.43	15.3
Bt$_{gc2}$	42-100	1.64	18.29	38.09	38.28	20.23	18.05
AZUKOUP-8							
A$_{c}$	0-12	1.49	89.21	43.76	13.44	7.05	6.39
Bt$_{c}$	12-40	1.54	151.5	41.91	20.05	10.77	9.28
AZUKOUP-9							
A$_{c}$	0-20	1.78	48.79	32.76	11.98	6.35	5.63
Bt$_{c}$	20-52	1.80	293.5	31.94	16.18	8.58	7.60
AZUKOUP-10							
A$_{c}$	0-15	1.64	190.8	38.01	20.32	10.77	9.55
Bt$_{c1}$	15-32	1.81	395.6	31.58	19.04	10.10	8.94
Bt$_{c2}$	32-60	1.86	365.6	29.85	19.71	10.45	9.26

BD= bulk density, AWC= available water capacity, por= porosity, Ksat = saturated hydraulic conductivity, pF 2.5= water content at field capacity, pF 4.2 = water content at wilting point.

AZUKOUP-6 to more than 65% in the B-horizon (Bt$_{c1}$) of AZUKOUP-10.

Soil hydraulic/hydrological properties

The saturated hydraulic conductivity (Ksat), bulk density (BD), porosity (P) and soil water characteristics results for the profiles studied were shown in Table 3. The Ksat value was lowest (1.68 cm/d) in a clay loam B-horizon (Bt$_{gc2n}$) of AZUKOUP-3, and highest (395 cm/d) in a sandy clay loam B-horizon (Bt$_{c1}$) of AZUKOUP-10.

The bulk density was relatively high while the porosity was moderate to low throughout the profiles studied (Table 3). The bulk densities range from 1.42 kgm^{-3} at the B-horizon of AZUKOUP-7 to 1.88 Kgm^{-3} at the B-horizon of AZUKOUP-3. Bulk density increases with depth in some profiles and vice versa in other profiles. The high bulk density (1.42 to 1.88 kgm^{-3}) above the optimal value of 1.40 Kgm^{-3} and the moderate to low porosity (< 50%) below the ideal value (>50%) for healthy root growth in most horizons of the profiles studied could be attributed to soil compaction caused by continuous and intensive pastoral activities and cultivation for many years, poor soil structure (less inter-ped spaces), low soil OM and to a lesser extent the texture especially the silt content as seen in AZUKOUP-3 profile.

The soil water content at field capacity (FC; 0.33 bars) and at Permanent Wilting Point (PWP; 15 bars) had shown a slight variation among the studied profiles (Table 3). The highest FC (38.28) and PWP (20.23) were recorded for the sub-surface horizon ($Btgc_2$) of AZUKOUP-7. This could be caused by high water table and to a lesser extent due to clay or silt content.

Soil pH

The soils pH varies from moderately acidic (5.2) in the B-horizon (Bt_{nc1}) of AZUKOUP-2 to slightly alkaline (7.6-9) in the B-horizon (Bt_{gc2n}) of the same profile (Table 4). Also shown in Table 4 is change in pH i.e. ΔpH ($pH_{H2O} - pH_{KCl}$) which were positive for all profiles and horizons studied. The values of ΔpH range from 1.1 in the A-horizon (Ap_c) of AZUKOUP-1 to 2.1 in the B-horizons (Bt_{gn} and Bt_{gcn}) of AZUKOUP-3.

Total Nitrogen (N), Available Phosphorus (P) and Soil Organic Carbon (SOC)

The total N ranged from 0.02 in the B-horizon (Bt_{gc}) of AZUKOUP-4 to 0.08 in the A-horizon (A_{gh}) of AZUKOUP-3 (Table 4). The SOC decreases with increasing depth in each profile and ranged from 0.048 in the B-horizon (Bt_c) of AZUKOUP-9 to 2.02 in the A-horizon (A_{gh}) of AZUKOUP-3. The available P ranges from 1 mg/Kg in most sub-surface horizons of the soil profiles to 6 mg/Kg in the surface or A-horizon (A_{gn}) of AZUKOUP-6.

The C:N ratio for the profiles and their horizons varied from a narrow range of 4.2 in the B-horizon (Bt_{ngc}) of AZUKOUP-6 to the wider range of 24.02 in the A-horizon (A_{gh}) of AZUKOUP-3 (Table 4). Generally, the C:N ratio shows a decreasing trend with increasing depth throughout the profiles and their horizons (Table 4).

Base saturation and cation exchange capacity

Generally, the base saturation (BS) was low to moderate (20-60%) for most soil profiles studied with few exceptions (Table 4). The exchangeable calcium (Ca) throughout the profiles ranged from very low (<2%) to moderately few (2-5%) in some horizons. The exchangeable Mg is low throughout the profiles except in some horizons where it is moderately high. The exchangeable K was also very low in most profiles and their horizons, although moderate to very high values were also recorded in few horizons. The exchangeable sodium (Na) was low throughout the profiles ranging from 0.281 in the A-horizon (A_{gn}) of AZUKOUP-6 to 0.545 in the B-horizon Bt_{c2}) of AZUKOUP-10. The trend or abundance in decreasing order is $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ except at AZUKOUP-4. The exchangeable sodium percentage ((ESP) was low throughout the horizons except at the B-horizon (Bt_{gc2n}) of AZUKOUP-3 where it is 17.3, a value that is above the critical level (> 15%) that causes deterioration of soil structure and Na toxicity (Landon, 1991). Since the BS indicates the degree of leaching of basic cations, most of the soil profiles studied was moderately (43-46%) to highly leached (16-29%) except AZUKOUP-3, AZUKOUP-4, AZUKOUP-7 and AZUKOUP-10 with higher BS values. The A-horizons of AZUKOUP-5 and AZUKOUP-8 also show some signs of weak/low leaching. The CEC across the landscapes and profiles ranged from 4.72-28.56 $Cmolkg^{-1}$ (Table 4). The lowest values for the CEC were recorded at AZUKOUP-5 with a range of 4.72-6.08 $Cmolkg^{-1}$ and the highest values at AZUKOUP-10 with a range of 10.8-28.56 $Cmolkg^{-1}$. The CEC of soil profiles followed the trend exhibited by the exchangeable basic cations especially exchangeable Ca^{++} reflecting that these basic cations are the main ion contributors in the exchange complexes.

Soil classification of Koupendri catchment

Soil classification of Koupendri catchment was done following World Reference Base for Soil Resources [WRB] (IUSS Working Group, 2006; 2014) and Soil Taxonomy (Soil Survey Staff, 2010) classification schemes, and then correlated with the FAO-UNESCO legend and French Classification schemes (Table 5). The table showed 7 soil types at sub-group level classification for Soil Taxonomy and 10 soil types for WRB correlated to 5 soil types for both FAO-UNESCO legend and French classification schemes.

DISCUSSION

The soils show indication of poor structure or structural deterioration caused by cultivation and compaction through trampling by human and animals that destroy or fragments soil aggregates. The soils were less deep with mainly Ap and Bt horizons while C horizon was virtually absent. This confirmed why cash crops and plantation agriculture could not thrive in the catchment. The soils were mostly gravelly ranging between 10% and above 60%. Such soils with gravel contents above 60% are

Table 4. Some Chemical Properties of Koupendri soils.

Horizon Name	Depth (cm)	pH (H_2O)	pH (KCl)	ΔpH	Total N	Organic C:N	NC	Avail. P	Exchangeable cation (Cmol Kg^{-1})					BS (%)	ESP (%)
					(%)		mg Kg^{-1}		Ca	Mg	K	Na	CEC		
AZUKOUP-1															
Ap_{c}	0-20	5.8	4.7	1.1	0.05	0.66	13.1	2	2.32	0.85	0.20	0.28	8.00	46	3.53
Bt_{nc}	20-30	5.9	4.4	1.5	0.05	0.49	10.8	2	1.54	1.22	0.18	0.31	7.36	44	4.17
AZUKOUP-2															
A_{c}	0-15	5.8	4.4	1.4	0.05	0.46	9.22	4	1.26	0.51	0.11	0.31	7.52	29	4.11
Bt_{nc1}	15-47	5.2	3.9	1.3	0.05	0.35	7.82	5	0.69	0.28	0.07	0.32	6.88	20	4.61
Bt_{nc2}	47-80	5.3	4.0	1.3	0.04	0.20	4.83	2	0.97	0.40	0.11	0.44	8.08	24	5.41
AZUKOUP-3															
A_{gh}	0-12	6.0	4.6	1.4	0.08	2.02	24.02	2	6.06	4.11	0.23	0.56	16.08	68	3.46
Bt_{gn}	12-30	7.0	4.9	2.1	0.06	0.54	9.07	1	4.43	2.72	0.09	1.21	14.4	59	8.39
Bt_{gcn}	30-60	6.8	4.7	2.1	0.06	0.46	7.81	1	4.38	2.05	0.13	2.24	17.52	50	12.8
Bt_{gc2n}	60-100	9.0	7.4	1.6	0.02	0.20	10.1	2	9.69	15.88	0.11	3.95	22.88	100	17.3
AZUKOUP-4															
A	0-12	6.6	5.4	1.2	0.06	0.66	11.79	1	2.48	2.87	0.14	0.31	7.84	74	3.93
AB_{g}	12-35	6.5	5.0	1.5	0.04	0.24	6.67	1	1.57	3.80	0.08	0.32	10.00	58	3.24
Bt_{g}	35-58	6.7	4.9	1.8	0.04	0.21	5.92	1	1.61	6.40	0.07	0.32	12.48	67	2.56
Bt_{gc}	58-120	7.6	6.0	1.6	0.02	0.20	11.65	1	2.15	14.35	0.10	0.49	19.28	89	2.55
AZUKOUP-5															
A	0-20	6.1	4.9	1.2	0.05	0.43	8.96	2	1.72	0.68	0.10	0.32	4.72	60	6.69
Bt_{ng}	20-56	5.6	4.0	1.6	0.04	0.17	4.07	2	1.46	0.63	0.11	0.44	6.00	44	7.30
BC_{ng}	56-100	5.8	4.2	1.6	0.03	0.22	6.97	1	0.75	0.44	0.076	0.29	6.08	26	4.80
AZUKOUP-6															
A_{gn}	0-20	5.4	4.1	1.3	0.05	0.73	14.66	6	0.72	0.21	0.09	0.28	8.24	16	3.41
Bt_{ng}	20-32	5.5	4.1	1.4	0.05	0.31	6.35	2	1.56	1.14	0.15	0.37	7.44	43	5.01
Bt_{ngc}	32-55	5.6	4.1	1.5	0.06	0.25	4.2	2	3.84	3.03	0.26	0.36	14.48	52	2.47
AZUKOUP-7															
A_{gc}	0-17	5.6	4.0	1.6	0.06	0.71	12.02	2	1.89	0.64	0.17	0.37	5.76	53	6.41
Bt_{gc1}	17-42	5.6	4.1	1.5	0.03	0.43	12.62	1	4.46	2.67	0.30	0.35	12.48	62	2.83
Bt_{gc2}	42-100	5.9	4.0	1.9	0.05	0.35	7.02	1	6.18	2.07	0.25	0.42	20.0	45	2.08
AZUKOUP-8															
A_{c}	0-12	6.0	4.8	1.2	0.08	1.27	16.71	3	2.71	1.08	0.22	0.32	7.84	55	4.09
Bt_{c}	12-40	5.5	4.1	1.4	0.05	0.63	12.6	2	1.11	0.46	0.22	0.32	9.76	22	3.26
AZUKOUP-9															
A_{c}	0-20	6.4	5.0	1.4	0.91	0.07	13.57	3	1.99	0.68	0.26	0.32	7.6	43	4.17

Table 4. Contd.

Bt_c	20-52	5.4	4.2	1.2	0.64	0.05	13.38	3	0.82	0.57	0.17	0.30	7.12	26	4.24
AZUKOUP-10															
A_c	0-15	6.8	5.3	1.5	0.10	1.22	12.81	3	4.48	2.43	0.52	0.33	10.8	72	3.05
Bt_{c1}	15-32	6.4	4.8	1.6	0.08	0.87	11.31	1	6.53	4.66	0.31	0.37	16.88	70	2.18
Bt_{c2}	32-60	8.0	6.8	1.2	0.06	0.31	5.27	3	9.29	11.24	0.44	0.55	28.56	100	1.91

N= nitrogen, C= carbon, C:N= carbon-nitrogen ratio, Avail.P = available phosphorus, Ca= calcium, Mg= magnesium, K= potassium, Na= sodium, CEC= cation exchange capacity, BS= base saturation, ESP= exchangeable sodium percentage, H2O= water, KCl = potassium chloride.

Table 5. Soil classification and correlation for Koupendri soils.

Soil profile identity	**Soil Classification System**		**Correlating System**	
	USDA soil taxonomy	**World reference base for soil resources (WRB)**	**FAO/UNESCO legend**	**French system**
AZUKOUP-1	*Typic plinthustults*	*Albic Petric Plinthosols* (Lixic, Dystric)	*Dystric Plinthosols*	*Sols ferrugineux tropicaux peu profonds lessivés concrétionné*
AZUKOUP-8		*Albic-Petric Plinthosols* (Loamic, Epi-Dystric)		
AZUKOUP-9		*Albic Pisoplinthic Plinthosols* (Dystric)		
AZUKOUP-2	*Plinthic- Kandiustults*	*Albic-Petric Plinthosols* (Hyper-Dystric, Loamic)	*Endo-dystric Plinthosols*	*Sols ferrugineux tropicaux moyennement profonds lessivés peu concrétionnés*
AZUKOUP-6		*Albi-Petric Plinthosols* (EndoClayic, Epi-Dystric)		
AZUKOUP-3	*Aquic Haplustepts*	*Eutric Vertic Gleyic Cambisols* (Petrocalcic, Takyric)	*Eutric Cambisol*	*Sols bruns eutrophes tropicaux*
AZUKOUP-4	*Aquic kandiustalfs*	*Albic Gleyic Anthraquic Abruptic Luvisols* (Hyper-Eutric)	Gleyic Luvisol	*Sols ferrugineux tropicaux lessivés profonds hydromorphes*
AZUKOUP-5	*Typic kandiustalfs*	*Albic Gleyic Abruptic Luvisols* (Hyper-dystric, Profondic)		
AZUKOUP-7	*Aquic kandiustalfs*	*Epi-Eutric Gleysols* (EndoSiltic, Vertic)	*Eutric Gleysols*	*Sols hydromorphes à pseudogley*
AZUKOUP-10	*Typic Plinthustalfs*	*Eutric Pisoplinthic Gleysols* (Endoclayic, vertic		

termed gravelly soils (Buol et al., 2003), and affect the physical and hydraulic properties of soil (Brakensiek and Rawls, 1994; Sauer and Logsdon, 2002). The combination of the soil structure and the gravel content also influenced the drainage of the catchment which ranged from good through normal to imperfect or very poor drainage.

The clay increase in most B-horizons especially the kandic horizons is a confirmation of reports from other studies. It has been reported that clay increase in most kandic horizons is as a result of clay migration-accumulation or illuviation, clay destruction, selective erosion, sedimentation or lithological discontinuity (FAO, 1988; Van Wambeke, 1989; Driesen and Dudal, 1991). The fact that clay minerals are unstable and break down under intense chemical weathering especially in humid and sub-humid climates further buttressed the claim. This was also reported in Alemayehu et al. (2014) for some Ethiopian soils. This also applied to the Argic B-horizon which is similar to kandic horizons since part of the pedon may meet the requirements of both horizons when considered at the same classification level (Ngongo and Langohr, 1992).

The decrease in silt/clay ratio with depth can be attributed to massive destruction of clay, selective erosion, and to a lesser extent illuviation of clay from the surface (Ap) horizon to the sub-surface (Bt) horizon. The decrease in silt/clay ratio with depth is in agreement with reports from some studies of Nigerian soils (Ezeabasili et al., 2014; Chukwu, 2013; Lal, 2000). Lal (2000) reported that the silt/clay ratio of most tropical soils decline with depth and widely ranged from soil to soil even within the same toposequence. However, a contrary result of an increasing silt/clay ratio with depth was reported for lowland soils in southwestern Ethiopia (Alemayehu et al., 2014). The silt/clay ratio is an index of weathering (Van Wambeke, 1959), and one of the most important criteria for the definition of the ferralic horizon. According to FAO (1988), this silt/clay ratio should be less than or equal to 0.2. This underscores the absence of a ferralic horizon and Ferralsols in all the studied profiles. High silt/clay ratios observed in most horizons alongside resistant skeletal composition of the parent material reflect that the soil is less weathered and thus, at less advanced stage of development.

The decreasing Ksat with increasing depth observed has also been reported in some tropical studies (Ziegler et al., 2004; Zimmermann and Elsenbeer, 2008; Zimmermann et al., 2006). Such decrease could result to saturation excess overland flow during high-intensity rainfall events (Germer et al., 2010; Godsey et al., 2004). The low values of Ksat at some soil depth can form an impeding layer and may lead to perched water tables, diminished groundwater recharge and the development of interflow. This is because, Ksat represent the capacity of the soil to drain or transmit water (Klute and Dirksen, 1986) and governs vertical percolation of water within the soil profile. The high bulk densities obtained agrees with that obtained for similar soils in Terou-Igbomakoro catchment, central Benin (Junge, 2004; Sintondji, 2005). Such high bulk density may present serious challenge to agronomic and hydrological processes. The available water holding capacity (AWHC) showed a closer relationship with silt content than with clay or SOC contents.

The acidic nature of the soils could be attributed to the parent material which is acid metamorphic schists. However, as an indication of soil acidification, soil pH is dependent not only on the nature of the parent material but also on the level of soil leaching in the environment. This may suggest why some of the soils were moderately alkaline. Based on the soil pH rating of Jones (2003), the pH_{H2O} throughout the profiles and their horizons fall within moderately/slightly acidic to moderately/slightly alkaline.

According to Soil Survey Staff (2006), ∆pH can be positive, zero or negative depending on the net surface charge at the time of sampling. The positive ∆pH which indicates presence of negatively charged colloids lends credence to the translocation of clay from the upper or surface horizon and its accumulation in the B-(illuvial) horizon through illuviation processes.

Generally, available P shows a decreasing trend with increasing depth for all the profiles. The slightly higher values of SOC and total N observed in the A-horizon of AZUKOUP-3 could be due to waterlogging of the location which slowed down the turn-over of the surface organic material while that of available P could be due to use of phosphate fertilizer for cultivation at the site of the profile pit (AZUKOUP-6). Similar decrease in SOC with increasing depth for each profile has been reported (Alemayehu et al., 2014; Campos, 2002; Agyare, 2004). There was no clear direct association of total N and SOC with increasing depth of the profiles as reported by Alemayehu et al. (2014) for some Ethiopian soils. However, the very low contents of total N, SOC, and available P may be attributed to the frequent annual bush burning and crop residues (a common land clearing practice for cultivation) at the end of the year or more explicitly during the dry season. This frequent bush burning practices, coupled with high temperature accelerates the rapid turn-over of organic materials in the catchment. This was also affirmed by Yilma (2006) who reported that burning of biomass in prevailing-slash-and burn systems and high temperatures lead to a rapid decomposition of organic matter and consequently, poor SOC. Studies in Ethiopia (Habtamu et al., 2009; Alemayehu et al., 2014), west Africa (Lal et al., 2003; Yilma, 2006) and other parts of the world had reported significant reduction in SOC and Total N caused by burning and removal of crop residue. Low fertility is linked with low CEC and low reserves of N and P-availability. The very low contents of available P suggest that it is a serious limiting nutrient for crop production in the catchment despite that moderately acidic to slightly alkaline soils (5.5-9.0) favour P- availability. This confirms the report that P is considered the main limiting nutrient for crop production in drier savanna (Sanchez, 1976, Kowal and Kassam, 1978).

The C:N ratio was low throughout the horizons and fall below the optimal range (10-12:1) acceptable for arable soils (Havlin et al., 1999). This could be attributed to high oxidation and loss of organic matter as evidenced by the poor or very low SOC in the two profiles. The C:N ratio is important because the availability of nitrogen (N) for plant growth is dependent on the ratio. High C:N > 30:1 implies N immobilization due to decomposition of organic residue by microbes while C:N < 20:1 implies limited immobilization and release of N into the soil environment for plant uptake (Jones, 2003).

The analytical result of the base saturation (BS) and cation exchange capacity (CEC) revealed that exchangeable Ca and Mg were dominant cations at the exchange complex accounting for more than 80% of exchangeable bases and between 50 to 65% of total cations of the exchange site. Both BS and CEC were low to moderate and could be due to the predominance of Kaolinite clay minerals and also, poor recycling and depletion of basic cations, OM and clay contents due to erosional processes and inappropriate management (incessant bush burning) of residues but to a lesser extent, soil reaction or pH. Similar reports were made for sub-humid catchment in central Benin (Igué, 2000; Impetus, 2003).

Conclusion

Soil survey and classification for Koupendri catchment in north western Benin, West Africa provided soil information for hydrological modeling, future agronomic decisions, soil and water management, engineering and other socio-economic purposes. The catchment has a relatively flat physiography with height above sea level ranging from 215-224 m above sea level, which is gently slopy (0 to 6%). The parent material is acid metamorphic mica schist. The soil pH ranges from slightly acidic to relatively alkaline with poor fertility status evidenced by poor SOC, total N, C/N ratio, low CEC, exchangeable cations, less weathered soil with textural characteristics that is prone to crusting, compaction and hinders root growth. The study also confirms that P-availability is the major agronomic constraints in drier savanna regions. The permeability and the available water capacity of the soil were very low, presenting a serious soil water management problem for both agronomic and hydrological purposes. The soil map of the catchment produced at a scale of 1:25000 using FAO/UNESCO legends showed five distinct soil types. The classification of the soils reveal seven soil types at sub-group level of classification belonging to three major orders: Ultisols, Inceptisols and Alfisols (USDA). The WRB gave ten distinct soil types belonging to five major or reference soil groups. These were correlated with Plinthosols, Cambisols, Luvisols and Gleysols for FAO-UNESCO legend; and *Sols ferrugineux tropicaux peu profonds lessivés concrétionnés, Sols hydromorphes à pseudogley, Sols tropicaux moyennement profonds lessivés peu concrétionnés, Sols bruns eutrophes tropicaux* and *Sols ferrugineux tropicaux lessivés profonds hydromorphes* for French classification system. The WRB gave a more detailed, concise and better soil classification that correlates better with FAO/UNESCO legend and French classification scheme than USDA Soil Taxonomy. Soil fertility or nutrient assessment for the catchment will provide information for improved soil nutrient management. Also, land cover and residue management with appropriate tillage and conservation practices is paramount for improved soil productivity and hydrological processes of the catchment.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Grain yield and NPK uptake of wheat (*Triticum aestivum* L.) as influenced by nitrogen, vermicompost and herbicide (*Clodinafop propargyl*)

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Application of Nitrogen (N) at 150 mg kg^{-1} soil significantly increased the grain and straw yield of wheat from 2.70 to 8.24 and 4.97 to 9.44 g pot^{-1}, respectively over control. Addition of vermicompost at 1% alone increased the grain and straw yield of wheat from 2.70 to 4.81 and 4.97 to 6.60 g pot^{-1} respectively over control and in combination with N at 150 mg kg^{-1} soil further improved from 4.81 to 10.73 and 6.60 to 11.89 g pot^{-1}, respectively. Use of *Clodinafop propargyl* at 60 and 90 g a.i. ha^{-1} significantly decreased the grain yield of wheat from 4.74 to 3.60 and to 2.93 g pot^{-1}, respectively and that of straw yield from 7.16 to 5.87 and to 4.31 g pot^{-1}, respectively over control (without *C. propargyl*). The grain and straw yield of wheat also decreased significantly with the application of *C. propargyl* (60 to 90 g a.i./ha) in presence of both vermicompost and N. Nitrogen, Phosphorus (P) and Potassium (K) uptake by grain and straw increased significantly with the increase in each successive dose of N up to the level of 200 mg kg^{-1} soil and highest uptake of NPK by grain were 149.56, 57.59 and 40.87 mg pot^{-1}, respectively and that of by straw the highest value recorded were 54.72, 18.24 and 143.78 mg pot^{-1}, respectively. Application of vermicompost at 1% significantly increased NPK uptake in both grain and straw over control. Use of *C. propargyl* at 60 and 90 g a.i. ha^{-1} significantly decreased the NPK uptake by grain and straw.

Key words: *Clodinafop propargyl*, Nitrogen, nutrient uptake, pot study, vermicompost and wheat yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a dominant *rabi* cereal crop of north-western zone of India. India is producing about 92.45 million tons of wheat from an area of 29.64 million hectare with an average productivity of 3119 kg/ha (Anonymous, 2013). Haryana, which is one of the major wheat growing states, produces 111.17 lac tons of wheat from 24.97 lac hectares area with an average productivity of 4452 kg/ha (Anonymous, 2013). N can limit crop yield and its judicious use is essential for sustainable crop production. It represents 28% of the cost of inputs. Mengel et al. (2006) reported that optimum N rate should be explored as too high rates may cause severe N losses and low rates depress the yield. Indiscriminate use of chemical fertilizers to get maximum yields leads to the depletion of inherent soil fertility (Gupta and Nath, 1998). With the improvement in the agricultural technologies and

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release of high yielding dwarf varieties of cereals, demand for fertilizers has increased manifolds and nitrogenous fertilizers in particular. Most soils are far from being ideally fertile and should therefore, be improved not only by adding nutrients, but also by other soil amendments, like organic matter for maintaining the activity of "Soil life". Since, agriculture becomes more intensive and chemical dependent, therefore soil toxicities and nutrient imbalance threaten sustainable production. So, we have to think about the cheap and easily available alternate source of nutrients. Thus, demand for fertilizers can be lowered by supplementing the nutrients through organic manures. Judicious use of farmyard manure (FYM) with chemical fertilizers improves soil physical, chemical and biological properties and improves the crop productivity (Sharma et al., 2007). Application of organic manures may also improve availability of native nutrients in soil as well as the efficiency of applied fertilizers (Sawrup, 2010). Among different sources of organic manures, vermicompost is most important source and used since long as a nutrients supplement to crop production.

Solid waste generation in India is about 115,000 tons per day with a yearly increase of about 5% (Jain et al., 2014). The estimated annual increase in per capita waste quantity is about 1.33% per year. The large amount of the agro waste generated has created major environmental problems. Vermicomposting is the best biotechnology to reduce the load on the treatment and disposal of biodegradable agro waste. Keeping this in view, the present study was planned to assess the effect of N and vermicompost in presence of herbicide (*C. propargyl*) on wheat yield and nutrients uptake by wheat.

MATERIALS AND METHODS

A pot culture experiment was conducted to study the response of graded levels of N in combination with vermicompost and herbicide on yield and nutrient uptake by wheat (*T. aestivum* L. cv. WH-711) at screen house, Department of Soil Science, CCS HAU, Hisar (29º 05' N, 75º 38' E, 222 m elevation). The soil used was sand in texture. Physico-chemical properties of the soil and vermicompost used and their methods of analysis are reported in Table 1. The treatment combinations comprised five levels of N (0, 50, 100, 150 and 200 mg/kg) applied through urea, two levels of vermicompost (0 and 1% on dry wt. basis) and three levels of herbicide (0, 60 and 90 g a.i./ha). Experimental data was statistically analysed by completely randomized design with three replications. Five kilogram air dried soil was spread on a polyethylene sheet and required amount of either fertilizer, vermicompost or in combinations as per above schedule were applied and thoroughly mixed. Half of N was applied through urea solution at the time of sowing and another half was applied 21 days after sowing (DAS). A basal dose of P, K and zinc (Zn) at 60, 75 and 5 mg kg^{-1} soil was added through potassium dihydrogen orthophosphate and $ZnSO_4.7H_2O$ solutions. Herbicide was applied after 35 DAS.

For these treatments, chemicals of analytical grade were used. Before sowing, about 200 g of soil was removed from each pot. The pot was irrigated with one liter of deionized water. On disappearance of free water from the surface, 10 seeds of wheat were placed eight in circle and two in centre of the pot. Then, these seeds were covered by spreading 200 g of soil. Thereafter, the pots were covered with newspaper to prevent drying out of soil. After 12 days, five plants in each pot were maintained. Intercultural operations and irrigations with deionised water were done as and when required. Crop was harvested at maturity. The plants were thoroughly washed with distilled water. The excess of water was removed by gentle shaking and pressing between two filter papers and then dried in oven at 50°C. The grains and straw were separated and weighed separately from each pot. The grains and straw were ground in a Willey mill using stainless steel sieve. Each sample was mixed thoroughly after grinding and stored in polythene bags. Then these samples were analyzed for total N, P and K in laboratory by following standard procedures. N in plant samples was determined by using Colorimetric (Nessler's reagent) method (Lindner, 1944). P in plant samples was determined by using Vanadomolybdophosphoric yellow color method (Koenig and Johnson, 1942). K in plant samples was determined by using flame photometer (directly).

RESULTS AND DISCUSSION

Grain yield

Data presented in Table 2 revealed that the grain yield of wheat increased significantly with the successive increase in N application up to the level of 150 mg N/kg soil and the extent of increase was from 2.70 to 8.24 g/pot over control. The difference in grain yield was non-significant between 150 mg N/kg soil (8.24 g/pot) and 200 mg N/kg soil (9.29 g/pot). Results are in agreement with Lloveras et al. (2001), Iqtidar et al. (2006), Ali et al. (2011) and Siddiqui et al. (2013). Application of vermicompost alone significantly increased the grain yield over the control (without vermicompost) and the extent of increase in grain yield was from 2.70 to 4.81 g/pot. Similar findings were reported by Ranwa and Singh (1999) and Khandal and Bhardwaj (2000). Similarly, N application in conjugation with vermicompost (150 mg N/kg soil + vermicompost) significantly increased the grain yield of wheat up to the levels of 150 mg N/kg soil and the extent of increase was from 2.70 to 10.73 g/pot. However, the difference between the conjugate use of 150 mg N/kg soil + vermicompost and 200 mg N/kg soil + vermicompost was found non-significant with respect to grain yield. The added beneficial effect of vermicompost was because of vermicompost contains macro and micro nutrients and also improves physico-chemical and biological properties of the soil, which may improves the availability of applied and native nutrients in soil. From the results presented above, it can be revealed that N in combination with vermicompost had more beneficial effect than their individual effect. These findings are similar to that reported by Sujathamma et al. (2001) and Shekhon et al. (2011).

Data presented in Table 2 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the grain yield from 4.74 to 3.60 and to 2.93 g/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha also declined the grain yield of wheat from 11.53 to 10.96 and

Table 1. Physico-chemical properties of soil and vermicompost.

Property	Values	Method used
Soil		
Organic carbon (%)	0.15	Walkley and Black Wet oxidation method (Jackson, 1973)
Soil pH	8.10	Glass electrode pH meter (Jackson, 1973)
EC (dS/m at 25ºC)	0.15	Conductivity bridge meter (Richards, 1954)
Available nitrogen (mg/kg)	54.50	Alkaline per magnate method (Subbiah and Asija, 1956)
Available phosphorus (mg/kg)	8.00	Olsen's method (Olsen *et al.*, 1954)
Available potassium (mg/kg)	83.70	Flame photometer method (USDA Hand Book No. 60, Richards, 1954)
Vermicompost (%)		
Total N	1.30	Colorimetric (Nessler's reagent) method (Lindner, 1944)
Total P	0.52	Vanadomolybdophosphoric yellow color method (Koenig and Johnson, 1942)
Total K	1.22	Using flame photometer (directly)
Organic carbon	15.23	Rapid titration method (Walkley and Black, 1934)

Table 2. Effect of Nitrogen, vermicompost and *Clodinafop propargyl* on grain and straw yield (g/pot) in wheat crop.

Treatments	Nitrogen levels (mg/kg soil)					
	0	50	100	150	200	Mean
Grain						
Vermicompost levels						
0	2.70	5.46	6.80	8.24	9.29	6.50
1%	4.81	7.13	9.25	10.73	11.18	8.62
Mean	3.75	6.29	8.02	9.48	10.23	
CD (5%) Nitrogen = 1.21, Vermicompost = 0.76 and Nitrogen × Vermicompost = 1.39						
***Clodinafop propargyl* levels (g a.i./ha)**						
0	4.74	6.82	8.38	10.06	11.53	8.28
60	3.60	6.54	8.10	9.78	10.96	7.79
90	2.93	5.23	6.84	8.01	9.20	6.44
Mean	3.76	6.19	7.77	9.28	10.56	
CD (5%) Nitrogen = 0.27, Herbicide = 0.21 and Nitrogen × Herbicide = 0.47						
Straw						
Vermicompost levels						
0	4.97	6.08	7.73	9.44	10.73	7.79
1%	6.60	8.28	10.35	11.89	12.93	10.01
Mean	5.78	7.18	9.04	10.66	11.83	
CD (5%) Nitrogen = 1.43, Vermicompost = 1.07 and Nitrogen × Vermicompost = 1.16						
***Clodinafop propargyl* levels (g a.i./ha)**						
0	7.16	7.95	9.70	11.22	13.10	9.82
60	5.87	7.43	9.14	10.79	12.02	9.05
90	4.31	6.15	7.88	9.06	10.81	7.64
Mean	5.78	7.17	8.90	10.35	11.97	
CD (5%) Nitrogen = 0.53, Herbicide = 0.41 and Nitrogen × Herbicide = 0.93						

to 9.20 g/pot, respectively in the presence of 200 mg N/kg soil. Data presented in Table 3 revealed that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the grain yield in the presence of

Table 3. Effect of vermicompost and *Clodinafop proparg*yl on grain and straw yield (g/pot) in wheat crop.

Vermicompost levels	*Clodinafop propargyl* levels (g a.i./ha)			
	0	60	90	Mean
Grain				
0	7.43	6.51	5.25	6.40
1%	9.08	8.91	7.63	8.54
Mean	8.25	7.71	6.44	
CD (5%) Vermicompost = 0.17, Herbicide = 0.21 and Vermicompost × Herbicide = 0.30				
Straw				
0	9.21	7.88	6.27	7.79
1%	9.93	9.27	8.45	9.21
Mean	9.57	8.57	7.36	
CD (5%) Vermicompost = 0.34, Herbicide = 0.41 and Vermicompost × Herbicide = 0.63				

vermicompost and the extent of decrease was from 9.08 to 8.91 g/pot and 7.63 g/pot, respectively. From the above results, it can be revealed that due to phytotoxic effect of *C. propargyl*, grain yield decreased and this deleterious effect of *C. propargyl* was reduced with the application of N and vermicompost. These results are similar to those reported by Duhan et al. (2006) and Wagner and Nadasy (2009).

Straw yield

It was observed that the straw yield data also followed the similar trend as that of grain yield. There was significant increase in straw yield of wheat with the successive increase in N levels up to the 150 mg kg^{-1} soil (Table 2) and the extent of increase from 4.97 to 9.44 g/pot. These findings are similar to Ali et al. (2011) and Siddiqui et al. (2013). Application of vermicompost alone also significantly increased the straw yield over the control (without vermicompost) and the extent of increase in grain yield was from 4.97 to 6.60 g/pot. Similar findings were reported by Ranwa and Singh (1999) and Khandal and Bhardwaj (2000).

The application of N as well as vermicompost significantly increased the straw yield (150 mg N/kg soil and vermicompost) and the increase was from 9.44 g/pot to 11.89 g/pot over control. Thus, there was significant added effect of vermicompost when applied in conjugation with N fertilizer. These findings were similar to those reported by Billore et al. (2009), Shekhon et al. (2011) and Duhan et al. (2011). The data presented in Table 2 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the straw yield from 7.16 to 5.87 and to 4.31 g/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha also declined the straw yield from 13.10 to 12.02 and to 10.81 g/pot, respectively in the presence of 200 mg N kg^{-1} soil. Data presented in Table 3 revealed that application of *C. propargyl* at 60 and 90 g a.i./ha also significantly decreased the straw yield in the presence of vermicompost and the extent of decrease was from 9.93 to 9.27 g/pot and further to 8.45 g/pot, respectively. Wagner and Nadasy (2009) and Kumar (2010) reported that herbicides (2,4-D and IPU) had phyto-depressive effects.

Nutrients uptake

Nitrogen uptake by grain

Uptake of N by wheat grains also increased significantly with the application of N and N + vermicompost (Table 4). It is so because uptake is a mathematical parameter calculated from yield and N content. As both yield and N content increased significantly over control, so uptake of N also increased significantly. A perusal of data (Table 4) indicated that with the increase in successive doses of N the uptake of N by grains increased significantly up to 200 mg N/kg soil and the extent of increase was from 25.92 mg/pot to 149.56 mg/pot over control. Similar, results were reported by Ahmad et al. (2007).

Data further revealed that application of vermicompost alone also significantly increased the N uptake from 25.92 to 63.49 mg/pot over control. Similar, results were reported by Sreenivash et al. (2000) and Davari et al. (2012). Conjugative use of N and vermicompost recorded the highest N uptake by grains and the extent of increase with nitrogen at 200 mg kg^{-1} soil + vermicompost at one percent was from 25.92 to 193.41 mg/pot over control. It is further reported that combined use of N and vermicompost was found superior than their individual use. Our results were in agreement with Jadhav et al. (1997), Khokhar and Nepalia (2010) and Sefidkoohi and Sepanlou (2013).

The data presented in Table 4 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly

Table 4. Effect of Nitrogen, vermicompost and *Clodinafop propargyl* on nitrogen uptake by grain and straw (mg/pot) in wheat crop.

Treatments	**Nitrogen levels (mg/kg soil)**					
	0	**50**	**100**	**150**	**200**	**Mean**
Grain						
Vermicompost levels						
0	25.92	74.25	103.36	127.72	149.56	96.16
1%	63.49	113.36	150.77	179.19	193.41	140.04
Mean	44.70	93.80	127.06	153.45	171.48	
CD (5%) Nitrogen = 1.59, Vermicompost = 1.01 and Nitrogen × Vermicompost = 2.26						
***Clodinafop propargy*l levels (g a.i./ha)**						
0	58.30	105.71	138.27	169.00	199.46	134.14
60	40.68	94.83	127.17	157.45	181.93	120.41
90	31.35	74.78	103.28	122.55	148.12	96.01
Mean	43.45	91.77	122.90	149.66	176.50	
CD (5%) Nitrogen = 1.59, Herbicide = 1.23 and Nitrogen × Herbicide = 2.76						
Straw						
Vermicompost levels						
0	15.40	21.88	32.46	47.20	54.72	34.33
1%	27.06	36.43	50.71	66.41	73.70	50.86
Mean	21.23	29.15	41.58	56.80	64.21	
CD (5%) Nitrogen = 1.93, Vermicompost = 1.22 and Nitrogen × Vermicompost = 3.10						
Clodinafop propargyl Levels (g a.i./ha)						
0	29.35	34.98	47.53	61.72	73.36	49.38
60	20.54	30.46	41.13	57.18	64.90	42.84
90	13.79	22.75	33.09	46.20	56.21	34.40
Mean	21.23	29.40	40.58	55.03	64.82	
CD (5%) Nitrogen = 1.93, Herbicide = 1.49 and Nitrogen × Herbicide = 3.34						

decreased the N uptake by grains from 58.30 mg/pot to 40.68 and to 31.35 mg/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha also declined the N uptake by wheat grains from 199.46 to 181.93 and to 148.12 mg/pot, respectively in the presence of nitrogen at 200 mg kg^{-1} soil. Data presented in Table 5 further revealed that application of *C. propargyl* at 60 and 90 g a.i./ha also significantly decreased the N uptake by grains in the presence of vermicompost and the extent of decrease was from 149.82 to 138.99 mg/pot and to 116.73 mg/pot, respectively. Wagner and Nadasy (2009) and Majumdar et al. (2010) also reported similar findings.

Nitrogen uptake by straw

N uptake by wheat straw also increased significantly with the application of N and N + vermicompost (Table 4). A perusal of data (Table 4) indicated that application of N significantly increased the uptake of N by straw up to 200 mg N/kg soil and the extent of increase was from 15.40 mg/pot to 54.72 mg/pot over control. Similar, results were reported by Ahmad et al. (2007). Data further revealed that application of vermicompost alone also increased significantly the N uptake from 15.40 to 27.06 mg/pot over control. Similar, results were reported by Gupta et al. (1996) and Sreenivash et al. (2000). Conjugative use of N at 200 mg/kg soil and vermicompost at 1% recorded the highest N uptake (73.70 mg/pot) by straw over control. It is further reported that combined use of N and vermicompost was found superior than their individual use. Results are in agreement with those reported by Khokhar and Nepalia (2010) and Sefidkoohi and Sepanlou (2013). The data presented in Table 4 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the N uptake by straw from 29.35 mg/pot to 20.54 and to 13.79 mg/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha also decreased the N

Table 5. Effect of vermicompost and *Clodinafop propargyl* on nitrogen uptake by grain and straw (mg/pot) in wheat crop.

Vermicompost levels	*Clodinafop propargyl* levels (g a.i./ha)			
	0	60	90	Mean
Grain				
0	109.96	90.48	69.82	90.08
1%	149.82	138.99	116.73	135.18
Mean	129.89	114.73	93.27	
CD (5%) Vermicompost = 1.01, Herbicide = 1.23 and Vermicompost × Herbicide = 1.75				
Straw				
0	40.52	33.09	24.45	32.68
1%	51.63	44.49	38.87	44.98
Mean	46.07	38.79	31.66	
CD (5%) Vermicompos t = 1.22, Herbicide = 1.49 and Vermicompost × Herbicide = 2.11				

uptake by straw from 73.36 to 64.90 and to 56.21 mg/pot, respectively in the presence of 200 mg N kg^{-1}soil. Table 5 revealed that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the N uptake by straw in the presence of vermicompost and the extent of decrease was from 51.63 to 44.49 mg/pot and further to 38.87 mg/pot, respectively. Majumdar et al. (2010) and Sarmamy and Khidir (2013) also reported similar results.

Phosphorus uptake by grain

A perusal of data (Table 6) indicated that with the increase in successive doses of N the uptake of phosphorus by wheat grains increased significantly up to 200 mg N/kg soil and the extent of increase was from 11.07 mg/pot to 57.59 mg/pot over control. Similar results reported by Nedelciuc et al. (1995) and Gupta et al. (1992). Data further revealed that application of vermicompost alone significantly increased the P uptake from 11.07 to 26.45 mg/pot over control. Similar, results were reported by Sreenivash et al. (2000) and Davari et al. (2012). Conjugative use of N and vermicompost (200 mg N/kg soil + vermicompost at 1%) recorded the highest P uptake (71.55 mg/pot) by grains over control. It is further reported that combined use of N and vermicompost was found superior than their individual use. Results are in agreement with Khokhar and Nepalia (2010) and Goel and Duhan (2011). The data presented in Table 6 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the P uptake by grains from 25.59 mg/pot to 17.28 and to 12.30 mg/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha also declined the P uptake by grains from 74.94 mg/pot to 69.04 and to 56.12 mg/pot, respectively in the presence of 200 mg N kg^{-1} soil. Data presented in Table 7 revealed that application of *C. propargyl* at 60 and 90 g a.i./ha also significantly decreased the P uptake by grains in the presence of vermicompost and the extent of decrease was from 57.20 to 54.35 mg/pot and further to 43.49 mg/pot, respectively. This decrease in P uptake by grains with the application of *C. propargyl* at both levels may be due to phytotoxic effect of herbicide. Osborne et al. (1993) and Sarmamy and Khidir (2013) also reported similar type of results.

Phosphorus uptake by straw

A perusal of data (Table 6) indicated that with the increase in successive doses of N the uptake of P by wheat straw increased significantly up to 200 mg N/kg soil and the extent of increase was from 3.74 mg/pot to 18.24 mg/pot over control. Similar, results were reported by Ahmad et al. (2007). Data further revealed that application of vermicompost significantly increased the P uptake from 3.74 to 6.60 mg/pot over control. Similar, results were reported by Sreenivash et al. (2000) and Bhardwaj et al. (2000). Conjugative use of N and vermicompost recorded the highest P uptake by wheat straw and the extent of increase with 200 mg N/kg soil + vermicompost at 1 % was from 3.74 to 25.86 mg/pot over control.

It is further reported that combined use of N and vermicompost was found superior than their individual use. Our results were in agreement with those reported by Benbi et al. (1998) and Sefidkoohi and Sepanlou (2013).

The data presented in Table 6 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the P uptake by straw from 7.16 mg/pot to5.28 and to 2.58 mg/pot, respectively over control (no *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha also declined the P uptake by straw from 28.82 to 22.83 and to 17.29 mg/pot, respectively in the presence

Table 6. Effect of Nitrogen, vermicompost and *Clodinafop propargyl* on phosphorus uptake by grain and straw (mg/pot) in wheat crop.

Treatments	Nitrogen levels (mg/kg soil)					
	0	50	100	150	200	Mean
Grain						
Vermicompost levels						
0	11.07	29.48	38.08	49.44	57.59	37.13
1%	26.45	42.06	58.27	68.66	71.55	53.39
Mean	18.76	35.77	48.17	59.05	64.57	
CD (5%) Nitrogen = 1.26, Vermicompost = 0.79 and Nitrogen × Vermicompost = 1.78						
***Clodinafop propargyl* levels (g a.i./ha)**						
0	25.59	40.23	52.79	64.38	74.94	51.59
60	17.28	37.93	49.41	60.63	69.04	46.85
90	12.30	27.71	37.62	47.25	56.12	36.20
Mean	18.39	35.29	40.60	57.42	66.70	
CD (5%) Nitrogen = 1.26, Herbicide = 0.97 and Nitrogen × Herbicide = 2.18						
Straw						
Vermicompost levels						
0	3.74	4.86	10.05	15.10	18.24	10.39
1%	6.60	9.10	14.49	21.34	25.86	15.47
Mean	5.17	6.98	12.27	18.22	22.05	
CD (5%) Nitrogen = 0.72, Vermicompost = 0.46 and Nitrogen × Vermicompost = 1.02						
***Clodinafop propargyl* levels (g a.i./ha)**						
0	7.16	8.74	13.58	21.32	28.82	15.92
60	5.28	7.43	11.88	19.42	22.83	13.36
90	2.58	4.92	8.66	13.59	17.29	9.40
Mean	5.06	7.03	11.37	18.11	22.98	
CD (5%) Nitrogen = 0.72, Herbicide = 0.56 and Nitrogen × Herbicide = 1.26						

Table 7. Effect of vermicompost and *Clodinafop propargyl* on phosphorus uptake by grain and straw (mg/pot) in wheat crop.

Vermicompost levels	***Clodinafop propargyl* levels (g a.i./ha)**			
	0	60	90	Mean
Grain				
0	43.09	35.80	26.25	35.04
1%	57.20	54.35	43.49	51.68
Mean	50.14	45.07	34.87	
CD (5%) Vermicompost = 0.79, Herbicide = 0.97 and Vermicompost × Herbicide = 1.38				
Straw				
0	12.89	9.45	6.27	9.53
1%	16.88	13.90	10.14	13.64
Mean	14.88	11.67	8.22	
CD (5%) Vermicompost = 0.46, Herbicide = 0.56 and Vermicompost × Herbicide = 0.80				

of nitrogen at 200 mg kg^{-1}soil. Data presented in Table 7 further revealed that application of *C. propargyl* at 60 and 90 g a.i./ha also significantly decreased the P uptake by straw in the presence of vermicompost and the extent of decrease was from 16.88 to 13.90 mg/pot and further to 10.14 mg/pot, respectively. Results are in agreement with

Table 8. Effect of Nitrogen, vermicompost and *Clodinafop propargyl* on Potassium uptake by grain and straw (mg/pot) in wheat crop.

Treatments	Nitrogen Levels (mg/kg soil)					
	0	50	100	150	200	Mean
Grain						
Vermicompost levels						
0	13.23	25.66	31.28	37.08	40.87	29.62
1%	25.97	37.07	46.25	49.35	51.42	42.01
Mean	19.60	31.36	38.76	43.21	46.14	
CD (5%) Nitrogen = 1.06, Vermicompost = 0.67 and Nitrogen × Vermicompost = 1.50						
***Clodinafop propargyl* levels (g a.i./ha)**						
0	27.96	38.87	45.25	51.30	55.34	43.74
60	20.16	35.31	40.50	45.96	48.22	38.03
90	15.23	25.62	31.46	35.24	37.72	29.05
Mean	21.12	33.27	39.07	44.17	47.09	
CD (5%) Nitrogen = 1.06, Herbicide = 0.82 and Nitrogen × Herbicide = 1.84						
Straw						
Vermicompost levels						
0	46.71	62.60	114.22	122.72	143.78	98.06
1%	65.34	98.53	150.28	162.48	178.43	131.01
Mean	56.02	80.56	132.25	142.60	161.10	
CD (5%) Nitrogen = 1.81, Vermicompost = 1.14 and Nitrogen × Vermicompost = 2.56						
***Clodinafop propargyl* levels (g a.i./ha)**						
0	73.03	92.22	126.10	150.34	182.09	124.75
60	56.93	82.43	115.17	143.50	163.47	112.30
90	39.22	65.80	95.34	118.68	143.77	92.56
Mean	56.39	80.15	112.20	137.50	163.11	
CD (5%) Nitrogen = 1.81, Herbicide = 1.40 and Nitrogen × Herbicide = 3.13						

those reported by Majumdar et al. (2010) and Sarmamy and Khidir (2013).

Potassium uptake by grain

It was observed from the data that uptake of K by wheat grains increased significantly with the application of N up to 200 mg N/kg soil (Table 8) and increase was from 13.23 mg/pot to 40.87 mg/pot over control. Similar, results were reported by Gupta et al. (1992). Data further revealed that application of vermicompost alone significantly increased the K uptake from 13.23 to 25.97 mg/pot over control. Results are similar to those reported by Sreenivash et al. (2000) and Davari et al. (2012). Conjugative use of N and vermicompost recorded the highest K uptake (51.42 mg/pot) by grains over control. Our results were in agreement with Duhan et al. (2006), Khokhar and Nepalia (2010) and Sefidkoohi and Sepanlou (2013).

The data presented in Table 8 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the K uptake by grains from 27.96 mg/pot to 20.16 and to 15.23 mg/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at 60 and 90 g a.i./ha decreased the K uptake by grains from 55.34 to 48.22 and to 37.72 mg/pot, respectively in the presence of 200 mg N kg^{-1} soil. Data presented in Table 9 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha also significantly decreased the K uptake by grains from 49.94 to 44.56 mg/pot and to 35.09 mg/pot, respectively in the presence of vermicompost. Similar findings were reported by Majumdar et al. (2010) and Sarmamy and Khidir (2013).

Potassium uptake by straw

A perusal of data (Table 8) indicated that with the increase in N doses, the uptake of K by wheat straw also increased significantly up to 200 mg N/kg soil and increase was from 46.71 to 143.78 mg/pot over control. Similar, results were reported by Ahmad et al. (2007).

Table 9. Effect of vermicompost and herbicide (*Clodinafop propargyl*) on potassium uptake by grain and straw (mg/pot) in wheat crop.

Vermicompost levels	***Clodinafop propargyl* levels (g a.i./ha)**			
	0	**60**	**90**	**Mean**
Grain				
0	37.89	29.30	21.52	29.57
1%	49.94	44.56	35.09	43.19
Mean	43.91	36.93	28.30	
CD (5%) Vermicompost = 0.67, Herbicide = 0.82 and Vermicompost × Herbicide = 1.16				
Straw				
0	111.45	92.19	69.60	91.08
1%	126.11	115.87	102.24	114.74
Mean	118.78	104.03	85.92	
CD (5%) Vermicompost = 1.14, Herbicide = 1.40 and Vermicompost × Herbicide = 1.98				

Data further revealed that application of vermicompost alone significantly increased the K uptake from 46.71 to 65.34 mg/pot over control. Rathore et al. (1995) and Sreenivash et al. (2000) reported similar results. Conjugative use of N and vermicompost recorded the highest K uptake by straw and the extent of increase with nitrogen at 200 mg/kg soil + vermicompost at 1% was from 46.71 to 178.43 mg/pot over control. It is further reported that combined use of N and vermicompost was found superior than their individual use. Our results were in agreement with Thakral et al. (2003) and Sefidkoohi and Sepanlou (2013).

The data presented in Table 8 indicated that application of *C. propargyl* at 60 and 90 g a.i./ha significantly decreased the K uptake by straw from 73.03 to 56.93 and to 39.22 mg/pot, respectively over control (without *C. propargyl*). Application of *C. propargyl* at both the levels significantly decreased the K uptake by straw from 182.09 to 163.47 and to 143.77 mg/pot, respectively in the presence of 200 mg N/kg soil. Data presented in Table 9 further revealed that application of *C. propargyl* at 60 and 90 g a.i./ha also significantly decreased the K uptake by straw in the presence of vermicompost and the extent of decrease was from 126.11 to 115.87 mg/pot and to 102.24 mg/pot, respectively. Similar findings were reported by Duhan et al. (2006) and Majumdar et al. (2010).

Conclusion

Grain and straw yield of wheat increased significantly with the increasing levels of N up to 150 mg/kg soil over control as well as vermicompost thereafter no significant increase in yield was observed. Application of vermicompost also increased the grain and straw yield over control. Application of *C. propargyl* significantly decreased the grain and straw yield at both the levels (60 and 90 g a.i./ha) either alone or in combination with N and vermicompost. Application of N as well as vermicompost subsides/lower down the phytotoxic effect of *C. propargyl*. NPK uptake by grain and straw increased significantly with increasing levels of N alone as well as in combination with vermicompost (at 1%). Application of *C. propargyl* significantly decreased the NPK uptake in grain and straw at both the levels.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Physiological quality and protein patterns of corn seeds produced under water and salt stresses

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This study evaluated the effect of water and salt stresses on the physiological quality and on the electrophoresis patterns of heat resistant proteins in corn seeds. The experiments were carried out in the laboratories of seed analysis and biotechnology at the Universidade Federal de Lavras. Corn seeds of the hybrid GNZ 2004 and the inbred line LE 57 were used. The seeds were produced in soils with an electric conductivity of 3 dS m^{-1} (under stress) and 0.4 dS m^{-1} (without stress) and in pots containing substrate with a water holding capacity of 40% (with stress) and 70% (without stress). The randomized complete block design with treatments arranged in a split-plot scheme was used with four replications. Seeds were harvested at different stages of development. Seed physiological quality was evaluated using the tests of germination, artificial aging and cold test. The patterns of heat resistant proteins were evaluated by electrophoresis. The results showed that depending on seed developmental stage there was an effect of water and salt stresses on the seed vigor. The electrophoretical patterns of heat resistant proteins were stable in seeds produced under different stress conditions.

Key words: *Zea mays,* developmental stages, late embryogenesis abundant proteins (LEA proteins).

INTRODUCTION

Seed physiological quality can vary with genotype, seed development stage and also with stress conditions imposed to the plants during the production process, such as water and salt stresses. According to Ferreira et al. (2011), moderate water stress reduces seed germination rate, but it does not affect their vigor. Faria et al. (2004) observed that under natural drying conditions, corn seed germination and vigor are acquired with their development and greater values are observed in the development stage known as ML5 (milk line 5).

The effect of irrigation on different plant development stages was evaluated by Schlichting et al. (2015), who observed that the water deficit during the vegetative stage, corresponding to 12 leaves, reduced corn seed production; however, no effects on seed physiological quality was observed. Irrigation was done by sprinklers based on the evaporation of the Class A tank, applying the coefficient of consumption (Kc) for corn. Another factor that can affect plant and seed development is salinity.

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Plant response to salinity is a complex phenomenon, involving changes at the morphological, physiological and biochemical levels (Fougère et al., 1991). Ferreira et al. (2005) observed that decreasing levels of calcium, magnesium, potassium, and increasing levels of sodium cause an unbalance and nutritional stress on maize.

Programs of seed quality control must guarantee seed genetic purity besides its physiologic quality. This process demands precise methods that can be routinely used by seed producing companies. Genetic purity certification, in Brazil, is generally does by seed, seedling and plant morphological markers at the flowering and maturation phases (Silva et al., 2000). However, for Gomes-Filho et al. (2010), Menezes et al. (2008) and Moreira et al. (2013), many morphological markers do not attend the criteria of discrimination, homogeneity and stability required for cultivar description. These markers can be affected by many environmental factors and especially by stress. In contrast, heat resistant proteins are potential markers that do not present any known catalytic activity (Silva-Mann et al., 2002) presenting polymorphism and stability in seeds, such as in maize (Roveri José et al., 2004).

Therefore, this study aimed to evaluate the effect of water and salt stresses on the physiological quality and on heat resistant proteins patterns of corn seeds harvested at different development stages.

MATERIALS AND METHODS

The experiments were done on November 2013 at the experimental area of the Department of Agriculture and at the Seed Sector of the Universidade Federal de Lavras (UFLA). Seeds of two genotypes, the single cross hybrid GNZ 2004 and its parent line LE 57 were used. Two experiments were carried out aiming to produce seeds under both, stress and no-stress conditions. The first one was conducted in the field, where the salt stress was applied. The second one was conducted in pots, where the water stress was applied.

The first experiment, carried out in the field under salt stress, was set up in a randomized complete block design with treatments arranged in a split-plot scheme, considering the stress factor (with or without salt stress) in the plot, and the stages of development in the subplots, with four replications. Each subplot was composed by 4 five-meter length rows, with a spacing of 0.8 m between rows and 0.2 m between plants, obtaining a density of approximately 62,500 plants ha^{-1}. In each plot subjected to salt stress was applied, directly on the soil 8.650 Kg NaCl, distributed in two applications, the first one immediately after sowing, with 3.460 Kg NaCl (40% of the total applied) and the second one at plant flowering, with 5.190 Kg NaCl. The amount of NaCl applied raised soil conductivity to 3 dS m^{-1}, which is considered stressing for plants. Plots not subjected to salt stress had soil electric conductivity about 0.4 dS m^{-1}.

Soil conductivity was measured four times: the first one was done before the test started to determine the amount of NaCl to be applied on each plot; the second one was done 16 days after the experiment started; the third one was done 98 days after the test had started, just before the second application of salt; and the last one was done when the seeds reached the stage of milk line 5 (ML5). Soil electric conductivity was determined at the Department of Soil Sciences of Universidade Federal de Lavras, according to the method proposed by Raij et al. (2001) for a 1:5 extract (10 cm^3 fine air dried soil for 50 mL water).

The amount of NaCl to be applied on each plot was determined using the following equation:

$$[\%Na] = \frac{[Na^+]\ x\ 100}{T}$$

where, T= soil potential CEC; [Na$^+$] = sodium concentration [cmolc/dm^3], and [%Na] = sodium percent saturation

A sodium concentration of 60% was required to reach soil conductivity of 3 dS m^{-1}, resulting on the application of 2702.0 mg NaCl Kg^{-1} soil, representing 8.650 Kg NaCl on each plot. Agricultural soil depth was considered as the 0.20 m.

In the second experiment, water stress induction was applied in 30 L pots, containing a sand and soil substrate in the proportion 1:1, in a total of 160 pots: 80 cultivated under water stress (40 with the hybrid and 40 with the parental line) and the other 80 cultivated with no water stress. Soil water capacity was maintained at 40% after pollination in the pots subjected to water stress, or at 70% during seed development in those not subjected to water stress. The experiment was carried out in a randomized complete block design with treatments arranged in a split-plot scheme, considering the stress factor (with or without water stress) in the plot, and the stages of development in the subplots, with four replications.

The seeds started to be harvested at the stage 2 of the milk line (ML2), when the seeds presented 25% of the endosperm solidified, according to the methodology proposed by Hunter et al. (1991). The seeds in the first experiment for both, the hybrid GNZ 2004 and the inbred line LE 57 were harvested at the stages of development ML2, ML3, ML4 and ML5. To the second experiment the seeds of both, hybrid and inbred line were harvested in the stages of development ML3 and ML5.

The stages of milk line were identified by visual inspection, based on a sample of six seeds removed from the middle of five ears. Each seed was cut longitudinally and the embryo and milky contents were removed from one of the halves. The percentage of solidified endosperm was estimated by comparison with the intact half.

Seed physiological quality was evaluated, for each cultivar and each treatment, by the tests of germination, accelerated aging and cold, in four replications. The moisture content of the seed was determined by the oven method at 105ºC for 24 h, using two replicates of each treatment.

The germination test was conducted with four replicates of 50 seeds, sowed between germitest paper towels moistened with distilled water in the ratio of 2.5 mL/g paper. The germination chamber was set at 25ºC and the evaluations of normal seedlings were performed on two counts, 4 and 7 days after sowing. This test was conducted according to the Seed Analysis Ruler [Regras para Análises de Sementes (RAS)] (Brasil, 2009).

The cold test was done as described by Loeffler et al. (1985). Twenty five seeds were distributed on a germitest paper moistened with water at 2.5 times its dry weight. After sowing, the rolls were placed in plastic bags, closed with tape, and maintained in a 10°C chamber for 7 days. Subsequently, the rolls were transferred to the germinator at 30°C. Normal seedling counts were done on the fourth and seventh day after the transfer.

The artificial aging test was performed in "gerbox" where seeds were suspended on a screen inside the box, containing 40 mL water. Seeds remained were incubated for 72 h at a temperature of 42°C, then was performed germination test as described previously.

Heat resistant proteins were extracted from 100 mg of embryo axes of seeds from each treatment, ground in ice cold mortar with 1:10 (embryo weight: extraction buffer volume) buffer (50 mM Tris-HCL-7.5; 500 mM NaCl; 5 mM $MgCl_2$; 1 mM PMSF) and transferred to 1500-μL microtubes. The mixture was centrifuged at 16000 x g for 30 min at 4°C, and the supernatant incubated in a water bath at

Table 1. Mean values (%) of seedlings vigor evaluated by the artificial aging (EA) and cold (TF) tests, of seeds of the hybrid GNZ 2004 and the inbred line LE 57 produced with or without salt stress, and harvested at different stages of milk line (ML).

Milk line	GNZ 2004		LE 57	
	TF		EA	
	With	Without	With	Without
ML5	99^{aA}	99^{aA}	97^{aA}	95^{aA}
ML4	90^{aA}	86^{aB}	91^{aA}	87^{aA}
ML3	66^{aB}	36^{bC}	93^{aA}	90^{aA}
ML2	39^{aC}	44^{aC}	74^{bB}	90^{aA}

*Averages followed by the same letter, small cap in the rows and capital in the columns, belong to the same grouping by the Scott-Knott test at 5% probability.

85°C for 15 min and centrifuged again as previously described. The supernatant was poured into microtubes while the pellet was discarded. Before applying the samples into the gel, the tubes containing 70 µL extract + 40 µL sample buffer (2.5 mL glycerol; 0.46 g SDS; 20 mg bromophenol blue, and completed to 20 mL with extraction buffer Tris pH 7.5) were placed in a water bath with boiling water for 5 min. A polyacrylamide SDS-PAGE gel was prepared at 12.5% (separating gel) and 6% (concentrator gel) and each well received 50 µL of the extract + sample buffer. Electrophoresis was done at 150 V, and stained with Coomassie Blue at 0.05%, as described by Alfenas (2006), for 12 h, and de-stained in 10% acetic acid.

Before undertaking statistical analysis of data, the normality as well as the homogeneity of the residuals variances was checked. After that, the analysis of variance was carried out for germination test, artificial aging and cold test. To the salt stress experiment the analyzes were carried out in a randomized complete block design with treatments arranged in a 2×4 split-plot scheme with two stress conditions (with or without) and four stages of seed development (ML2, ML3, ML4 and ML5). To the water stress experiment the analyzes were carried out in a randomized complete block design with treatments arranged in a 2×2 split-plot scheme with two stress conditions (with or without) and two stages of seed development (ML3 and ML5). Means values were grouped by the Scott-Knott test at 5% probability. The statistics analyzes and the Scott-Knott test was performed using the software SISVAR (Ferreira, 2011). The analysis of the heat resistant proteins was qualitative, observing the presence or absence of bands in the gels for each treatment.

RESULTS AND DISCUSSION

There was significant interaction between salt stress and the stages of seed development. A significant double interaction was observed between the stages of seed development and salt stress in the cold test for the hybrid and in the artificial aging test for the inbred line. Also, significant differences were found in the germination and artificial aging test for the hybrid and in the cold test for the inbred line when seeds were harvested at different stages of development.

A significant interaction was observed between stages of development and water stress in the germination test and artificial aging for both, the hybrid and the inbred line. Also, significant differences were found between the two genotypes when the seeds were harvested in different stages of seed development.

The cold test demonstrated that seeds of the hybrid harvested at ML3 under no salt stress had lower vigor than those subjected to stress (Table 1). No significant differences were observed in the cold test for the seeds harvested on any of the other milk lines subjected to stress or not. The artificial aging test of the parent line demonstrated that the stress at ML2 caused lower germination values, which was not observed in any other stage of development.

The germination test of seeds of the hybrid GNZ 2004 and its parental line LE 57 harvested in the stages of development ML2, ML3 and ML4, subjected or not to salt stress, presented lower values than those observed for seeds harvested at ML5 (Table 2). Probably, the seeds harvested at these stages are not physiologically mature and, thus, had lower germination. The artificial aging test demonstrated that seeds of the hybrid harvested in any stage of development had greater germination than those observed in the germination test. It is possible that, under the test conditions, the incubation dried the seeds, inducing their germination. Seeds of the parent line harvested in the stages ML2 and ML3 had lower germination in the cold test than those of the other stages.

In the germination test, both seed sources produced with stress or without it, had greater germination when harvested at ML5 (Table 3). For hybrid seeds, harvested at ML3, it was observed higher germination values on seeds produced under water stress conditions. Lower vigor values were found in the artificial aging test for seeds not subjected to water stress and harvested at ML3 for both the hybrid and the line. In contrast, at ML5 no effect of the water stress was observed on seed vigor for this test.

Greater vigor values were found in the cold test for seeds of the hybrid GNZ 2004 and its parent line LE 57 subjected to water stress, when harvested at the stage of development ML5 (Table 4).

It is possible to state that the seeds of the inbred line

Table 2. Mean values (%) of normal seedlings evaluated by germination test (TG), artificial aging test (EA) and cold test (TF) of seeds of the hybrid GNZ 2004 and the inbred line LE 57 harvested at different stages of milk line (ML).

Milk line	GNZ 2004		LE 57	
	TG	EA	TG	TF
ML5	99^{a}	99^{a}	98^{a}	98^{a}
ML4	76^{b}	92^{b}	51^{b}	79^{b}
ML3	31^{c}	95^{b}	17^{c}	27^{d}
ML2	16^{d}	85^{c}	8^{d}	44^{c}

*Averages followed by the same letter, in the columns, belong to the same grouping by the Scott-Knott test at 5% probability.

Table 3. Mean values (%) of normal seedlings in the corn seed germination test (TG) and artificial aging test (EA) of the hybrid GNZ 2004 and the inbred line LE 57 produced with or without water stress, and collected at different stages of milk line (ML).

Milk line	TG				EA			
	Hybrid		Line		Hybrid		Line	
	With	Without	With	Without	With	Without	With	Without
ML5	99^{aA}	99^{aA}	94^{aA}	92^{aA}	100^{aA}	100^{aA}	99^{aA}	99^{aA}
ML3	77^{aB}	65^{bB}	35^{bB}	48^{bB}	97^{aA}	66^{bB}	93^{aA}	76^{bB}

*Averages followed by the same letter, small cap in the rows and capital in the columns, belong to the same grouping by the Scott-Knott test at 5% probability.

Table 4. Mean values (%) of normal seedlings after cold test (TF) of corn seeds of the hybrid GNZ 2004 and the inbred line LE 57, collected at different stages of milk line (ML).

Milk line	TF(%)	
	Hybrid	Line
ML5	99^{a}	92^{a}
ML3	69^{b}	65^{b}

*Averages followed by the same letter, in the columns, belong to the same grouping by the Scott-Knott test at 5% probability.

and the hybrid presented low germination values when harvested in the stage of development ML2 and ML3 in the cold and germination tests. The greatest germination values were observed on seeds harvested at the stages ML4 and ML5. Greatest vigor values were found in the artificial aging test for seeds harvested at the stages ML2, ML3 and ML4. Seeds harvested at the stage LL5 had high germination and vigor values in all tests, for both the hybrid and the inbred line.

The average values of water contents in the seeds of the hybrid GNZ 2004 harvested at the stages of development ML2, ML3, ML4 and ML5 were 45.9, 43.5, 33.7 and 19.9%, for seeds produced under salt stress, and 45.9, 42.9, 33.2 and 19.3% for the seeds without salt stress. In contrast, the seeds of the inbred line LE 57, harvested at the maturation stages ML2, ML3, ML4 and ML5 presented average water contents of 48.1, 41.4, 36.4 and 17.3%, respectively, for seeds produced under salt stress, and of 47.5, 42.3, 36.7 and 17.6% for seeds produced without salt stress.

The average seed water contents of the line grown under water stress and harvested at the maturation stages ML3 and ML5 were 37.8 and 15.2%, respectively. In contrast, those grown without the water stress had average values of 39.6 and 16.0%. The seeds of the hybrid, harvested at the same stages of development, ML3 and ML5, had average water contents of 38.6 and 17.2% for seeds produced under water stress, and 38.9 and 17.1% for those produced without that stress.

The patterns of heat resistant proteins of the single cross hybrid (GNZ 2004) and its parental line (LE 57) were not affected by either salt or water stresses, as shown by the

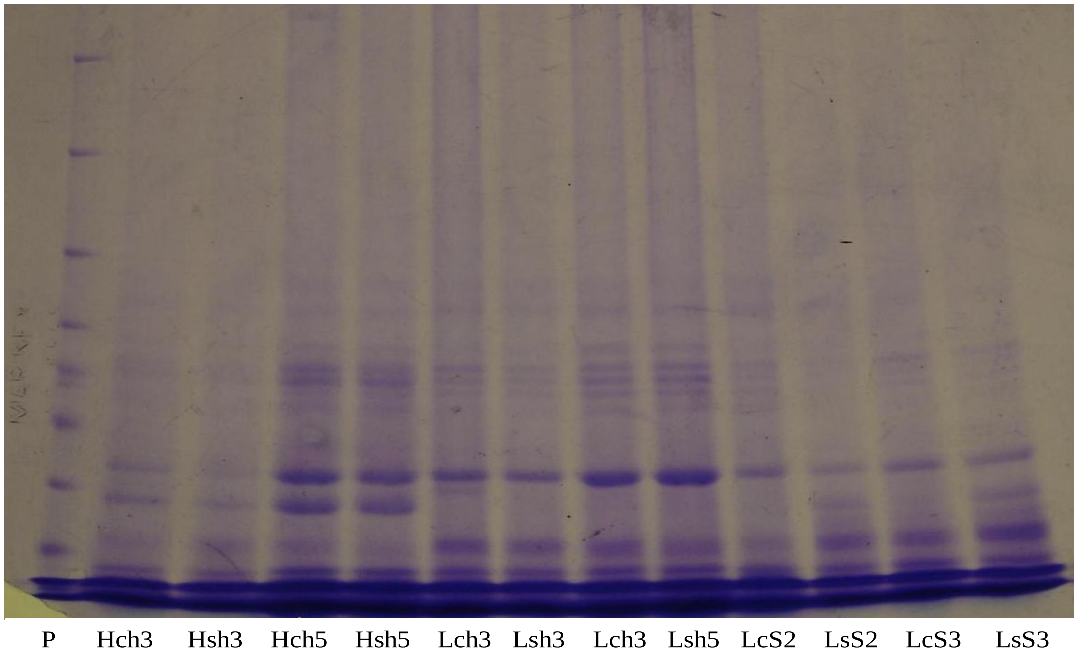

Figure 1. Heat resistant protein electrophoretic patterns of seeds of the single cross hybrid GNZ 2004 (H) and its parent line LE 57 (L) produced under water stress (ch) or not (sh), or under salt stress (cS) or not (sS), and harvested at different development stages, ML2 (2), ML3 (3) and ML5 (5); protein standard (P).

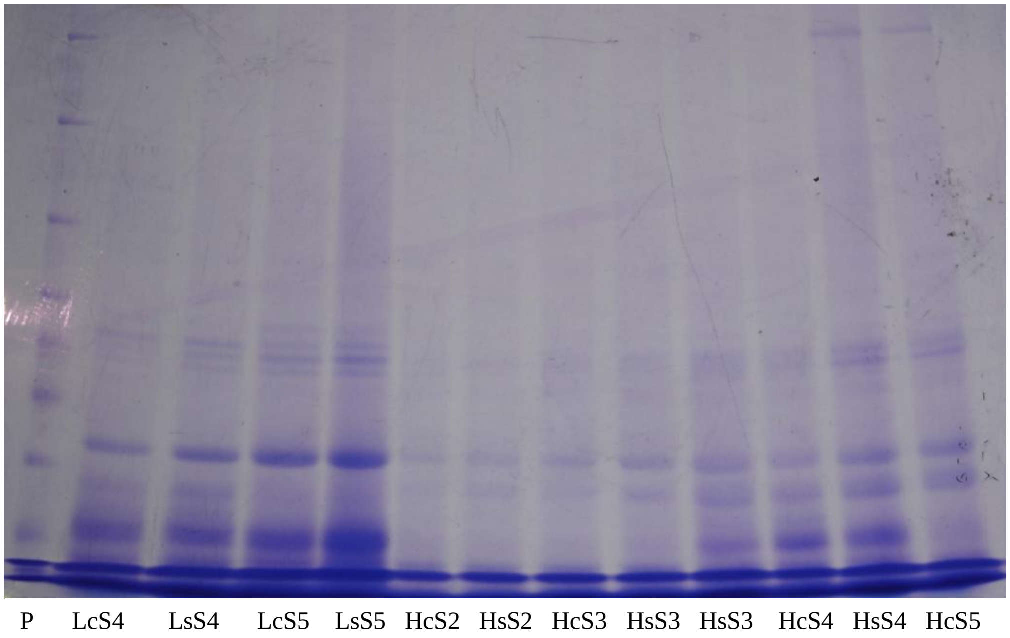

Figure 2. Heat resistant protein electrophoretic patterns of seeds of the single cross hybrid GNZ 2004 (H) and its parent line LE 57 (L) produced under water stress (ch) or not (sh), or under salt stress (cS) or not (sS), and harvested at different development stages, ML2 (2), ML3 (3), ML4 (4) e ML5 (5); protein standard (P).

zymograms (Figures 1 and 2). Also, lower protein expression was observed at the maturation stages LL2 and LL3, reflected by the low band intensity. Greater expression of these proteins was found at the maturation stage LL5. Similar results were found by Faria et al. (2004) in corn seeds harvested at different development stages.

This study demonstrated that it is possible to identify the cultivar, certifying their genetic purity in early development stages. Moreover, the patterns of these proteins are stable, even when the seeds are produced under different stress conditions.

Seeds of corn lines subjected to artificial or natural drying, even those that showed large variations on germination, had stable patterns of heat resistant proteins (Roveri José et al., 2004).

Conclusions

Salt and water stresses affect seed vigor depending on their development stage. Greater germination levels and vigor were observed on corn seeds harvested at the maturation stage ML4 and afterwards. Heat resistant proteins presented stable patterns, even when the seeds are produced under water or salt stresses.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Supplemental irrigation levels in bell pepper under shade mesh and in open-field: absolute growth rate, dry mass, leaf area and chlorophyll

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This study aims to evaluate the effect of supplemental irrigation levels on vegetative parameters of bell pepper grown in open field and under shade mesh. The experimental design was a randomized complete block with four replications and ten treatments in factorial scheme (four irrigation levels combined with shade). Irrigation treatments consisted in 0.25, 0.50, 0.75 and 1.0 rate of crop evapotranspiration and the control (no-irrigation). Shading treatment was of 50% reduction of the photosynthetically active radiation compared to open field conditions. Vegetative parameters were influenced by irrigation. The growth rate of plants present no significant difference. The growth rate of stem diameter present difference, being treatments 0.50 and 0.75 the highest.Significant interaction was present in the rate of chlorophyll, dry matter, leaf area index and number of leaves per plant. Plots under shade mesh showed the highest growth rate in plant height and stem diameter and leaf area index, number of leaves per plant, dry matter and lower chlorophyll index. As irrigation strategy, considering the water use efficient and vegetative characteristics of bell pepper, the most favorable irrigation levels were 0.5 and 0.75 of ETc, under shade and in open field, respectively, without affecting the vegetative parameters and yield.

Key words: *Capsicum annuum*, water stress, water use efficiency, drip irrigation.

INTRODUCTION

Bell pepper (*Capsicum annuum* L.) is a member of the Solanaceous family, native to Mexico, Central America and northern South America (Echer et al., 2002; Filgueira, 2003; Souza et al., 2011). It is an important crop in many parts of the world, given their economic importance, ranking second in world production. It is

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

Month	Relative humidity mean (%)		Insolation (hour)		Evaporation (mm)	
	2013-2014	2014-2015	2013-2014	2014-2015	2013-2014	2014-2015
Nov	71.60	71.0	229.2	173.1	144.5	131.8
Dec	69.45	76.1	286.2	211.0	175.2	142.2
Jan	73.15	78.3	219.2	212.4	158.3	142.0
Feb	73.79	79.7	211.2	218.0	137.9	123.9
Mar	76.87	77.6	212.6	208.4	112.8	114.1
Sum	-	-	1376.8	1189.6	850.8	804.7

considered one of the ten species of greatest economic importance in the Brazilian vegetable market, and the area annually cultivated is around 13 mil hectares, with production close to 290 mil tons of fruit, generally grown in open field (Marouelli and Silva, 2012).Water use by plants and all the physiological processes are directly related to their status in the soil-water-plant system.The interrelationships between these factors are fundamental for the planning and the operation of irrigation systems to maximizeyield and product quality (Trani and Carrijo, 2004). There are many motivations to study the physiology of plants under stress, among which: knowledge of stressors on plants can be crucial for the development of mechanistic models predictive in nature, for example, the study of the possible effects of climate change. The analysis of the interaction of the plants with the environmental factors are fundamental to comprise the distribution of the species in the different ecosystems and the performance of the crop is strongly limited by the impact of the environmental stress (Nilsen and Orcutt, 1996).

Increased temperatures occurring in late spring and early summer reduce bell pepper yields and increase incidence of physiological disorders in fruit, such as blossom-end rot and sunscald (Olle and Bender, 2009). High temperatures induce flower abortion and fruit in bell pepper (Deli and Tiessen, 1969). Bell pepper is a very demanding plant in luminosity, especially in the early stages of reproduction (Prieto et al., 2003). The increment in crop production is able to be possible only knowing the pushing effects of irrigation and radiation on plant growth and yield (Kara and Yildirim, 2015). The amount of solar radiation intercepted by plants is a major determinant for the total dry matter produced by a crop (Biscoe and Gallagher, 1978). The most effective development forces on plants are “Carbon”, “Water”, “Radiation” and energy supply of plants’ comes from radiation also (Steduto, 2003). Plant development depends on the amount of radiation, duration of light in a day, relative humidity, wind speed and temperature (Boztok, 2003). Also, plant water, nutrient uptake and transpiration rate are closely related with solar radiation (Adams, 1992).

The analysis of plant growth allows evaluating the behavior of crop genotype in relation to different crop systems, influenced by management, climate and crop physiology (Oliveira et al., 2015). The indexes wrapped in the analysis of growth, as foliar area index, growth rate, and liquid assimilation indicate the capacity of plants assimilatory system in synthesize and destine the organic matter in the diverse organs (Monte et al., 2009; Silva et al., 2010).That depend on photosynthesis, breathing and assimilate translocation of carbon fixation sites for local use and storage, where there are growth and differentiation of organs (Lopes et al., 2011).

Studying water requirements of plants has become increasingly important for agriculture, mainly for areas with deficit of irrigation water. This study aims to evaluate the effect of supplemental irrigation levels on vegetative parameters of bell pepper grown in open field and under shade mesh.

MATERIALS AND METHODS

The field study was conducted in the experimental area of the Polytechnic School of the Federal University of Santa Maria, located at an altitude of 110 min the geographic coordinates 29°41'25"S, 53°48'42"W, during the Spring Summer seasons of 2013-2014 and 2014-2015. The soil is classified as typical dystrophic yellow argissolo, with a loam texture (Streck et al., 2008). The climate of the region, according to the Köppen classification is subtropical humid (Cfa). According to the National Institute of Meteorology (INMET), mean annual evaporation, temperature and rainfall range from 800 to 1200 mm, 18 to 20°C and 1450 to 1650 mm, respectively. In Table 1 we can see the summary of the mean monthly climate data during the period of the experiment. The monthly cumulative insolation and evaporation in 2013-2014 season were higher than those in 2014-2015, except mean relative humidity. Solar radiation, evaporation, rainfall and daily temperature during the experimental period are shown in Figure 1. The monthly mean solar radiations in 2013-2014 were higher than in 2014-2015. The daily mean temperatures in 2013-2014 were higher than those in 2014-2015 except December and March. The monthly maximum temperatures were higher in December, January and February. The rainfall cumulative was higher in 2013-2014 (892.8 mm) and 2014-2015 (834 mm); the maximum monthly rainfalls were in November and December, respectively. The monthly radiation in 2013-2014 was higher in December and January.

The experimental design was a randomized complete block with

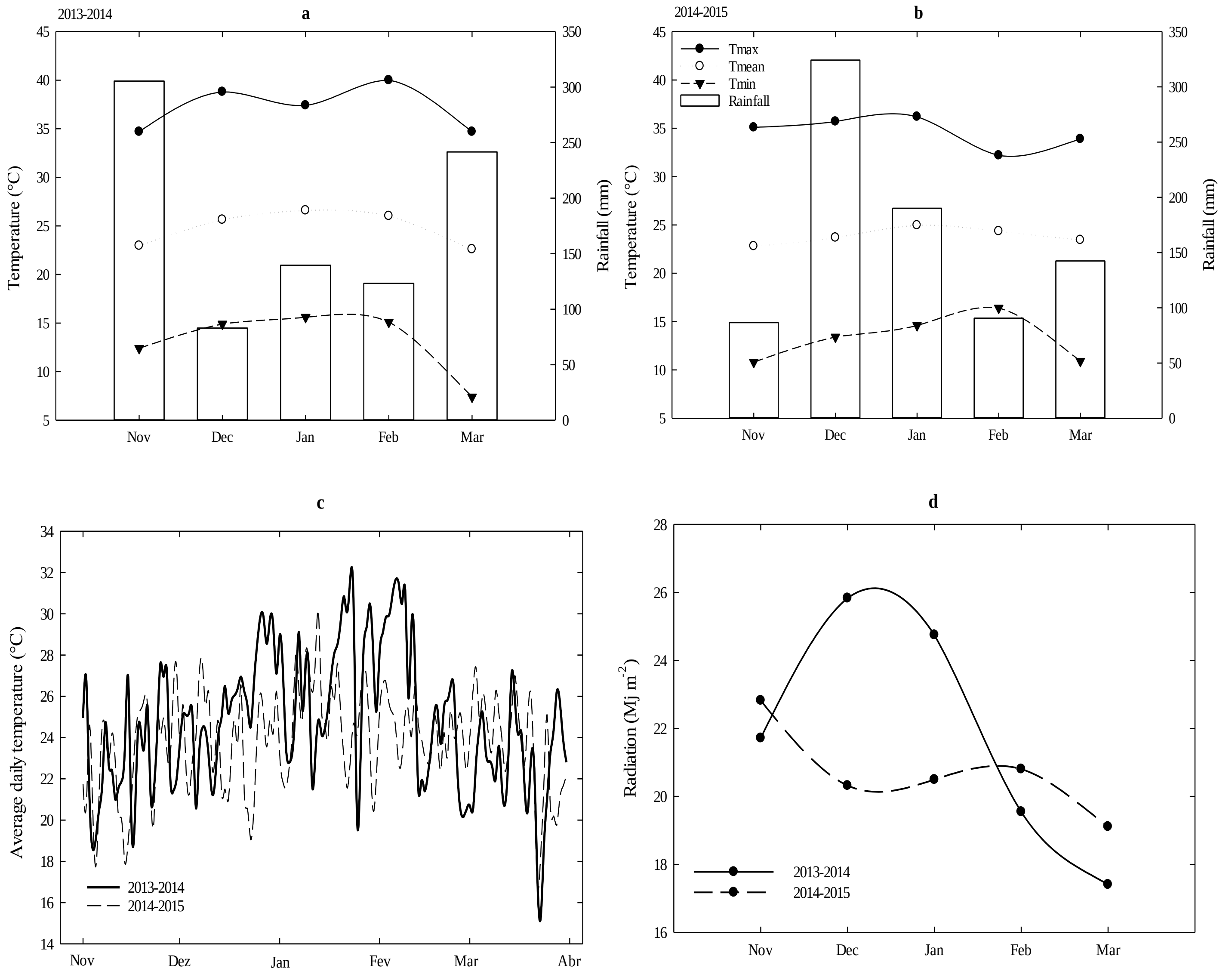

Figure 1. (a, b) Climograph of the experimental area, (c) average daily temperature and (d) radiation during the seasons 2013-2014 and 2014-2015.

four replications and ten treatments in factorial arrangement (four irrigation levels combined with shade mesh). Irrigation treatments were: 25% ($I_{0.25}$), 50% ($I_{0.50}$), 75% ($I_{0.75}$), and 100% ($I_{1.0}$) rate of crop evapotranspiration (ETc) and the control [no irrigation (I_0)].Shading treatments were 50% reduction of the photosynthetically active radiation (according to the manufacturer) and open field conditions (control, 0% shading). There were 40 experimental plots, each of 5.0 m long and 2 m wide (10 m^2), for a total area of 400 m^2, not including border plants. Moisture overlap between rows was avoided by border plants (1 m). Arcade was the variety of bell pepper used due to its commercial importance in the region. Plants were transplanted in the field with two months old at separation of 1.0 m between rows and 0.4 m between plants (density of 2.5 plantsm^{-2}), in Nov. 16, 2013 and Nov. 23, 2014. Shade mesh (polyethylene black shade mesh) was supported with metallic cable, in arectangular structure with the highest point at 2 m. The shade mesh was set two weeks before transplanting. The level of shading was verified by using digital radiometer (Model: MS-100). Leaf temperature was measured in each plot with an infrared thermometer gun (Model: AR 320)

It was used a localized irrigation system (drip) placed as lateral by row, spacing among emitters of 0.2 m and flow of 0.8 Lh^{-1}. It was installed in each experimental plot a ball valve for regulating the irrigation time and pressure regulating valve for uniformity. The irrigation strategy is described as follow: during the first 20 days after transplantation it was applied 100% of ETc to all treatments, to ensure in plants establishment. The levels of supplementary irrigation were applied from 20 to 119 days after transplanting and the frequency of daily watering was established. Due to the characteristics of soils and climatic conditions after the effective precipitation exceeds evaporation, irrigation was applied two days after with the frequency set.

The crop reference evapotranspiration (ETo) and crop evapotranspiration (ETc) were calculated using the following Equations (1) to (2).Use of reference evapotranspiration leads to increasing uncertainty comparing actual evapotranspiration. There

Table 2. Average soil parameters of the experimental area.

Soil layers (m)	Bulk density (g cm^{-3})	Field capacity (m^3 m^{-3})	Wilting point (m^3 m^{-3})	Water content (m^3 m^{-3})	Infiltration (mm h^{-1})	Texture
0-0.2	1.42	0.31	0.14	0.18	15.0	Loam
0.2-0.4	1.38	0.34	0.17	0.17		Clay-loam
0.4-0.6	1.36	0.37	0.23	0.13		Clay

are other models that can estimate evapotranspiration reference than have had successful results. Also, they are useful for selecting the best model when researchers must apply temperature-based models on the basis of available data (Valipour and Eslamian, 2014; Valipour, 2014a, b, c; Valipour, 2015a, b). Weather data was collected from an automatic weather station located 1 km from the experimental area. The crop reference evaporation (ETo) was calculated based on the method of FAO Penman-Monteith (Allen et al., 2006), (Equation 1) as follows:

$$\mathrm{ETo} = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{\mathrm{T}+273}\,U_2.(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \quad (1)$$

Where ETo is reference evapotranspiration (mm day^{-1}), Rn, G and T are net radiation value at crop surface (MJ m^{-2}day^{-1}), soil heat flux density (MJ m^{-2}day^{-1}) and mean daily air temperature at 2 m height (°C), respectively. Also, u_2, $e_s e_a$, (e_s- e_a), Δ and γ represent wind speed at 2 m height (ms^{-1}), saturation vapor pressure (kPa), actual vapor pressure (kPa), saturation vapor pressure deficit (kPa), slope of the saturation vapor pressure curve (kPa/°C) and psychrometric constant (kPa/°C), respectively.

The crop evapotranspiration (ETc) was calculated with the method of dual crop coefficient for each crop phonological stage (Allen et al., 2006), (Equation 2) as follows:

$$\mathrm{ETc} = (\mathrm{K_{cb}} + \mathrm{K_e}) \times \mathrm{ETo} \quad (2)$$

Where ETc crop evapotranspiration (mm), ETo reference crop evapotranspiration (mm) and splitting Kc into two separate coefficients, the basal crop coefficient Kcb and soil water evaporation coefficient Ke.

Before the plants were transplanted randomly sampling points were selected in the experimental area, to determine basic soil parameters, including soil texture, bulk density, field capacity, and permanent wilting point (Table 2). Also, it was performed an infiltration test to design the irrigation system.

The soil water content over the season was measured before and after irrigation every two days (four readings per experimental plot), with a portable time domain reflectometry (TDR-100). The two metallic sensor 0.2 m rods of the TDR were inserted vertically within the row between plants. Also monitoring was performed with neutron probe (CPN Model 503, DR), with calibration previous to execution of the experiment (Padrón et al., 2015a). PVC tubes (50 mm) were installed between row (1 m distance) and plant of each experimental plot at a depth of 0.7 m. Readings were performed once a week at 0.125, 0.30 and 0.50 m of soil depth.

Plant height and stem diameter was measured in ten plants per plot, sampled in a fifteen day interval. The absolute growth rate determination was done according to the formula described by Radford (1967). Equation (3), as follows:

$$\mathrm{AGR} = \frac{\mathrm{W}_2 - \mathrm{W}_1}{\mathrm{T}_2 - \mathrm{T}_1} \quad (3)$$

Where: AGR=absolute growth rate, W=mean plant height and mean stem diameter, T = time.

Leaf area and leaf number per plant was measured in three plants randomly selected per experimental plot, which were sampled in a fifteen-day interval. Eight samples during the experiment were determined with the application of model (LI-COR, Inc., USA). The leaf chlorophyll index was determined once a week over the season in five leaves per plant, in each plot, using a chlorophyll meter (ClorofiLOG, CFL1030, FALKER). Dry weight of the plant was performed at the end of the culture cycle in five plants per plot, randomly selected.The samples were determined separately (root and vegetative top). The plant samples were dried at 65°C until constant weight was obtained.

The main tasks of agricultural management were: weeding, weed control, insecticide and fungicide application and fertigation was according to the nutritional needs of the crop and chemical analysis of the soil. Fertigation was performed with irrigation (daily) at an irrigation rate of 40 t ha^{-1}. All plants received 368 kg ha^{-1} of a complete fertilizer (13N-14P_2O_5-13K_2O), 290 kg h^{-1} of ammonium nitrate (36% N) and 396 kg ha^{-1} of potassium nitrate (35% K_2O). The statistical analysis was performed using the SPSS software package (SPSS V17.0). Significant differences between means for different treatments were compared using Tukey test at $P<0.05$. Data from all years were pooled if no treatment interactions were found.

RESULTS AND DISCUSSION

The absolute growth rate of the plant height and diameter of stem for each treatment are shown in (Table 3). There was no significant interaction effect between treatments in open field and under shade mesh. On the other hand, the treatments under shade mesh showed higher growth rate. The stem diameter in open field and under shade mesh ($P<0.05$), the treatments $I_{0.75}$ and $I_{1.0}$ showed the highest growth rate in open field and under shade mesh $I_{0.25}$ and $I_{0.50}$. The treatments with lower growth rate were without irrigation.

The absolute growth rate of plant height and stem diameter during the crop cycle, for each treatment is shown in Figure 2. The height of the bell pepper plant showed a sigmoidal growth curve with a rapid vegetative growth from the transplanting until 65 days after transplantation (DAT). The maximum rate was of 1.1 cmday^{-1} on open field in $I_{0.75}$ and under shade was 70 DAT, with a maximum of 1.32 cmday^{-1} in $I_{0.50}$, according to the results of polynomial regression curve. Valles et al. (2009), found out that pepper plants showed a sigmoidal growth curve in where a rapid vegetative growth from the transplanting until 47 DAT, moment from which the

Table 3. Average of the absolute growth rate of the plant height and stem diameter of the bell pepper in open field and under shade mesh.

Treatment	Open field		Shade mesh	
	Plant height (cm day^{-1})	Stem diameter (mm day^{-1})	Plant height (cm day^{-1})	Stem diameter (mm day^{-1})
I_0	0.75	0.12^b	0,97	0.11^b
$I_{0.25}$	0.79	0.13^{ab}	1,01	0.13^a
$I_{0.50}$	0.85	0.13^{ab}	1.00	0.13^a
$I_{0.75}$	0.85	0.15^a	0.91	0.11^{ab}
$I_{1.0}$	0.81	0.14^{ab}	1.01	0.12^{ab}
Significance	ns	*	ns	*

Letters indicate significant differences at $^*P<0.05$ and $^{**}P<0.01$.

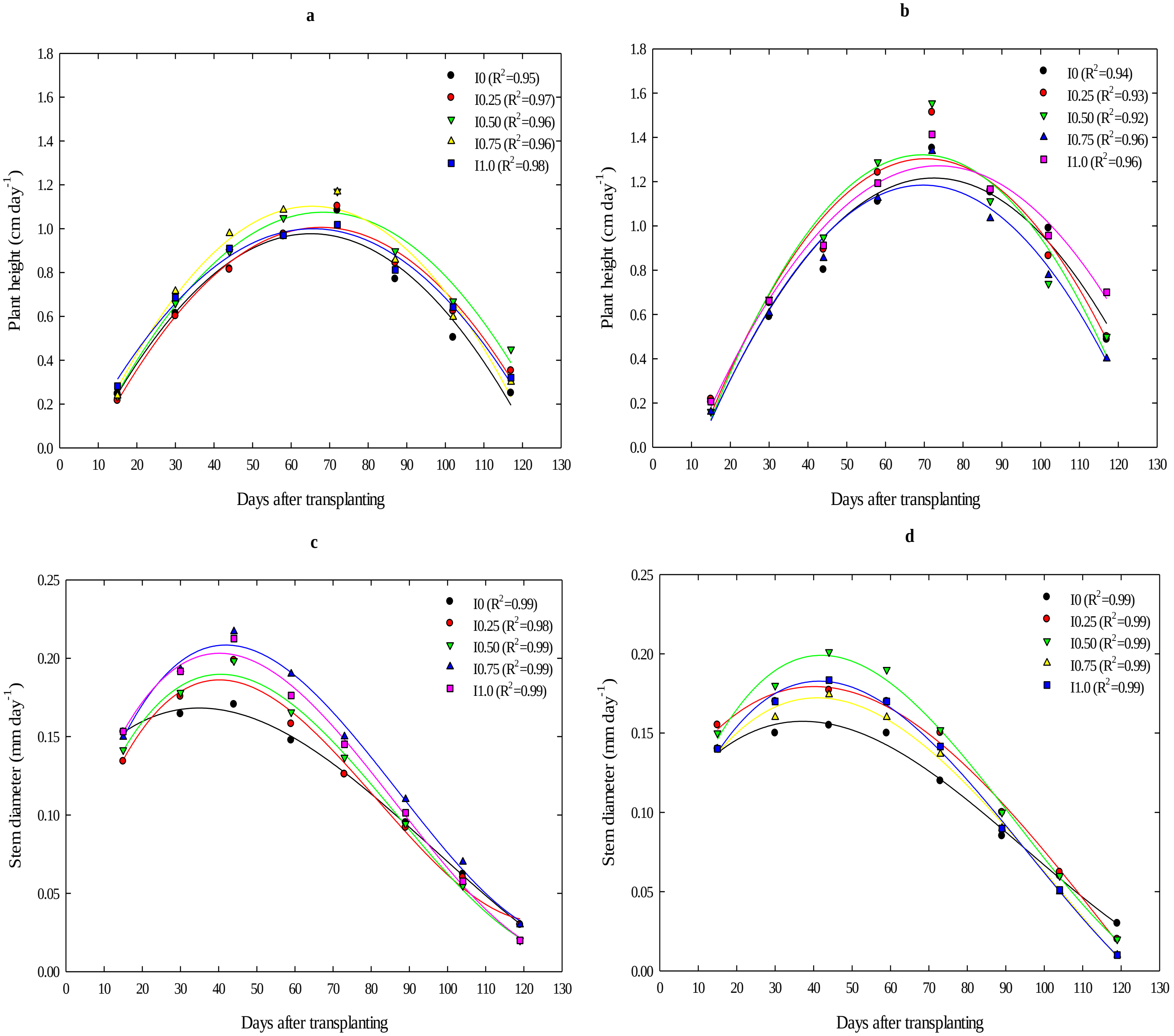

Figure 2. The absolute growth rates of the plant height and stem diameter of bell pepper in open field (a, c) and under shade mesh (b, d).

Table 4. Average leaf area index and number of leaves per plant at 90 days after transplanting of the bell pepper in open field and under shade mesh.

Treatment	Open field		Shade mesh	
	Leaf area index	**leaves per plant (number)**	**Leaf area index**	**leaves per plant (number)**
I_0	0.43^{cB}	119^{bB}	0.95^{bA}	187^{abA}
$I_{0.25}$	0.60^{bcB}	131^{abB}	0.95^{bA}	215^{bA}
$I_{0.50}$	1.01^{aA}	204^{aA}	1.13^{bA}	209^{aBA}
$I_{0.75}$	0.73^{bB}	144^{abB}	1.51^{aA}	269^{abA}
$I_{1.0}$	0.45^{cB}	121^{bB}	1.48^{aA}	316^{aA}
Significance	*	*	*	*

Letters indicate significant differences at $^{*}P<0.05$ and $^{**}P<0.01$.

growth rhythm decreased toward 62 DAT. This change point in growth rate corresponded with the formation of reproductive structures, which confirmed the undetermined growth of pepper plant.

The stem diameter showed rapid growth until 40 DAT in $I_{0.75}$ and 43 DAT in $I_{0.50}$ on open field and under shade, respectively. Under shade the growth rate is slower compared to open field conditions. Generally, in open field plots, lower plant height and higher stem diameter was observed. These results are similar to Díaz-Pérez (2013), that studied shade net levels in bell pepper, reporting that the stem diameter and the plant height were increased with increasinglevels of shade.Stems under shade were thinner and presumably less lignified than those in higher light conditions. Also, Ayala et al. (2015), studying different shade mesh colors in bell pepper, reported that shading provide an increase in plant height.This effect occurs significantly with black mesh, beige, red and green, where the plants grew from 23.1 to 33.0% more than those grown in the open field. Similarly, Márquez et al. (2014), studied different shade mesh colors (30% shade) in the cultivation of cherry tomato andthey recorded an increase in final plant height in all treatments compared to open field. The increase in plant height is a response of the reduced light. In this regard, Rylski and Spigelman (1986), studied the effect of different levels of shading (0, 12, 26 and 47% shading) in the development of sweet pepper plants cultivar 'Maor', reported that plant height increased as light intensity decreased (29.9, 30.3, 35.9 and 40.2 cm), respectively. The increase in plant height of shaded plants was a result of both internode elongation and node number, the apical growth was strongest under the lowest radiation.

The average leaf area index and number of leaves per plant at 90 DAT, is shown in (Table 4). Treatments in open field and under shade mesh had significant interaction effect on the leaf area index and number of leaves per plant. In all plots under shade it could be seen a greater leaf area index and number of leaves per plant. It the open-field plots, $I_{0.50}$ and $I_{0.75}$, had a greater development during the crop cycle and under shade, $I_{1.0}$ and $I_{0.75}$ (Figure 3). In I_0 and $I_{1.0}$open field plots,a less leaf area index was observed and under shade, I_0 and $I_{0.25}$. The leaf area index of $I_{0.50}$ was similar in both environments. It could be infer that the leaf area index was affected by the deficit and excess water. Generally, excess damp have an adverse effect on treatment with 50% shading, possibly optimal humidity is 50% of ET. Yildirim et al. (2012), observed that the plant development parameters of the bell peppers, such as plant weight, canopy and stem diameter, and LAI, decreased according to the amount of water applied from 367 to 164 mm. Good plant development in terms of whole plant weight, leaf area and LAI were observed in the full irrigation treatment, and those parameters were, 340 gplant^{-1}, 4012.9 cm^{2} and 1.22. Excess water application did not increase the quality and development parameters of the peppers. Rylski and Spigelman(1986), reported leaf size increased as light intensity decreased.In shaded environment, leaves were bigger, total leaf area measured between the first and the fourth flower node was about 60% greater than that on plants grown in full light. These results are similar with studies showing that pepper under shade has large internodes, larger leaves, greater leaf area, and thinner leaves (Kittas et al., 2008; Ayala et al., 2011; Díaz-Pérez, 2013).

Chlorophyll index was higher in open plots in all measurements and irrigation shows no significant effect (Figure 4). However, in open field plots, it was observed a significant effect ($P<0.05$) at 60 DAT, being I_0 the lowest. On the other hand, significant interaction between treatments in open field and under shade mesh was observed in 90 and 105 DAT. Díaz-Pérez (2013), studyingshade levels in bell pepper, reported that chlorophyll index decreases as shading levels increase. Also they noted that a possible cause of inaccuracy under shade is related to the increased thickness of the leaf. Xiao et al. (2012), studying the effect of low light on the characteristics of photosynthesis and chlorophyll as fluorescence during leaf area development of sweet pepper, reported that under low light chlorophyll content, net photosynthetic rate, photosynthetic apparent quantum

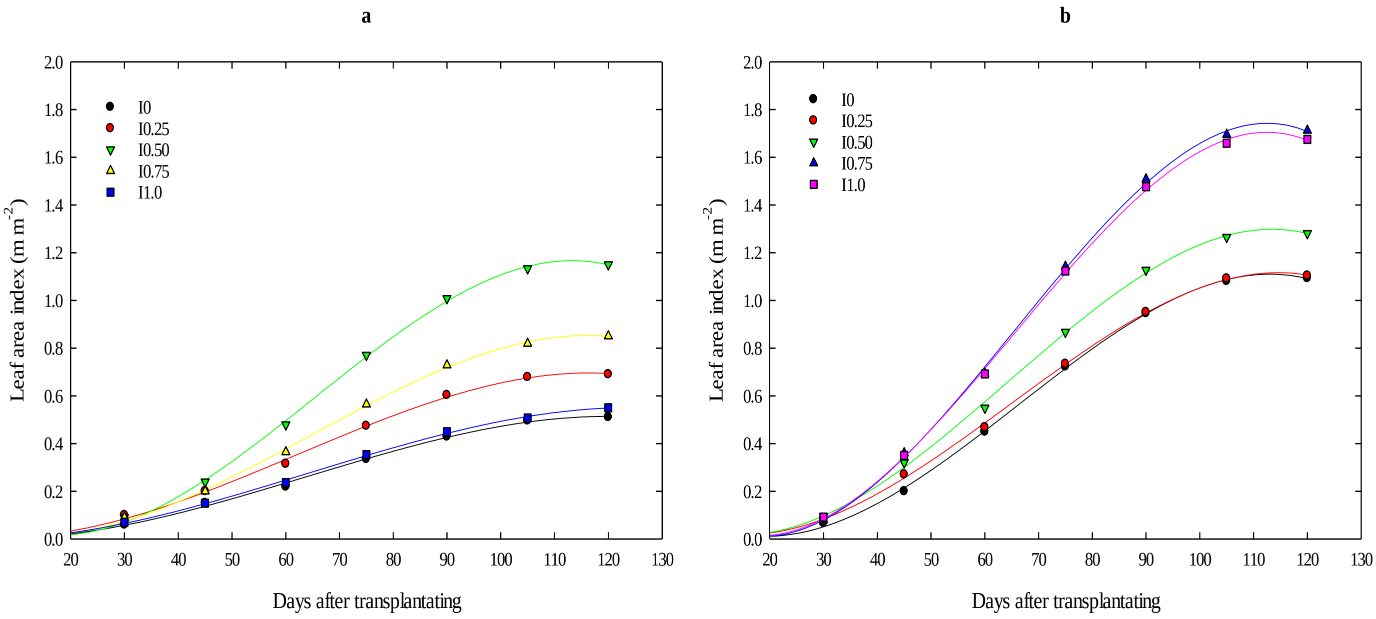

Figure 3. Leaf area index of the bell pepper in open field (a) and under shade mesh (b).

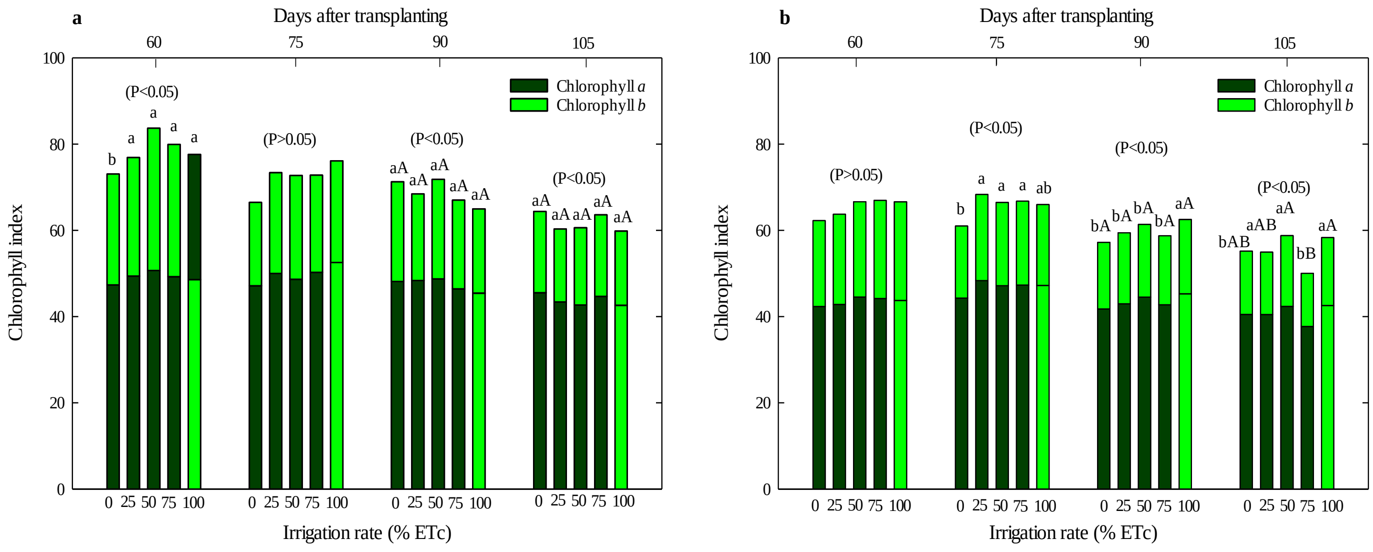

Figure 4. Chlorophyll content (index), Chlorophyll *a*, Chlorophyll *b* and Chlorophyll total of the bell pepper in open field (a) and under shade mesh (b).

efficiency and carboxylation efficiency of sweet pepper leaves increased gradually and decreased after reaching the maximum levels on 21st day under optimal light and the 42nd day under low light. Ferreyra et al. (1985), study chlorophyll content in pepper with different soil moistures, reported that with increasing soil moisture, apparently chlorophyll content decreases.

The average stem weight, root and part vegetative top, is shown in (Table 5). The treatments in open field and under shade showed significant effect interaction on stem weight, root and part vegetative top ($P<0.05$). The treatments I0.75 and I1.0 showed greater weight on part vegetative top in open field and under shade on I0.50 and I1.0. This result correlates with the leaf area index. Possibly open field plants are more lignified. Root development was higher in the treatments I0.75 and I1.0

Table 5. Average of dry mass of stem, root and vegetative top of the bell pepper in open field and under shade mesh.

Treatment	Open field (g plant^{-1})			Shade mesh (g plant^{-1})		
	Vegetative top	Root and stem	Total	Vegetative top	Root and stem	Total
I_{0}	117.7^{eB}	38.7^{cB}	156.3	157.8^{dA}	44.6^{bB}	202.4
$I_{0.25}$	141.3^{dB}	39.8^{cA}	181.1	150.5^{eA}	35.1^{dB}	185.6
$I_{0.50}$	145.1^{cB}	34.3^{dB}	179.4	228.4^{aA}	61.7^{aA}	290.1
$I_{0.75}$	206.7^{aA}	55.4^{bA}	262.0	164.2^{cB}	45.6^{bA}	209.7
$I_{1.0}$	201.7^{bA}	58.6^{aA}	260.3	179.9^{bB}	41.9^{cB}	221.8
Sig.	*	*	-	*	*	-

Letters indicate significant differences at *P<0.05 and **P<0.01. Sig: Significance.

in open field and under shade mesh on I0.50 and I0.75. This is due to excess moisture under shade, affecting soil aeration and consequently affecting root growth. In open field plots, weight of root and stem represent 21.9% and the aerial part of the plant 78.1%. The plant dry matter was 32.4 and 29.1%, in open field and under shade mesh, respectively.

The higher moisture content in soil was determined under shade mesh. Root development was mainly on 0 to 30 cm depth. Under shade, plants grew vigorously, leading to increased water consumption. On open field conditions, water consumption was lower, which contributed to low plant height and leaf area. Ferreyra et al. (1985), studied the effect of excessive use of water in pepper, reported that the total amount of root decreased markedly with excessive water application. Padrón et al. (2015b), studied irrigation levels in bell pepper, and reported that a decrease in irrigation water of 60% ET, roots grown deeper and the adventitious roots are thicker. On 100% of ET, ithas the highest vegetative growth. Nilsen and Orcutt (1996), reported that plants, as a strategy to increase water absorption capacity, increases the root surface, decreasing hydraulic resistance. This is common in plants known as wasteful water. Tambussi (2004), studying water saving plants, adopted as reverse strategy, minimizing water loss through various pathways, as: stomata closing and reducing perspiration coticule, within this same line conservative procedure. It could be included plants that produce less biomass to suffer water stress and increasing the relative proportion of the radicular mass.

Conclusions

The deficit and excess water affect on crop vegetative growth parameters. The determination of irrigation optimum levels provides vegetative and sustainable production characteristics. The cultivation of bell pepper with daily irrigation interval in a condition of 50% shading is recommended with the application of 0.50 of ETc and in open field 0.75 of ETc.These levels are not affected by the vegetative parameters of the crop.

Conflict of Interest

The authors have not declared any conflict of interest.

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Modeling the apparent volume of bamboo culms from Brazilian plantation

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Brazil has a great potential for cultivation of bamboo species. However, there is a scarce research on the biometric relationships in such plants, which may represent a limitation for its management and use. This article aims to evaluate six methods for estimating the total apparent volume of two species of the genus *Bambusa*, namely: *B. oldhamii* Munro and *B. vulgaris* Schrad. Ex J.C. Wendl. The models tested to estimate the apparent volume of the culms were: (1) Form factor; (2) Hush simple entry volume model; (3) Schumacher-Hall double entry volume model; (4) 5th order polynomial taper function; (5) Taper function using a polynomial with flexible exponents, and (6) Four options of the Data Mining technique (models 6-9). We found that the model 5 provided the best fitting for *B. oldhamii* and model 3 was the most reliable for *B. vulgaris*. For both species combined model 5 provided best fitting. Model 4 was also considered satisfactory. We concluded that the model 5 is the most accurate, although models 3 and 4 also generate reliable estimates. The models 3, 4 and 5 may be used by people and companies that cultivate, sell and produce the bamboo species included in this research work.

Key words: Accuracy, bamboo, modeling, regression, taper function.

INTRODUCTION

The term bamboo designates the members of the taxonomic group of large woody grasses belonging to the family Poaceae, subfamily Bambusoideae. Its distribution is wide with occurrence in the tropics, subtropical regions and temperate zones of the world (Scurlock et al., 2000). There are approximately 1,200 species and 90 genera of bamboos in the world (Lobovikov et al., 2007).

Millions of people in the world depend economically on bamboo in some way (Lobovikov et al., 2007; INBAR, 1999). China is the country that holds the highest trade in bamboo products, of whom was formally exported approximately US$ 2 billion in 2010 for the entire world (INBAR, 2010). However, the trade in smaller scale, at local and regional level, is not computed entirely in statistics and involves much informality. There are no statistics on the production and trade of bamboo resources in Brazil.

On the other hand, Brazil has one of the largest reserves of native bamboo (Judziewicz et al., 1999) and

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a large potential for cultivation of indigenous and introduced species. However, the national report of Brazil to FAO (Food and Agriculture Organization of the United Nations), entitled FRA-2010 (FAO 2010), observes that there is no reliable information on the area of forests with bamboo in the country, but that exists around 9 million hectares in the southeast Amazon dominated by bamboos. Also it is included in the report, that there is a private planted bamboo area, with 30,000 ha of *B. vulgaris*, which provides raw material for a paper mill in the Northeast. The document mentions also a growing interest on bamboo, especially for industrial use, which is growing rapidly at the moment.

Management and conservation of this important natural resource should be based on reliable information. Although the amount of bamboo marketed worldwide is reported in 20 Mt.ano^{-1}, it is not clear if this amount represents the dry weight or (more likely) the weight newly harvested. Studies have shown that the moisture content of the culms varies considerably with the seasons and ages of plants, which means that the volume of the culms with the same weight can change according to the environmental conditions. For this reason, the quantification of bamboo resources should be expressed not only by weight unit, but also by volume (Inoue et al., 2011).

There is scarcity of mathematical models in the international literature for the quantification of stocks of the main species of bamboo. Also there is a great lack of biometric data on the bamboo species in Brazil and scarcity of basic models to estimate apparent volume of culms (that is, the total volume including empty part) or wood volume (that is, the volume of walls of the woody culms). Although the wood volume of bamboos has a major importance on estimating fiber and biomass production, as it represents the effectively useful parts of the plant, the apparent volume of the culms is an important variable for purposes of logistics from the field to the industrialization process, as it comprehends the real dimension of the culms.

Some of the few studies in the country include the work of Nascimento and Della Lucia (1994), which adjusted volume equations for *Dendrocalamus giganteus* Wall. Ex Munro. Recently, Martins et al. (2013) introduced the use of taper functions to estimate volume of culms of the genus *Bambusa*. This type of function is largely employed in the forest area to estimate timber volume (Machado et al*.,* 2004; Souza et al*.,* 2008; Fonweban et al*.,* 2010). These models are usually adjusted by ordinary linear regression. This assumes that the statistical constraints of homoscedasticity of variables, normality and independence of residuals must be satisfied.

New forms to model plants' stem volume that do not require the attendance of those assumptions, need to be sought, assuming that it is common to observe data series to which such constraints naturally are not attainable. Sanquetta et al. (2013a) proposed the technique of data mining to model the biomass of trees and the results were promising.

The purpose of this study was to examine some methods of modeling the apparent volume of culms of two major species of bamboo grown in the country. Particularly this paper aimed to evaluate more simple models with direct application of average form factor, regression models for volume and taper, and the technique of data mining.

MATERIALS AND METHODS

The present study was carried out at the Experimental Station of Canguiri, belonging to the Federal University of Parana, located in the municipality of Pinhais, on the First Parana Plateau, metropolitan region of Curitiba, Parana, Brazil, as shown in Figure 1. According to the classification of Köppen, the predominant climate is temperate or subtropical, humid mesothermal (Cfb), with severe winters and cool summer. The rain is present in all the seasons of the year (Ribeiro et al. 2008).

In February 2013 twenty four culms were cut, randomly selected in a planting experimental area deployed in December 2008, of which 12 were individuals of *B. vulgaris* species and 12 of the *B. oldhamii*. In the month of May 2014 the sampling was completed by measuring other 36 culms, 18 of each species, completing a total of 60, or 30 for each one.

Diameters and heights were measured along the culms at different sections of 0.5 m, with a slight displacement of the measurement in the sections, when deformities were detected. The diameters were taken with a caliper and heights (lengths) of the culms were measured with a tape. The actual apparent volumes (considering the hollow) of the culms were calculated by the formula of Smalian, considering the sections as small cylinders, except the last, which was calculated by the formula of a cone.

The models to estimate the total apparent volume of culms were the following:

1. Form Factor:

$$\hat{v} = \frac{\pi d^2}{40.000} h\, f \tag{1}$$

Where:

$$f = \frac{v}{v_c} = \text{form factor} \tag{2}$$

V = actual volumes of culms measured (m^3)

$$v_c = \text{volume of cylinder} = \frac{\pi d^2}{40.000} h \ (\text{m}^3) \tag{3}$$

d = *dbh* of the culms (cm), h = height/total length of the culms (m).

2. Volumetric model of simple entry of Husch logarithmic:

$$log(\hat{v}) = a + b.log(d) + e_i \tag{4}$$

Where: d , h and v = as defined previously; *a and b* =

Figure 1. Location of the experimental area in the municipality of Pinhais, PR.

coefficients to be adjusted; *log* = logarithm in base 10, and e_i = associated error.

3. Volumetric model of double entry of Schumacher-Hall:

$$\log(\hat{v}) = a + b\log(d) + c\log(h) + e_i \qquad (5)$$

Where: d, h and v = as defined previously, *a*, *b*, *c* = coefficients to be adjusted, *log* = logarithm in base 10, and e_i = associated error.

4. 5th order polynomial taper function:

$$\hat{v} = \frac{\pi}{40.000}\int_o^h y^2 dh \qquad (6)$$

$$y = a + b\frac{h_i}{h} + c\left(\frac{h_i}{h}\right)^2 + d\left(\frac{h_i}{h}\right)^3 + e\left(\frac{h_i}{h}\right)^4 + f\left(\frac{h_i}{h}\right)^5 + e_i \qquad (7)$$

Where: h_i = relative height of section of the culms in relation to h, *a, b*, *c*, d , e and *f* = coefficients to be adjusted, d, h and v = as defined previously, and e_i = associated error.

5. Taper function using a polynomial with flexible exponents:

$$\hat{v} = \frac{\pi}{40.000}\int_o^h y^{p^i} dh \qquad (8)$$

$$y = a + b\left(\frac{h_i}{h}\right)^{p_1} + c\left(\frac{h_i}{h}\right)^{p_2} + d\left(\frac{h_i}{h}\right)^{p_3} + \ldots + z\left(\frac{h_i}{h}\right)^{p_n} + e_i \qquad (9)$$

Where: *a* , *b*, *c*, *d* and *z* = coefficients to be adjusted, $p_1 \ldots p_n$ = powers to be adjusted, d, h, v and h_i = as defined previously, e_i = associated error.

Taper is a technical term used in forest environment to refer to the profile of the trunk of a tree and is defined as the rate of decrease in diameter along the trunk of the trees (Silva et al*.*, 2011). Also applies to culms of bamboos. By means of the integral of the taper function (Equations 6 and 8) the estimated apparent volume of the culms is obtained.

1. Data mining:

$$\hat{v} = \frac{\sum_{i=1}^{m} v_i . p(d,q)_i}{\sum_{i=1}^{m} p(d,q)_i} \qquad (10)$$

Where: v_i = actual volume of culms of nearest neighbors (m³);

p(d,q) = weighting, that can be = $\frac{1}{d(p,q)}$ or $\frac{1}{d(p,q)^2}$ which gives better result, and *m* = number of nearest neighbors, defined by Euclidean distance:

$$d(p,q) = \sqrt{(X1_p - X1_q)^2 + (X2_p - X2_q)^2} \qquad (11)$$

Where: *d(p,q)* = Euclidean distance; X_1 *and* X_2 = independent variables (in this study: *dap* and *h*, respectively), and (p, q) = any combination of two specific values of the variables X_1 and X_2. For this study, the number of nearest neighbors considered was 3 and 5.

The data mining technique (DM) has as objective the discovery of useful information in a data set (Tan, 2009). This technique, used in learning algorithms, whose metrics can be found in detail in Aha (1991) and Bradzil (2003), is already widespread in several areas and applications. However, its potential has been little explored for modeling of forest resources.

The method uses a technique known as cross-validation, in which each instance is compared to the rest of the sample, and selected one with smaller distance. Its estimated volume will be that of the instance whose distance had the lowest value. We have used two variations of the technique with 3 and 5 nearest neighbors, with weighting (1/d) and (1/d^2). In this case, the 3 (or 5) trees nearest to a chosen tree were considered and, to give the volume of trees by distance order, the weighting was calculated using the inverse of the distance. Similar to nearest neighbor, once having a tree to estimate the volume, the distance between the vector formed by their dimensions of dbh and height up to all the trees of the sample

Table 1. Criteria for model selection.

	Criterion	Formulation	
1	Coefficient of determination adjusted	$R^2{}_{adj.} = 1 - \frac{(n-1)}{(n-k)}(1-R^2)$ where	(12)
		$R^2 = 1 - \frac{\sum_{i-1}^{n} e_i{}^2}{\sum_{i-1}^{n}(v_i - \bar{v})^2}$	(13)
2	Standard error of estimate	$Syx = \sqrt{\frac{\sum_{i-1}^{n} e_i{}^2}{n-k}}$	(14)
	Akaike Information Criterion (Akaike, 1973) Or	$AIC = -2\left(\frac{-n}{2} ln\left(\frac{1}{n}\sum_{i-1}^{n} e_i{}^2\right)\right) + 2k$	(15)
3	Akaike Information Criterion not biased for small samples * , used when $\frac{n}{k} < 40$	$AIC_c = -2\left(\frac{-n}{2} ln\left(\frac{1}{n}\sum_{i-1}^{n} e_i{}^2\right)\right) + 2k\frac{n}{(n-k-1)}$	(16)
4	Baysian Information Criterion or Schwarz Criterion (Schwarz, 1978)	$BIC = -2\left(\frac{-n}{2} ln\left(\frac{1}{n}\sum_{i-1}^{n} e_i{}^2\right)\right) + ln(n)k$	(17)
5	Willmott Concordance Index (1985)	$dW = 1 - \frac{\sum_{i-1}^{n}(v_i - \hat{v}_i)^2}{\sum_{i-1}^{n}(\lvert\hat{v}_i - \bar{v}\rvert + \lvert v_i - \bar{v}\rvert)^2}$	(18)
6	Analysis of residuals	$e_i = (v_i - \hat{v}_i)$	(19)

Source: Burnham and Anderson (2002). Where: n = number of observations; k = number of parameters of the model. $\hat{v}_i$ = Estimated volume v_i = Actual volume. $\bar{v}$ = = Average of observed volume. In AIC, AICc and BIC, the value of *k* must be increased by 1, which refers to one degree of freedom for the variance.

must be calculated. The unknown volume will be the result of this weighting.

The adjustments were made for each species separately and for the two sets of clustered data (considering genus). It was used regression by ordinary least squares for methods 2, 3 and 4, and the stepwise method to the adjustment of regression for model 5, whereas variations in powers up to the minimization of the sum of the squares of residuals was used to assess the significance of the coefficients of the regression models. Statistical programs were used for those adjustments. A computer program was specifically built for the method 6.

The models of estimation were evaluated by five general criteria of goodness of fit and by graphical analysis of residuals (Table 1).

RESULTS AND DISCUSSION

The culms of bamboos here analyzed reached approximately 4 cm dbh and height of 7 m on average for the considered ages. The size of the culms of *B. vulgaris* was larger than those of *B. oldhamii* in terms of diameter and height, but not in volume, because the second has presented smaller form factor than the first

Table 2. Biometric variables of bamboo culms with 50 to 64 months in Pinhais, PR, Brazil.

Statistics	Variable	*B. oldhamii*	*B. vulgaris*	Both
Average	*d* (cm)	4.16±1.43	4.26±1.74	4.21±1.58
±	*h* (m)	6.82±2.55	7.39±3.25	7.10±2.90
Standard deviation	*v* (m^3)	0,008461±0.006792	0.008417±0.009489	0.0084390.008181 ±
n		30	30	60

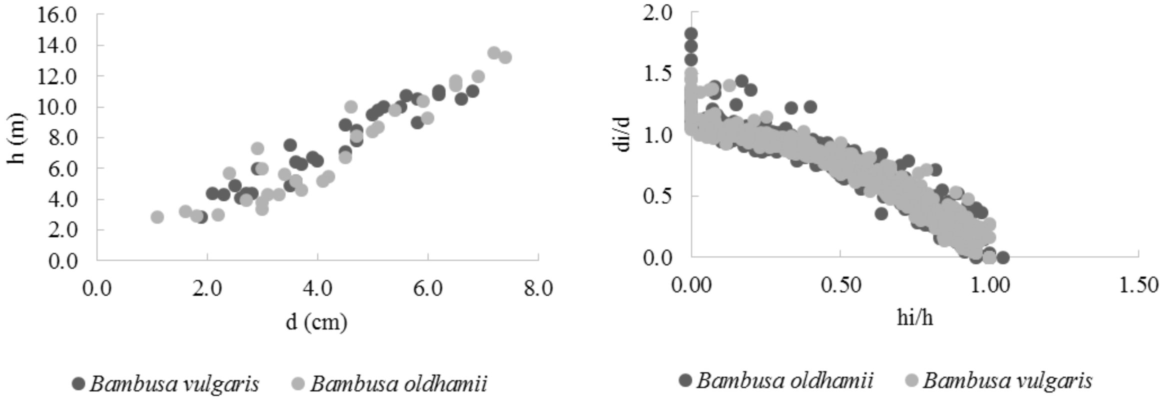

Figure 2. Hypsometric relation (a) and profile of the form of bamboo culms (b) with 50 to 64 months of age, in Pinhais, PR, Brazil.

one (Table 2).

There was no difference in terms of hypsometric relationship (height-diameter) between the species (Figure 2a), indicating that the degree of slenderness for both species is almost the same, that is, the relationship between the growth in diameter and height of them is similar.

The ratio *h*/*d* was 1.65 and 1.75, for *B. oldhamii* and *B. vulgaris*, respectively. These values are higher than those observed in tree species in the study area (Sanquetta et al*.,* 2013b). The decrease in the degree of slenderness with the height increase means that, to every meter that the plants grow in height, they increase more than one centimeter in dbh, becoming more robust and stable (Selle and Vuaden, 2010). The authors have studied the behavior of tree species. It is appropriate to stress that the behavior in terms of static stability is distinct between trees and bamboos, being these proportionally thinner and higher. This justifies the use of bamboo as structural parts in construction, particularly in Asia.

The profiles of the culms of the two species, on the other hand, are very similar, indicating that their taper forms are not distinct from one to another, despite the difference in diameter and height (Figure 2b).

This fact is also confirmed by the values of the artificial form factor of the two species, which are close numerically, with a value slightly higher in *B. oldhamii*, indicating less taper in comparison to *B. vulgaris* (Table 3). Therefore, in theory, the data of the two species could be treated in an aggregated form, without considering the species separately.

Culm analyzes are not only interesting from the point of view of plant architecture, but are also relevant for estimating the volume of the culms (Inoue et al*.,* 2011, 2012). As bamboo culms are usually hollow, not only the wood volume has to be analyzed, but also the apparent volume along the culm profile. There are few reports in the literature that describe the profile of culms of bamboos. Inoue and Suga (2009) studied the relationship between the surface of the culms, and other dimensions of them. Inoue (2013) has made a detailed analysis of the form of the culms of *Phyllostachys pubescens* Mazel ex J. Houz. in Japan. The analysis indicated, for the studied species, that the stem consists of three or four segments with multiple forms. Also he showed that the hypsometric relationship can be expressed by an equation of the straight line in log-log scale. Interpreting the data of the author, it can be assumed that the ratio *h*/*d* exceeds the value of 1, considering the general amplitude of diameters and heights, which coincides with the results of this study. Similar results regarding the hypsometric relations can also be inferred from the work of Yen and Lee (2011).

All the coefficients of the adjusted equations, according to the models 1 to 5, were significant ($p < 0.05$), except for coefficient "*f*" of the 5th degree polynomial model (Table 3).

Table 3. Coefficients for different methods of estimation of the apparent volume of bamboo culms with 50 to 64 months of age, in Pinhais, PR, Brazil.

Method	Coefficient	*B. oldhamii*	*B. vulgaris*	Both
1	*f* *	0.6431±0.1646	0.6333±0.0890	0.6382±0.1313
2	*a*	-0.003530	-0.002416	-0.003091
	b	0.000593	0.000538	0.000572
3	*a*	-9.590919	-9.683586	-9.629054
	b	1.586756	1.617251	1.591686
	c	1.123892	1.158956	1.145398
4	*a*	1.253268	1.196220	1.214942
	b	-2.920443	-2.098875	-2.360642
	c	12.440347	8.015261	9.396430
	d	-26.882310	-17.232041	-20.187235
	e	24.227519	14.968994	17.783044
	f	-8.098925	-4.814283 **	-5.818184
5	*a*	1.267810	1.210710	1.238150
	b	-0.234264	-0.203355	-0.225170
	c	-1.010920	- 0.978992	-0.985848
	p_1	0.060000	0.100000	0.100000
	p_2	2.000000	2.000000	2.000000

*Mean ± standard deviation; ** $p = 0.0573$. For all other coefficients $p < 0.05$.

High values of $R^2aj.$ and *dW* with the data of *B. oldhamii* suggest that the models presented good adjustment (Table 4). However, when examining the values of *Syx* and *Syx%* we realize that not all models fitted well, with relative errors reaching values higher than 20% in some cases. The lowest values of *Syx%* were obtained with the model 5, which also showed the highest values for $R^2aj.$ and *dW*, and lowest for *AIC* and *BIC.* The models 3 and 4 have approached the model 5 in terms of performance, but the distribution of residuals proved to be more balanced as the application of the model 5 (Figure 3a, b and c). The model 5 was selected as the best.

Adjustments for *B. vulgaris* presented better performance than those for *B. oldhamii* for all tested models, considering the majority of the statistics indicating goodness of fit. This occurred due to lower dispersion of data and higher simple linear correlation between diameters and height of the culms with the volumes (0.92 and 0.93, respectively for *d-v* and *h-v* in *B. oldhamii* and 0.94 and 0.96 for *B. vulgaris). Syx%* reached maximum values around 15% for the adjustments of *B. vulgaris*. The model 3 presented the best performance in terms of goodness of fit, following closely by models 4 and 5. The graphical distribution of residuals indicates that the models 3 and 4 have presented more balanced dispersions along the estimated line (Figure 3d, e and f). In general, the model 3 can be selected as the best.

Considering the grouped data for the two species, the adjustments lost accuracy, driven by higher dispersion of data and a lower correlation between the dependent and independent variables. The model 5 present the best goodness of fit, followed by 4, with graphical distribution of residuals very similar (Figure 3 g, h and i). The model 5, in general, was selected because of its best performance.

All the estimates with the use of model 1 have presented skewness, despite their general indicators, even though, apparently, they suggest satisfactory adjustments. This fact can only be detected by graphical analysis of residuals (Figure 4a). This is due to the fact that the form factor is not constant for diameter, height, or volume of the culms, on the contrary, tends to form a curving downward, that is, the smaller plants present form factors higher than the taller ones. The adjustment of the model 2 also resulted in residuals distributed in an unacceptable way. The distribution of residuals resulted in a “U” shape (Figure 4b) suggesting that the relationship between the dependent and independent variable follows a quadratic trend, non-linear, a fact confirmed by the data of both species. Both models should be rejected for estimation of apparent volume of culms of *B. oldhamii* and *B. vulgaris*.

Models 3, 4 and 5 could be indicated for application in practice, due to their goodness of fit. However, in general, the model 5 was the one that presented better performance. The taper function using a polynomial with

Table 4. Statistics of fit of different models for estimating apparent volume of bamboo culms, with 50 to 64 months of age, in Pinhais, PR, Brazil.

Kind	Model	$R^2aj.$	*Syx*	*Syx%*	*AIC*	*BIC*	*dW*
B. oldhamii	1	0.9750	0.0015	17.72	-389,04	-387,78	0.9943
	2	0.9399	0.0023	27.50	-358,94	-355,66	0.9918
	3	0.9787	0.0014	16.08	-395,92	-384,46	0.9945
	4	0.9866	0.0010	12.01	-396,46	-391,75	0.9973
	5	0.9902	0.0009	10.51	-407,94	-403,18	0.9979
	6	0.9641	0.0018	21.65	-378,08	-376,83	0.9902
	7	0.9710	0.0016	19.44	-384,53	-383,27	0.9925
	8	0.9519	0.0021	25.05	-369,32	-368,06	0.9863
	9	0.9713	0.0016	19.36	-384,78	-383,52	0.9925
B. vulgaris	1	0.9705	0.0012	13.84	-404,15	-402,90	0.9934
	2	0.9660	0.0012	13.78	-400,73	-397,45	0.9973
	3	0.9920	0.0006	7.07	-438,03	-434,02	0.9981
	4	0.9885	0.0007	8.00	-421,21	-416,49	0.9977
	5	0.9902	0.0006	7.51	-428,10	-423,34	0.9979
	6	0.9650	0.0013	15.36	-398,99	-397,73	0.9909
	7	0.9650	0.0013	15.36	-398,99	-397,73	0.9909
	8	0.9640	0.0013	15.59	-399,10	-396,84	0.9905
	9	0.9661	0.0013	15.13	-399,89	-398,63	0.9910
Both	1	0.9767	0.0013	14.81	-801,14	-799,81	0.9947
	2	0.9492	0.0026	31.46	-751,07	-747,29	0.9760
	3	0.9865	0.0014	16.10	-829,17	-824,29	0.9980
	4	0.9912	0.0011	12.75	-849,68	-842,02	0.9980
	5	0.9911	0.0010	12.34	-856,17	-849,34	0.9981
	6	0.9887	0.0017	19.93	-810,19	-808,16	0.9971
	7	0.9904	0.0015	18.40	-819,80	-817,77	0.9975
	8	0.9045	0.0020	23.32	-791,37	-789,35	0.9959
	9	0.9899	0.0016	18.88	-816,69	-814,66	0.9974

changeable exponents of Hradetzky (1976) is powerful, because it is an extremely flexible polynomial and assumes a variety of different shapes. This model has often been selected as the best to describe the bole profile of different tree species in Brazil (Silva et al., 2011; Teo et al., 2013; Kohler et al., 2013).

DM models (6 to 9) have not adjusted well in this study, with indicators of worst quality in comparison to models 3, 4 and 5. Their residuals also have not presented a balanced distribution, showing a trend of heteroscedasticity and greater dispersion. They could not be used accurately in the estimates for *B. vulgaris*. Its application would be recommended only if the assumptions for using linear regression have not been attained, but this was not the case in this study. Such results using DM were not satisfactory due to the low number of individuals in the sample. As the method uses the information of nearest neighbors, its efficiency improves when we have a larger sample size.

Models for estimating the shape and volume of tree species are widespread in the literature and have great practical application for different purposes in forest science. In Brazil these work are extremely limited. There is more research directed to estimate biomass and productivity (Bonilla, 1991; Mendes, 2005; Silva, 2008; Dallagnol et al., 2013). Even in international context, works on modeling are quite restricted. The amount of research is much greater on the use of bamboo than on its management.

Studies of greater prominence in this field are those of Japanese researchers, who developed scientific works related to different species of the genus *Phyllostachys* (Watanabe et al., 1980, 1989; Inoue et al., 2011, 2012). Suga et al. (2011) developed the theory and applications in estimating volume of *P. pubescens* in Japan. The equation for volume was obtained from the assumptions that the culm forms could be expressed by Kunze's equation and the form factors in two different heights of the culms are stable regardless of their size and, because of this, they have proposed the so called: The bidirectional volume equation. Equations for length and volume of culms for *Guadua angustifolia* were adjusted

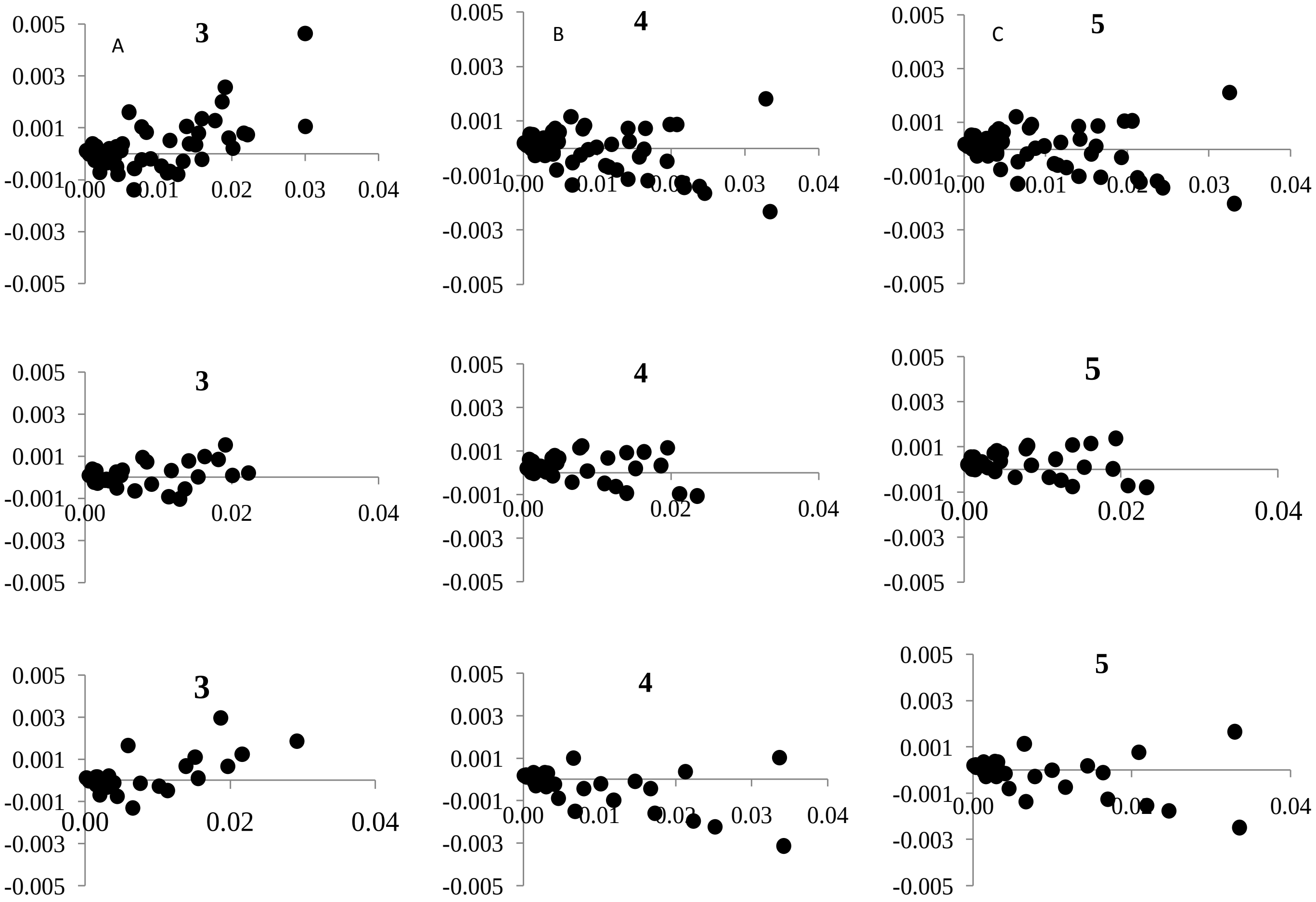

Figure 3. Graphical distribution of residuals of models 3, 4 and 5 applied to data of apparent volume of culms of *B. oldhamii* (a, b, c) and *B. vulgaris* (d, e, f) and for both species (g, h, i), in Pinhais, PR, Brazil.

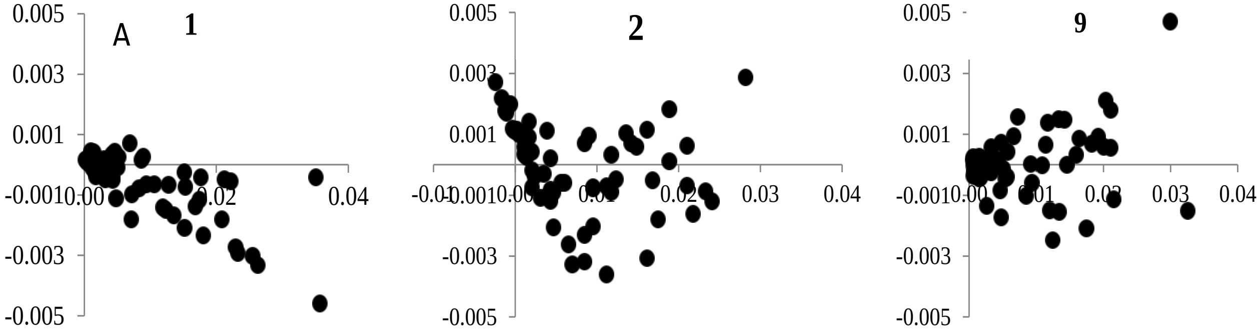

Figure 4. Graphical distribution of residuals of models 1, 2 and 9 applied to overall data of apparent volume of culms for both species (*B. oldhamii* and *B. vulgaris*), in Pinhais, PR, Brazil.

in coffee-growing region of Colombia (Garcia and Klein, 2010). They have concluded that regression models commonly used in forest inventory were adequate for estimation of the variables of their study. In Brazil, Nascimento and Della Lucia (1994) have tested models for volume and weight on *D. giganteus*, one of the few studies devoted to this subject in the country. Analyzing the data of 14 culms, the authors have concluded that, for this particular case, the model $\log(v)=\beta_0+\beta_1\log(d^2h)+e_i$ presented the best performance.

Spolidoro (2008) found that the model $\log(v)=\beta_0+\beta_1\log(d)+e_i$ expresses adequately the relationship between the volume of the culms of *B. vulgaris* and *Bambusa tuldoides* Munro. The author made his conclusion based on the analysis of 12 culms of the two mentioned species.

There are no comparative studies between different methodological approaches to estimate volume of bamboo culms, even in the countries of the East, which have the greatest tradition in the management and use of bamboos.

In this study it was found that the model 5 has more predictive quality. However, mathematically, is the most complex, it is not possible to estimate the coefficients and the exponents of the taper model by ordinary linear regression, which demands using the stepwise method with attempts for different power variations. In the same way, it is necessary to integrate mathematically the taper function in order to calculate the volume. This procedure is still more complex, requiring specific software, because the resulting mathematical operation is not obvious. The model 4 presents mathematical properties similar to model 5. The unique feature of this model in relation to its competitor is that the coefficients can be obtained by ordinary linear regression. The integration of the 5th order polynomial taper function is also a little simpler.

Models 1 and 3 are the simplest among all tested, but they have not adjusted well to the data of the present study and, when of its application, they have generated inconsistent estimates. The model 3 is relatively simpler when compared to model 5, since after obtaining the coefficients a, b and c, one needs just enter dbh and height of the culms in the equation to get the apparent volume. The coefficients, in this case, are easily obtained by linear regression solved by the least squares method.

The DM models showed poor goodness of fit to data of this study. Only 4 DM models were tested. Possibly other models with different distances, weights and number of nearest neighbors could get more interesting results. This is a lesser-known technique for estimation of volume of stems or culms of plants, but may be more applied only when the assumptions for the application of the regression method are not met.

Conclusions

Of the nine models for estimation of apparent volume of culms of bamboo of the two studied species, three may be considered satisfactory: Schumacher-Hall double entry volume model (3); 5th order polynomial taper function (4); and Taper function using a polynomial with flexible exponents (5), being the last model with the best predictive quality;

The model 5 is more complex mathematically, which could represent an obstacle to its use in practice. However, with the statistical, mathematical and computational resources currently available, their application is fully viable, generating reliable estimates of total apparent volumes of culms of *B. oldhamii* and *B. vulgaris*, besides the possibility of calculating partial volumes in different lengths and diameters. The model 3 can be a simpler alternative, representing more appropriate compromise between simplicity and accuracy, because it only requires the obtainment of three coefficients by ordinary linear regression method. However, it is appropriate only to estimate the total apparent volume. The models 3, 4 and 5 may be used by people and companies that cultivate, sell and produce the bamboo species included in this research work.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Growth, productivity and fatty acid composition of oils of peanut genotypes submitted to different levels of water replacement

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The aim of this study was to evaluate the agronomics, physiological and biochemical characteristics of different peanut seeds and plant genotypes. The procedures have been performed during the secondary crop in the agricultural year 2013 to 2014, after the peanut harvest in Barbalha, Ceará – Brazil. The experiment was laid out in split-plot in randomized complete block design with four replicates, constituting scheme 4×5 factorial analysis, providing four levels of replacement of ET0 (40, 70, 100 and 130%) and five genotypes of peanut (BRS Perola Branca, L7 Beje, Runner, BRS Havana, BR 1), which were measured: number of leaves, total phytomass, and total chlorophyll content was performed, as well as hundred-seeds weight, pods weight per plant, number of pods per plant and seed yield per plant oil yield and fatty acid composition. It is shown herein that the interaction between peanut genotypes and water restriction levels promote a decrease in plant growth, physiological factors, and biochemical production of oil, possibly due to a decrease in the photosynthetic metabolism, whereas the plants exposed to water stress conditions modulated all ecophysiological responses in favor of a better performance in the harsh environment. The significant differences exhibited by different cultivars in this study for oil content, some productive characteristics and fatty acids compositions could be attributed to the genetic make-up of a particular cultivar (BR 1), its place of the environmental to reach high oil quality. Knowing better combination effects of climatic fluctuations and botanical types on fatty acid composition would be useful in designing management practices to obtain a specific oil quality and improving predictions of crop models in northeastern Brazil.

Key words: *Arachis hypogaea* L., water deficiency, adaptability, tolerance.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is grown in many arid and semi-arid regions of Brazil and, therefore, needs to

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be irrigated for economical yield. However, the vegetative preflowering growth stage and the late stage of pod maturation have been shown to be non responsive to water stress (Gohari and Bazkiyaei, 2012).

Peanut is tolerant to water stress conditions but drought conditions have adverse effects on the pod yield and seed quality (Nageswara Rao et al., 1989; Sulc and Franzluebbers, 2014). The effect of drought on the chemical composition of the Peanut seeds has been reported to be limited in the mid-season drought but significant in end-season drought (Sun et al., 2014).

Furthermore, increased worldwide demand for water due to rapid population growth and non sustainable irrigation practices have resulted aquifer depreciation, limiting the availability of water for irrigation. To meet future food supply demands, crop production has to be increased, but it must do so under the constraints of less water and, most likely, less farm land. EMBRAPA - National Center for Research on Cotton, Campina Grande-PB, Brazil, and The State University of Paraíba are working in cooperators to help peanut farmers to maintain and improve production in a water-limited changing environment.

Drought-stressed plants lose moisture from pods which lead to the reduction in the seeds physiological activity, thereby increasing the susceptibility to fungal invasion. Besides affecting food quality, drought stress is also known to alter nutritional quality of peanut seed proteins (Holbrook et al., 2000).

Peanut is cultivated in different regions of the world, under diverse climate conditions and in Brazil it grows primarily under rain fed conditions in the northeastern region (Santos et al., 2006). EMBRAPA - National Center for Research on Cotton has been conducting research on peanut cultivars BR 1, BRS 151 L-7 and BRS Havana, among others (Santos et al., 2006). Faced with scarcity of water resources, drought is the single most critical threat to world food security. It was the catalyst of great famines in the past. Because the world's water supply is limiting, future food demand for rapidly increasing population pressures is likely to further aggravate the effects of drought (Somerville and Briscoe, 2001). The severity of drought is unpredictable as it depends on many factors such as occurrence and distribution of rainfall, evaporative demands and moisture storing capacity of soils (Wery et al., 1994).

Reddy et al. (2003) observed the application of the different irrigation rates amounts has induced different responses on the protein content of the seeds; the plants with adequate water irrigation not only give more kernels, but also higher levels of total proteins and oil content. The major fatty acid components of peanut oil are oleic, linoleic, palmitic and stearic acids, but others are found in different proportions: 0.13 to 0.33% myristic, 8.70 to 13.03% palmitic, 0.23 to 0.47% palmitoleic, 3.77 to 4.53% stearic, 43.13 to 55.10% oleic, 25.13 to 35.20% linoleic, 0.20 to 0.30% linolenic, 1.53 to 1.93% arachidic, 0.40 to 1.37% gadoleic and 2.40 to 3.47% behenic acids (Özcan and Seven, 2003).

The objective of the present study was to determine the effect of differentiated irrigation on the agronomic performance, productivity and fatty acid composition of peanut oils of several genotypes subjected under drought stress conditions.

MATERIALS AND METHODS

Field experimentation

This experiment was conducted in Barbalha-CE where is the Northeast area of Brazil with an altitude of 414 m above sea level and average temperature of 25.2°C. Annual precipitation varies from 1001.4 to 1054.1 mm distributed into two distinct rain seasons. Weather data were obtained from the meteorological office in Barbalha-CE. Five genotypes of peanut (BRS Perola Branca, L7 Beje, Runner, BRS Havana, BR 1) were grown under four irrigation levels L1, L2, L3 and L4. The value of accumulated total evaporation four different levels (L1=40%, L2=70%, L3=100%, and L4=130%) were measured using Class A Pan evaporation containers during 130 days after plant emergence. The experiment was conducted in the trial area of EMBRAPA - National Center for Research on Cotton. The experiment was laid out in split-plot in randomized complete block design with four replications on the entisol soil with an initial characterization of soil fertility are presented for the respective soil depths of 0.00 to 0.20 and 0.20 to 0.40 m as follows: OM (12.3; 8 mg dm^{-3}), pH (7.65; 7.8), lime content of 8.67%, P (8; 3 mg dm^{-3}); K (0.2; 0.1 mmol$_c$ dm^{-3}); Ca (1; 0 mmol$_c$ dm^{-3}), Mg (1; 0 mmol$_c$ dm^{-3}), H+Al (28; 23 mmol$_c$ dm^{-3}), Al (0; 6 mmol$_c$ dm^{-3}), BS (19; 9 mmol$_c$ dm^{-3}), CEC (47; 32 mmol$_c$ dm^{-3}), V (40; 28%), and m (32; 42%). In initial characterization of physical properties, we verify that soil resistance to penetration at the depths of 0.00 to 0.10, 0.10 to 0.20, 0.20 to 0.30, and 0.30 to 0.40 m were 1.054, 1.445, 1.558, and 1.513 MPa and soil moisture at those depths were 0.035, 0.030, 0.030, and 0.040 kg kg^{-1}, respectively. Sowing was performed on irrigated seedbeds. Plot area was 2.8 × 7.0 m. The seeds were sown by using sewing machine at a spacing of 0.38 m distance between seeds and 0.70 m distance between the rows (Figure 1).

Variables measured

At the 130th days after sowing (DAS), plants were collected to determine the initial growth characteristics: number of leaves, total phytomass (g plant^{-1}) and total chlorophyll content (mg g^{-1} FW). The harvest was performed taking five random plants from the center line of each treatment, in each block. The plants were separated by treatment and placed in screened greenhouse for three days in order to dry the pods. The productive components evaluated in this study was 100-seeds weight (g), pods weight per plant (g), number of pods per plant, seed yield per plant (g), oil content and fatty acid composition.

Chlorophyll determination

Extraction and determination of chlorophyll were performed according to the method of Arnon (1949). Five hundred milligrams of fresh leaf material was ground with 10 ml of 80% acetone at 4°C and centrifuged at 2500 rpm for 10 min at 4°C. This procedure was repeated until the residue became colorless. The extract was transferred to a graduated tube and made up to 10 ml with 80%

Figure 1. Peanut plots with different applications levels of water replacement.

acetone and assayed immediately. Three milliliters aliquots of the extract were transferred to a cuvette and the absorbance was read at 645 nm with a spectrophotometer (UV-1800 UV-VIS - SHIMADZU) using 80% acetone as blank. Chlorophyll content was expressed in mg g^{-1} fresh weight (FW) using the formula: (mg ml^{-1}) = (0.0202) × (A.645) + (0.00802) × (A.663).

Oil content

Oil content was determined using a commercial nuclear magnetic resonance spectrometer as described by Jambunathan et al. (1985). All readings were taken on oven-dried (110°C, 16 h) samples and the values were expressed on a uniform 5% seed moisture content basis.

1H NMR Spectra

1H NMR spectra were recorded on a Bruker AMX500 spectrometer operating at 500 MHz for the proton nucleus at room temperature. The phosphitylated oil samples used in 31P NMR experiments were used to obtain 1H NMR spectra with the following acquisition parameters: time domain, 32K; 90° pulse width, 9.3 µs; spectral width, 12 ppm; relaxation delay, 2 s. Sixteen scans and four dummy scans were accumulated for each free induction decay. Baseline correction was performed carefully by applying a polynomial fourth order function in order to achieve a quantitative evaluation of all signals of interest. The spectra were acquired without spinning the NMR tube in order to avoid artificial signals, such as spinning sidebands of the first or higher order.

Preparation of fatty acid methyl esters (FAMEs) and gas chromatography

Seed samples were taken for total fatty acid analyses. Total fatty acid content was analyzed by using a method modified by Wu et al. (1994). In this method seed samples were soaked in 2 ml of 2% sulphuric acid in dry methanol for 16 h at room temperature, followed by 80 min of heating at 90 °C to convert the fatty acids into methyl derivatives (FAMEs). Methyl-heptadecanoate (17:0-ME) was added as an internal standard. The FAMEs were extracted in 2 ml water and 3 ml hexane and then determined by gas liquid chromatography (GLC). The fatty acid methyl ester composition was analyzed by using a Varian 3400 gas chromotography equipped with a Supelcovax-10 fused slica capillary column (30 m × 0.25 µm film thickness). The column's initial temperature was kept at 160°C for 15 min so that in this temperature an increase could be occurred at the rate of 5°C min^{-1}. The temperatures of the injector and the detector (FID) were 240 and 280°C, respectively. The carrier gas was nitrogen with a flow rate of 1 to 2 ml min^{-1}. Split ratio was adjusted to 30 ml min^{-1}. The injected volume of the sample was 1 µl. Fatty acids were identified by retention time relative to that of an internal standard. FAMEs were identified by comparing the retention times with those of the standards. Fatty acid content was computed as weight percentage of the total fatty acids by using the GC area counts for various FAMEs.

Statistical analysis

Statistical evaluation was carried out by using Sigma Plot 11.0. An analysis of variance was performed on the data, and means were separated using Tukey's multiple comparison procedure (probability of 5%).

RESULTS AND DISCUSSION

According to the analysis of variance (data not shown), the irrigation levels × genotypes interaction effects were significant ($P<0.01$) for all characters. The effect of irrigation levels and genotypes was also significant ($P<0.01$) for all characters.

The number of leaves of all peanut genotypes significantly was decreased with increasing water deficit levels (Figure 2).

BR 1 showed significantly higher number of leaves values than the other genotypes at different levels of water. BR 1, BRS Havana and L7 Bege showed significantly higher leaves number than BRS Perola Branca and Runner in irrigation level L2, except for the L1 treatment. Non-significant differences were observed in number of leaves of L7 Bege, BRS Havana and BR 1 for all irrigation treatments (L2, L3 and L4). In water treatment L1, genotype BR 1 showed higher leaves number compared to the other genotypes. Water deficit induces several physiological and biochemical changes in plants depending on intensity and duration of stress (Pattangual and Madore, 1999). General effect of water

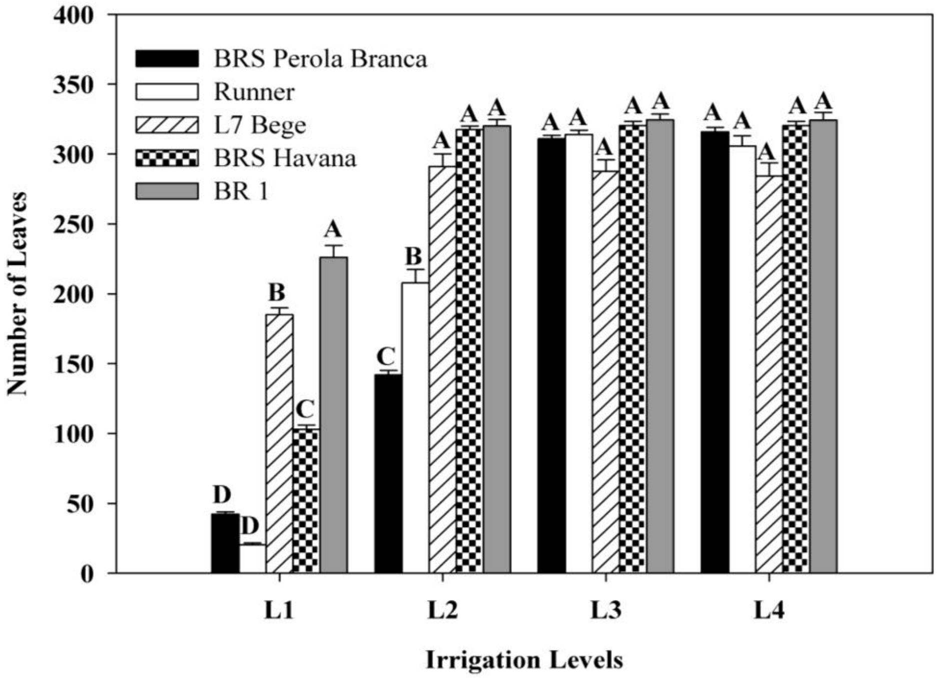

Figure 2. Number of leaves of 5 genotypes in 4 levels of water replacement. Bars represent the standard error (n=4). Different letters indicate statistical difference (Tukey´s test, P<0.05). Higher case letters were used to compare the genotypes at each level of water restriction.

stress in plants is manifested in terms of osmotic stress which results in lower leaf water potential, turgor potential and stomatal conductance (Dzotsi et al., 2015). This study demonstrated that water stress led to differential responses in peanut genotypes. The reduction in the number of leaves is presumably a response to the decrease in leaf water content and changes in membrane stability under water stress (Chakraborty et al., 2015).

Plant weight of all genotypes was decreased significantly by applying different water stress levels as compared to control treatment (Figure 3). At L1, BR 1 showed significantly plant weight than the other peanut genotypes.

At L1 and L2, BRS Perola Branca, Runner, L7 Bege and BRS Havana showed low plant weight, whereas BR 1 showed significantly highest plant weight. It is reported that a positive association is observed between total phytomass accumulation and pod yield under moisture stress conditions (Reddy et al., 2003). Total phytomass accumulation of peanut was reduced due to stress (Richards et al., 2014). Sulc and Franzluebbers (2014) reported a decrease in total phytomass production due to drought in peanut. Reddy et al. (2003) reported that there was a close relationship between total phytomass production and transpiration with an average production of 3.0 mg total phytomass g^{-1} water. They also noted that the amount of total phytomass accumulated by a crop was closely related to the water transpired. Reddy et al. (2003) reported that there was no recovery of total phytomass in peanut when stress was imposed at of the beginning of emergence, while recovery of total phytomass was found when stress was imposed from emergence to the begining of flowering and from emergence to start of pegging.

The total chlorophyll content of all peanut genotypes was decreased significantly with increasing water deficit levels as compared to control treatment (Figure 4). At L1, BR 1 showed significantly higher total chlorophyll content than the other genotypes.

At L1 and L2, phenotype L7 Bege showed significantly higher chlorophyll content compared to the other genotypes, except for BRS Havana and BR 1 in L2. Non-significant differences were observed in total chlorophyll content of BRS Perola Branca and Runner. In the present study, the total chlorophyll content of the leaves was decreased in most peanut cultivars when exposed to drought stress. Water deficit degrades chlorophyll and impairs its biosynthesis as well (Reddy et al., 2003), which was reported by other researchers in many crops, including peanut (Chakraborty et al., 2015). The ability to maintain a stable content of chlorophyll under water deficit conditions is a good measure of the peanut genotypes capability to cope with drought stress during initial stages of growth (Arunyanark et al., 2008). Here, the tolerant cultivar BR 1 showed higher adaptation to maintain stable contents of chlorophyll at final growth stage indicating more tolerance to water stress conditions.

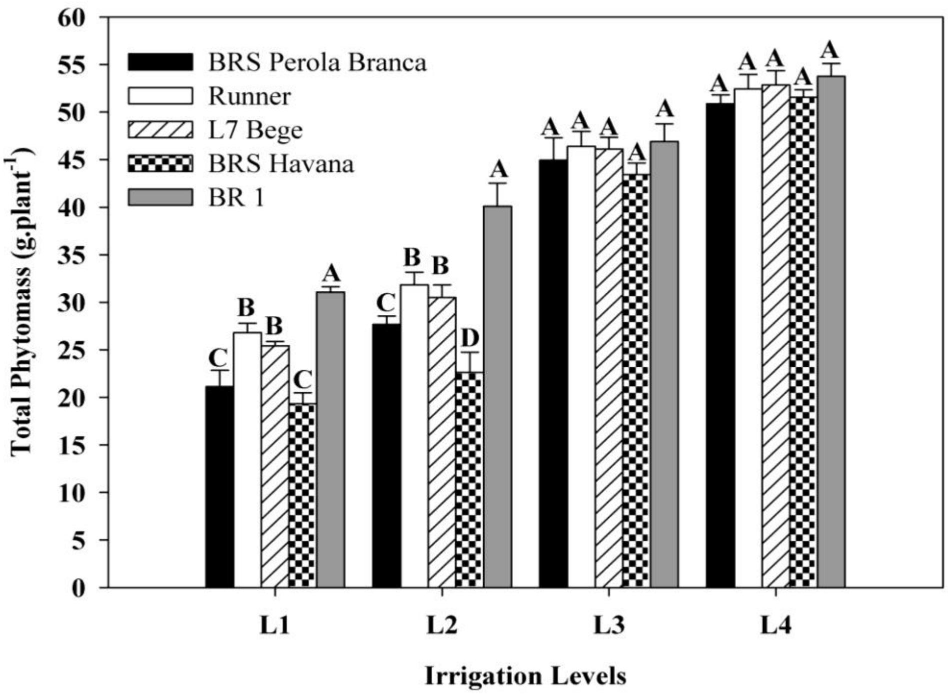

Figure 3. Total phytomass of 5 genotypes in 4 levels of water replacement. Bars represent the standard error (n=4). Different letters indicate statistical difference (Tukey´s test, P<0.05). Higher case letters were used to compare the genotypes at each level of water restriction.

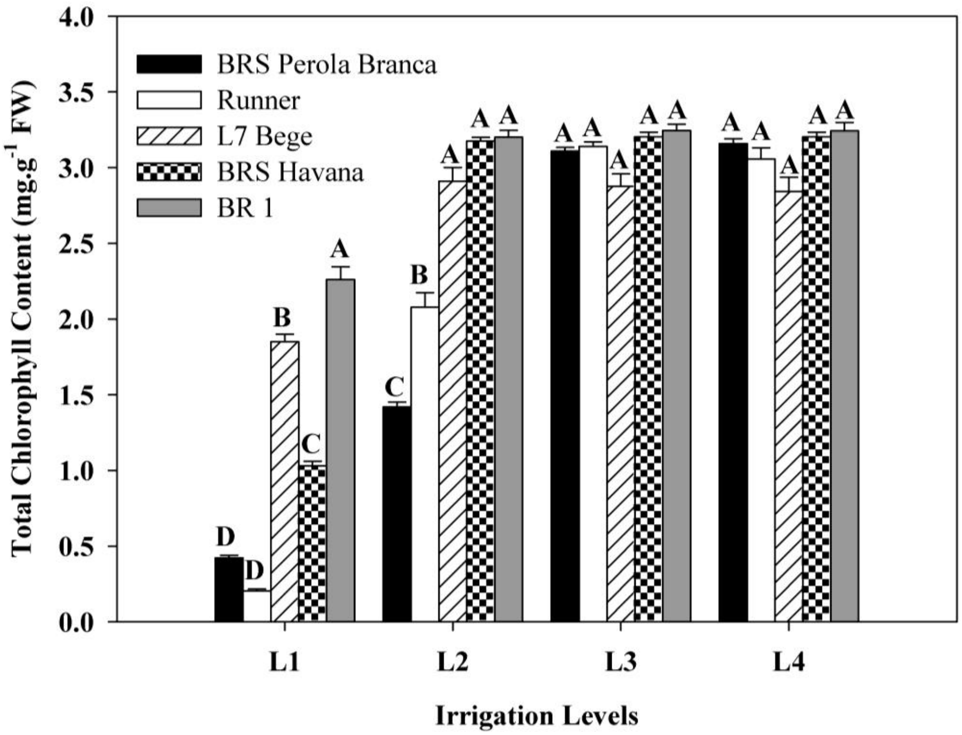

Figure 4. Total chlorophyll content of 5 genotypes in 4 levels of water replacement. Bars represent the standard error (n=4). Different letters indicate statistical difference (Tukey´s test, P<0.05). Higher case letters were used to compare the genotypes at each level of water restriction.

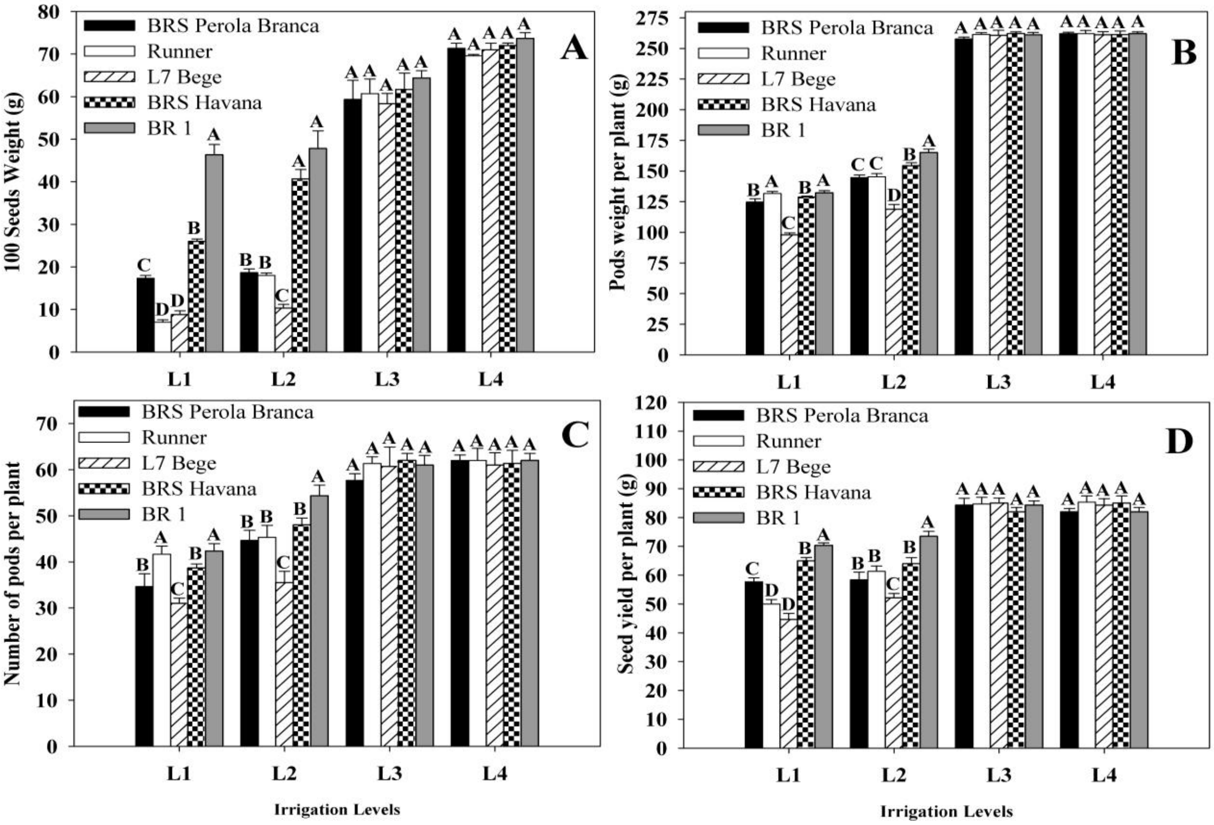

Figure 5. Productive components of 5 genotypes in 4 levels of water replacement. A. Hundred seeds weight; B. Pods weight per plant; C. Number of pods per plant; and D. Seed yield per plant. Bars represent the standard error (n=4). Different letters indicate statistical difference (Tukey´s test, P<0.05). Higher case letters were used to compare the genotypes at each level of water restriction.

The 100-seeds weight, pods weight per plant, number of pods per plant and seed yield per plant of all genotypes significantly decreased with increasing water deficit levels (Figure 5A, B, C and D). At L1, highest 100-seeds weight, pods weight per plant, number of pods per plant and seed yield per plant were observed for BR 1, being significantly higher than the other peanut genotypes.

Non-significant differences were observed in 100-seeds weight of genotypes in L3 and L4. Whereas, BRS Perola Branca, L7 Bege and Runner showed consistently the lowest 100-seeds weight, pods weight per plant, number of pods per plant and seed yield per plant values. At L2 and L3, more pronounced differences in the seeds weight, pods weight per plant, number of pods per plant and seed yield per plant were observed compared to L1 and L2. BR 1 showed significantly higher 100-seeds weight, pods weight per plant, number of pods per plant and seed yield per plant than the other genotypes.

For the variable weight of a hundred seeds (100SW, shown in Figure 5A), the statistical analysis that best significant. From this result, it was calculated that 100SW reached a maximum (77.50 g) at the irrigation level of L3 and L4. Corroborating with this study, Araújo and Ferreira (1997) showed a 100SW of 75.25 g for the peanut crop grown without water stress. On the other hand, Silva et al. (1998) obtained opposite results for this study. According to the authors, the irrigation depths applied measuring (300, 500 to 700 mm) by furrow irrigation, did not significantly influence this variable in the peanut crop. Du et al. (2015) reported that the pods weight of peanut variety TMV-2 was decreased under water stress conditions. Arunachalam and Kannan (2013) reported that seed weight was deceased significantly due to moisture stress during pod development stage in peanut. Junjittakarn et al. (2014) reported that moisture stress at flowering stage in peanut increased 100-seeds weight, while at pegging reduced weight compared to control. Water deficit during kernel or seed development stages reduced the weight of kernel. Srinivasan et al. (1987) reported that pod weight of peanut decreased due to water stress. A reduction of 22% in 100-seed weight was observed during flowering stage compared with control under drought stress conditions (Pathak et al., 1988). Nautiyal et al. (1991) reported that peanut cultivars exposed to soil moisture stress at different growth stages

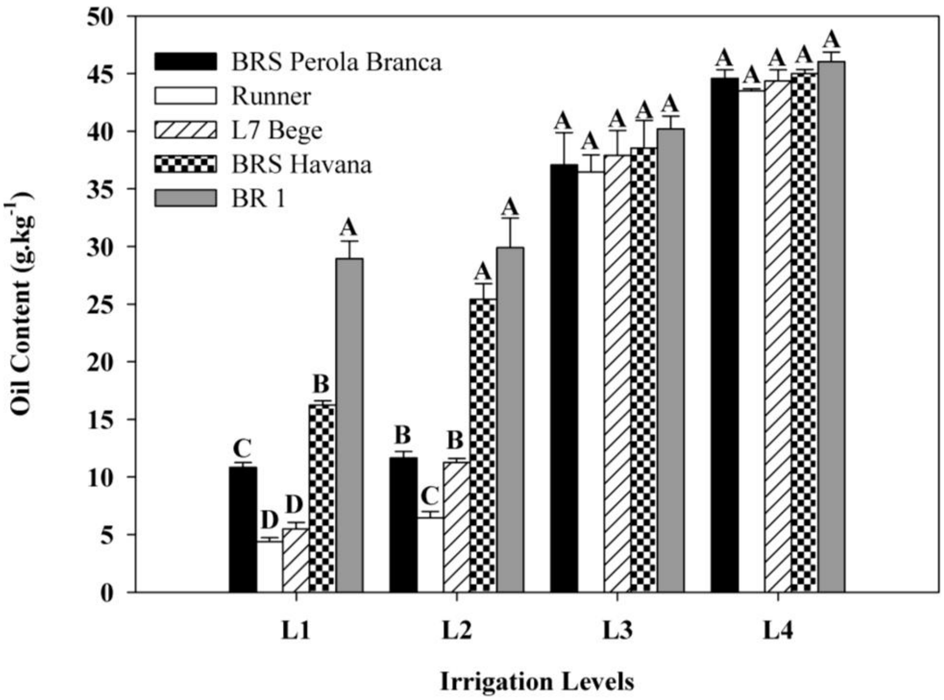

Figure 6. Oil content of 5 genotypes in 4 levels of water replacement. Bars represent the standard error (n=4). Different letters indicate statistical difference (Tukey´s test, P<0.05). Higher case letters were used to compare the genotypes at each level of water restriction.

especially during early vegetative phase resulted in an increase in seed weight. Hundred-seeds weight was reduced greatly due to the moisture stress occurred at pod development stage (Reddy et al., 2003). Pathak et al. (1988) reported that plants subjected to drought stress during flowering stage resulted in reduction (29%) in 100-pods weight compared with control. Arunachalam and Kannan (2013) stated that there was decrease in 100-kernels weight and 100-pods weight under moisture stress conditions in simulated drought treatments compared to adequately irrigated control.

It can be seen in Figure 5B there was a significant response of pods weight per plant with increased irrigation levels. The model estimates an optimum pods weight per plant of 271.86 g per plant for the irrigation level of L3 and L4, in other words, the pods weight per plant would increase from the treatment in 44.64% for an irrigation depth L3 and L4. In pepper crop, Azevedo et al. (2005), testing different irrigation levels, although based on water evaporation in Class “A” tank, they observed that increasing irrigation levels influence significantly the average pod weight.

The statistical analysis showed that the number of pods per plant, relatively to the different irrigation levels, between genotypes, except for L3 and L4 (Figure 5C). The increasing of irrigation amount resulted in a maximum number of pods per plant equal to 65, obtained with irrigation level of L3 and L4. Távora and Melo (2001) working with the peanut crop in greenhouse conditions, observed similar results to this study for this variable. It should be noted that the occurrence of a water deficit in a peanut crop, during the growth and development phases of the gynophores and pods, causes a decrease in the number of pods (Távora and Melo, 2001).

The productivity of grain in the peanut crop was influenced by the increase in the amount of water applied (Figure 5D). This data estimates a maximum grain yield value of 88.97 g per plant which corresponds to an irrigation level of L3 and L4. The yield obtained with this irrigation level is above the average grain yield values of 1,151.6 kg ha^{-1} in Ceará (IPCE, 2010) and below the average productivity values of 2,225 kg ha^{-1} in Brazil (IBGE, 2011). Under field conditions, the irrigation depth of 700 mm provided a peanut yield of 2,026 kg ha^{-1} (Silva et al., 1998). On the other hand, Silva and Beltrão (2000) found a grain yield of 1,671 kg ha^{-1} with the peanut crop being irrigated with a 500 mm of irrigation depth.

The oil content of all peanut genotypes was decreased significantly with increasing water deficit levels as compared to the control treatment (Figure 6). At L1, BR 1 maintained significantly higher oil content than the other peanut genotypes in L1 and L2, with the exception of BRS Havana in L2.

Phenotype Runner significantly maintained lowest oil content compared to the other genotypes under all irrigation treatments. At L2 and L3, genotypes were

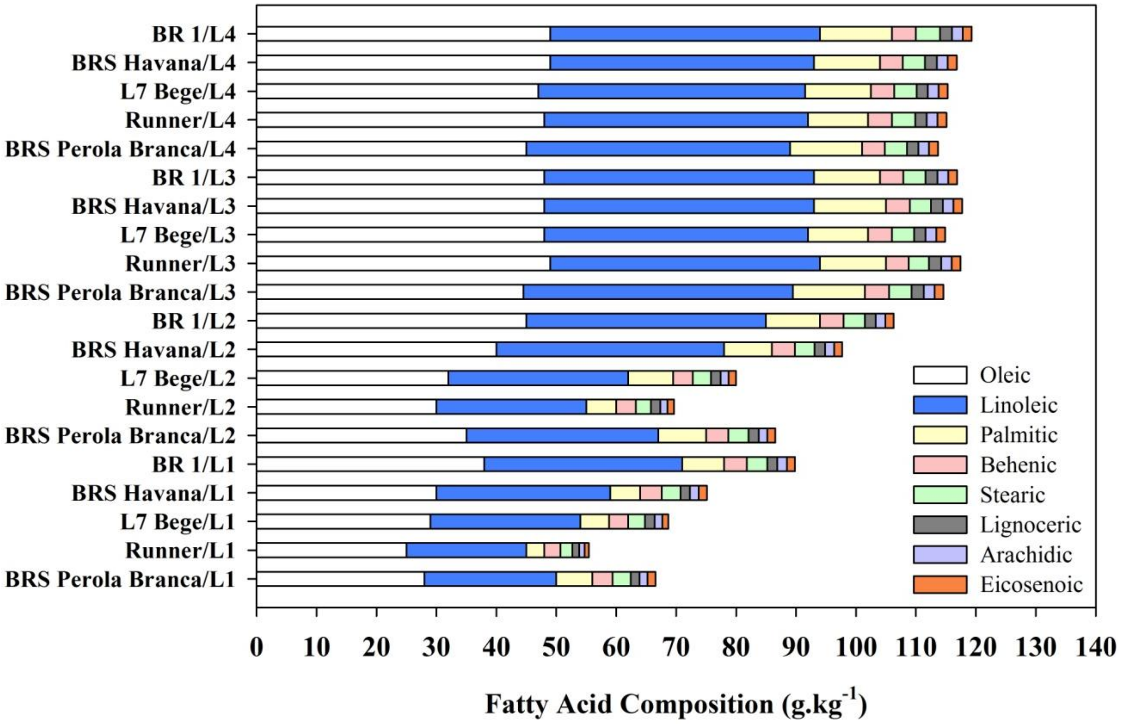

Figure 7. Fatty acids composition´s of 5 genotypes in 4 levels of water replacement.

ordered in terms of oil content as: BR 1 > BRS Havana > L7 Bege > Runner. The chemical composition of peanut seed is influenced, among other factors, by its stage of maturity (Akhtar et al., 2014). The present study therefore included only sound mature seeds to eliminate maturity-related differences in seed chemical composition. Total oil was affected by water deficit levels. This decrease was progressive, corresponding to the intensity of water deficit. Differences in oil content became significant only under moderate to intense water deficit. Our results, however, are in agreement with previous reports that late-season drought had great effect on total oil content (Sun et al., 2014), or that mid-season drought reduced total oil content (Bhalani and Parameswaran, 1992). This could be due to the differences in genotypes and in the timing and intensity of drought in these studies. Further, growing conditions and crop management practices (foliar diseases control) also influence total oil, total protein and fatty acids in peanut (Akhtar et al., 2014). In the present study, genotypes interacted with water deficit levels for total oil.

Palmitic, stearic, oleic, linoleic, arachidic and behenic acids are the principal fatty acids that these constitute whole peanut seed fatty acid composition's of 98%. The interaction effect of irrigation levels x genotypes was found highly significant (P<0.01) for all tested fatty acids (Figure 7). The fatty acid composition of all peanut genotypes changed significantly with increasing water deficit levels as compared to the control treatment. Non-significant differences were observed in fatty acid composition of genotypes at L3 and L4.

In L1 and L2 the highest Oleic acid content was obtained from BR 1 and the lowest was obtained from Runner, the highest Linoleic acid was obtained from BR 1 and BRS Havana, while the lowest was obtained from Runner. The highest Palmitic acid content was obtained from BR 1, while the lowest was obtained from L7 Bege and Runner, the highest Behenic acid content was obtained from BR 1, while the lowest was obtained from Runner. The highest Stearic acid content was obtained from BR 1 and the lowest was obtained from Runner interaction. The highest Lignoceric, arachidic and Eicosenoic acids content were obtained from BR 1 and the lowest were obtained from Runner, respectively. Fatty acids are synthesized by consecutive desaturation from stearic (C18:0) to oleic (C18:1) to linoleic (C18:2) fatty acid (Akhtar et al., 2014). In the present study, water deficit levels had significant effect on the major fatty acids. Stearic and oleic acids decreased, just like linoleic and behenic acids decreased under water deficit levels. The decrease was progressive with increasing water deficit. Differences in oleic, stearic, linoleic and behenic acids became significant at a low level of moisture deficit. These results differ from those of Hashim et al. (1993), who reported an increase in palmitic and linoleic acids and a decrease in stearic, oleic and eicosenoic acids when Runner was exposed to drought stressed for 30 days at maturation. When water stress was occurred at the pre-flowering and pod formation periods, an increase in behenic and lignoceric acids was observed. These differences between the two studies could be ascribed to the larger number of genotypes in the present study.

Conclusions

Water deficit levels affect the chemical composition of peanut seed in a significant manner, and total oil and fatty acids decreased in seeds, due to water deficit levels. This decrease was progressive and associated with increasing degree of water deficit. The plants irrigated from 100% and 130% had better response. Among all genotypes analyzed, cultivar BR 1 showed better agronomic performance, being more adapted to water deficiency, therefore showing a better economic viability, and would be the ideal for family farming in semi-arid regions of northeastern Brazil.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

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Full Length Research Paper

Effects of fertilizer type on chlorophyll content and plant biomass in common Bermuda grass

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Use of biological fertilizers is one of the most important steps in remediating soil contaminated by chemical fertilizer on Bermuda grass. Four fertilizer treatments were examined in the greenhouse. Plant biomass and chlorophyll meter measurements were determined. Results showed that high rate of bio-fertilizer, fast-release and slow-release fertilizers had better shoot and whole plant dry weight than other treatments after ten weeks of treatment. The proportions of whole plant dry weight partitioned to shoots exceed that partitioned to roots for fertilizer treatments. Additionally, root/shoot ratio increased with the increasing levels of bio-fertilizer and fertilizer treatment. The study also found that 50 ml of bio-fertilizer appreciation achieved significantly greater than other treatments but lower dose was that effective. The results also indicated that shoot dry weight (R^2 = 0.7213) and whole plant dry weight (R^2 = 0.6213) was closely linked to shoot Shalini Pereira Design Associates (SPDA), but was not significantly correlated to root dry weight (R^2 = 0.2181).

Key words: Bermuda grass, bio-fertilizers, dry weight, chlorophyll, Shalini Pereira Design Associates (SPDA).

INTRODUCTION

Common Bermuda grass is one of the most widely distributed and genetically diverse grass species, and is widely used worldwide in lawns (Turgeon, 2001). Previous investigation suggested that root adaptation was likely a mechanism for regulating cadmium (Cd)-tolerance in Bermuda grass (Kuo et al., 2005). The effects of sources of nutrients and their levels on the performance of crops were investigated in many studies (Barad et al., 2011; Sharma et al., 2011). However, soil contamination caused by excessive chemical product use, is a general problem in Taiwan, particularly high maintenance turf grounds such as golf courses. The use of bio-fertilizer is an important step in remediating farmland contaminated by chemical fertilizers or pesticides, especially in developing countries (Suresh et al., 1996). Using bio-fertilizers for crops has achieved numerous benefits, including: (i) Improved soil physical structure; (ii) Improved soil biological properties, and (iii) Improved synergy with chemical fertilizers (Mba, 1996). The most important types of beneficial microbes are: (1) *Rhizobium*, *Cyanobacteria*, and *Azospirillum*, which enhances N_2 fixation (Adams, 1999); (2) *Mycorrhizae*, which mobilize soil essential elements for plant absorption (Galleguillos et al., 2000), and (3) Compost, which also performs better than existing methods for improving soil microbial activity (Morsch and Martin, 1999).

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Table 1. Comparisons of plant root dry weight (Rt), shoot dry weight (St), whole plant dry weight (Wp) accumulation, and root/shoot dry weight ratios (RtDw/StDw) of common bermuda grass grown under four different fertilizer treatments and control after 10 weeks.

Treatment	Wp	Rt	St	RtDw/StDw
Bio-fertilizer 50 ml	4.17^{a*}	2.03^{a}	2.14^{ab}	0.95^{a}
Fast-release	4.18^{a}	1.78^{b}	2.30^{a}	0.77^{bc}
Slow-release	4.00^{ab}	1.80^{b}	2.20^{ab}	0.82^{b}
Bio-fertilizer 10 ml	3.66^{b}	1.78^{b}	1.88^{c}	0.84^{b}
Control	3.62^{b}	1.74^{b}	1.88^{c}	0.93^{a}
$LSD_{0.05}$	0.22	0.06	0.20	0.08

* Values followed by different letters are significantly different at the 0.05 probability level.

While numerous investigations have examined these species, turfgrass has been a neglected species comparatively in developing countries (Wagner and Azolla, 1997).

Turfgrass quality determined by visual assessment is generally imprecise, non-definitive, and dependent on individual prejudice (Morris, 2007). Consequently, more efficient and non-intrusive methods of pre-screening turfgrass growth are require owing to excessive fertilizer use in intensively managed farmland areas. The chlorophyll meter allows users to measure leaf blade greenness rapidly and easily, which is determined by shoot chlorophyll content. This device also displays promise for improving N management, because it has the potential to detect N deficiencies (Kuo et al., 1999; Peterson et al., 2002). Tsai (2000) investigated the positive linear relationship between tissue N status and chlorophyll meter readings for carpet grass and centipede grass. A chlorophyll meter was also successfully correlated with traditional methods to measure nitrogen concentration (R^2= 0.71) and visual quality (R^2= 0.74) of St. Augustine grass (Rodriguez and Miller, 2000). Therefore, the objectives of this work were to: (1) Examine the growth effect of bio-fertilizer applications on Bermuda grass biomass production; (2) To compare visual quality ratings and chlorophyll meter readings and its performance.

MATERIALS AND METHODS

Common Bermuda grass seeds were sown in a 15 cm diameter × 20 cm deep plastic pot containing vermiculite: peat moss: soil (loam: peat moss: vermiculite = 1:1:1) (1:1:1= v:v:v), and covered with a thin layer of the same media to reduce desiccation. The seeding rate (pure live seed of 85.5%) was 10 g/m^2. The greenhouse study was conducted in the climate-controlled greenhouse located in the campus of Chinese Culture University on Yang-Ming Mountain (400 m above sea level), Taipei (20/15°C day/night, 222/148 mol m^{-2} s^{-1} sun/shade) (Model LX-102 potable light meter, Alfa Electronics inc., New Jersey, U.S.A). Pots were watered twice per week with potable water. After 6 weeks, germinated seedlings were trimmed twice to maintain a mowing height of 2.5 cm, and then with fertilizer treatment were given. Pots were not clipped after the application of treatment.

Fertility treatments included a control (water only), a 5 g-N/m^2 of fast-release fertilizers [15N (NO_3^--N):6.6 P:12.5 K:2.8 Mg; Tai-Fertilizer Company, Taipei, Taiwan], a 5g-N/m^2 slow-release fertilizer [34 N (S-coated urea):1.3 P:2.5 K; Scotts Company, Ohio., U.S.A], and both 10 (4 mg-N/m^2) and 50 ml (20 mg-N/m^2) of bio-fertilizer [a complex microbial populations containing *Rhizobium*, *Azotobacter*, *Cyanobacteria*, *Rhizobacteria*, and phosphor-bacteria for N_2 fixation, potassium decomposition, phosphorus decomposition and weathered coal decomposition, and also containing 3.5 N:2.2 P:2.8 K; Fong-Yuban Company, Taipei, Taiwan]. Plants were mowed every other week and fertilizer treatments were applied once before measurement after 10 weeks.

Chlorophyll content ratings (0-100 unit) were performed at the first and tenth wks after fertilization with a chlorophyll meter (Minolta SPAD-501, Spectrum Technologies, Inc., Illinois, U.S.A). This measurement was based on the difference between light attenuation at 430 and 750 nm, with no transmittance. One fully expanded blade from each pot was used as samples for chlorophyll measurement, thus five samples for each treatment were detected. To ensure the same leaf from each plant was sampled, five selected samples before mowing were marked with rubber rings. The relative increase rate (RIR) of chlorophyll meter reading (CMR) through first to tenth week was calculated as the ratio of tenth week CMR substrate first week CMR to first week CMR. N sufficiency index defined as the SPAD value of a plant receiving fertilizer divided by the SPAD value of a plant not receiving fertilizer times 100 was established (Idso et al., 1996). Samples were divided into root and shoot components and oven dried at 68°C for 72 h. The root, shoot, whole plant dry weight, and the root/shoot dry weight ratio were recorded. The experimental design was completely randomized with five replications. The experiment was repeated once under the same conditions. Mean separation was evaluated at the 0.05 probability level using a qualified LSD test (SAS institute, 1987).

RESULTS AND DISCUSSION

Analysis of Bermuda grass dry weight under five different treatments demonstrated that 50 ml of bio-fertilizer, fast and slow-release fertilizers achieved better shoot and whole plant dry weight following ten weeks of treatment than lower levels of bio-fertilizer and control (Table 1). However, root dry weight exhibited no significant differences among different treatments. The results indicated that the proportion of whole plant dry weight partitioned to shoots exceeds that partitioned to roots for fertilizer treatment of common Bermuda grass. It was

Figure 1. Growth conditions of common Bermuda grass grown under five different fertilizer treatments (after 10 weeks).

Table 2. Effect of nitrogen applications on average chlorophyll meter reading (CMR) of first and tenth week, and the relative increase rate (SIR) of common Bermuda grass grown under five different fertilizer treatments after 10 weeks (1: biofertilizer 10 ml; 2: biofertilizer 50 ml; 3: fast-release; 4: slow-release; 5: control).

Treatment	**CMR at**		**RIR**
	First week	**Tenth week**	
Bio-fertilizer 50 ml	5.40*	22.60	3.19^{aZ}
Slow-release	6.20	21.00	2.39^{b}
Fast-release	6.80	20.20	1.97^{b}
Bio-fertilizer 10 ml	4.60	13.30	1.8^{9c}
Control	4.50	6.80	0.51^{d}
$LSD_{0.05}$		0.21	

* Values followed by different letters are significantly different at the 0.05 probability level.

seen that whole plant dry weight mostly came from the mown portion of turfgrass clippings. Bio-fertilizer treatments displayed higher root/shoot ratios than the compared to of other treatments (Table 1). This may be so that most of carbohydrates contributed to shoots from photosynthesis are removed periodically by mowing (Figure 1). Microbial biological activity is slow to degrade organic soil matter, which is absorbed by plants after degradation, contributing to plant biomass. From the comparison of relative CMR increase rate showed significantly differences among fertilizer treatments (Table 2). It was found that 50 ml of bio-fertilizer appreciation achieved significantly greater than other treatments but lower dose was that effective (Figure 1). Thus, more observations may be required to measure the response of microbial populations towards degradation time.

The relationship between adequately fertilized turf and N sufficiency index must be established in turfgrass. The experiment showed that the lowest sufficiency index (195 and 332 for low and high rate of bio-fertilizer) observe

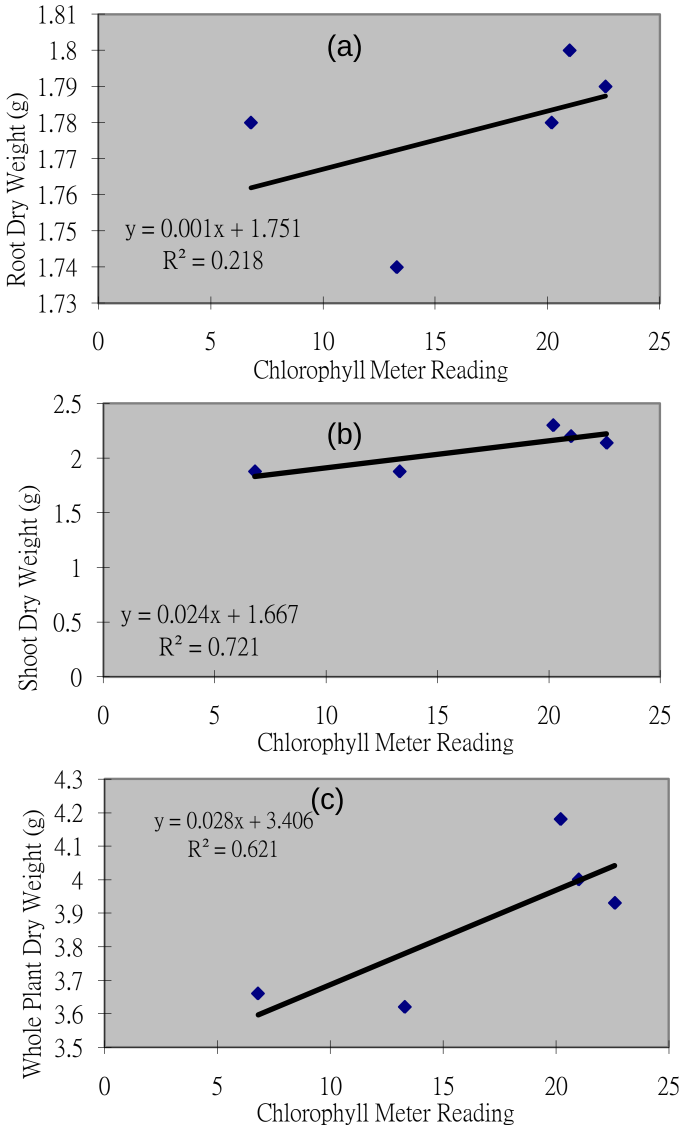

Figure 2. Correlation between leaf chlorophyll meter readings and (a) root dry weight, (b) shoot dry weight, and (c) whole plant dry weight in common Bermuda grass.

was for turf fertilized with low rate of bio-fertilizer indicating a slight N deficiency which could be rich with low level of nitrogen. The average sufficiency index (297-308) showed an adequate amount of tissue N supplied at this stage of Bermuda grass growth (Table 2).

Regression curves of root, shoot, and whole plant dry weight accumulation and SPAD values were calculated. The results indicated that shoot dry weight (R^2 = 0.7213) and whole plant dry weight (R^2 = 0.6213) were closely linked to shoot SPAD, but were not significantly correlated to root dry weight (R^2 = 0.2181) (Figure 2). Due to this relatively consistent degree of agreement between SPAD values and plant biomass, it appears that the chlorophyll meter may be useful in indirectly measuring the leaf tissue nitrogen in common Bermuda grass. This greenhouse experiment examined bio-fertilizer to obtain more detailed information of the effect on the growth conditions and chlorophyll variations of Bermuda grass prior to screening in the field experiment. Within product labeled recommendation rate, high Bio-fertilizer mixed at 50 ml dose showed greater CMR than commercial chemical fertilizers and maintained healthy plants.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Foliar application of zinc fertilizer on different schedules of application, as cover in the winter maize

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Corn is the most important crop in the world market, being greatly used for human and animal nourishment. Corn has limited production with the zinc deficiency of the Brazilian soils which requires proper and correct application for optimizing its productivity. This study aims to evaluate the foliar application of zinc at different times in the corn variety RB 9110 PRO. Analyzing zinc absorption with influecia temperature and relative humidity. The experiment was conducted in the village of Corbélia – PR in Brazil. The used design was completely randomized, consisting of 4 treatments: Treatment 1 - Control without zinc; Treatment 2 - application of zinc at 08 h:00 min; Treatment 3 - Zinc application at 16 h:00 min; Treatment 4 - application of zinc at 20 h:00 min was used in the basic fertilization formulated 10-15-15. The weight of a thousand grains and the productivity was assessed. Treatment 2 was statistically superior to all treatments producing 360 kg / ha^{-1} higher than the witness, as the spike in size only witness was lower than the others, weight of 1000 grains there was no difference.

Key words: Productivity, *Zea mays*, Zn.

INTRODUCTION

Corn (*Zea mays*) belongs to the family of poaceas. It is a monocot plant of highest importance to the world market, of American origin, it has high importance for being used in many different ways, from animal and human food to the industries (Embrapa 2014). The corn crop in Brazil is highlighted as one of the most important ones, with a cultivated area estimated at 12 million hectares (Agrianual, 2008). As reported by Pinazza (1995), the corn is a plant which presents a cycle of 110 to 180 days, differentiated by the characterization of hybrids, as very early, early, and normal.

The second harvest, called “safrinha”, is of great importance in the Brazilian scenario, where it optimizes the use of the property. It began in the 80s in the state of Paraná, standing out as an alternative (Pitol et al., 1996). In Brazil, the first report of zinc deficiency in corn was made by Igue and Gallo (1960). According to Büll (1993), zinc is a limiting micronutrient corn production in Brazil, with common deficiency in all regions, as corn is a crop that responds well to the application ofzinc, where

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many studies have shown greater efficiency corn plants, on the application in the corn through the foliar system than through the ground.

Its most common form in the soil solution is Zinc $(Zn)^{2+}$cation which moves in the soil by diffusion, walking in favor of the concentration gradient that is, from a region of higher concentration to another of lower concentration (Malavolta, 2006).

Considering the many problems regarding Zn, plus the difficulty of distributing small quantities of fertilizer on the field (Lopes and Guilherme, 1992), alternative methods to the application of zinc have been sought, among these methods are the seed treatment and the foliar application.

Sakal et al. (1983) found that the foliar application of zinc obtained similar results to soil and to sowing furrows applications, where it is difficult to perform a uniform application on the soil, turning the foliar application into an alternative, although there is the disadvantage of low mobility of zinc via phloem.

According to Borkert et al. (1989), zinc performs one of the most important functions in corn. It takes part as a component of enzymes as the dehydrogenases, proteinases, peptidases. It is also related to the metabolism of phenols and the formation of starch, increasing and multiplication of cells and the fertility of the pollen grain. Decaro et al. (1983) mention that obtained results show positive effects of zinc in the corn, from plant growth, grains and fodder production, increasing of the protein content on the grains, thus having a significant increase in the production of corn crop. The function of the microelements is related to the metabolism of carbohydrates, proteins and also to the formation of auxin, RNA and ribosomes (Thorne, 1957).

The answer to the foliar application depends on several determining factors, where it happens in the process of penetration of the element through the cuticle, of the absorption of the leaf cells and in the transportation via phloem to the preferential drains, the main factors that could be stressed being the environmental and climatic factors (Ribeiro and Santos, 1996). This study aims to assess responses of the corn crop with different foliar schedules of application, when it will be evaluated, the weight of a thousand grains, the number of cobs and the productivity in bags / ha^{-1}.

MATERIALS AND METHODS

The experiment was conducted in the year 2014, in the city of Corbélia – PR, Brazil, with latitude 24°48'30" south, 53°15'59" west and an altitude of 683 m.

In this study it was used the hybrid RB 9110 PRO, of low scale, high productive potential, having a very early characteristic. The design was done in a completely randomized design (CRD) with fields of 6.3 x 5 m coming to a total of 31.5 m^2. Each field consisting of 7 lines with a spacing of 90 cm between the lines, with 4 treatments and 6 repetitions, coming to a total of 20 plots. Five collections were withdrawn from each field for the analysis of weight of a thousand grains, of productivity and of cob size.The treatments were distributed in the following manner:

Treatment 1Control without Zinc;
Treatment 2 Zinc application at 08 h:00 min; with a temperature of 25°C and RH of 71%.
Treatment 3 Zinc application at 16 h:00 min; with a temperature of 29°C and RH of 59%.
Treatment 4 Zinc application at 20 h:00 min; with a temperature of 24°C and RH of 65%.

The sowing was performed in February of 2014, done through mechanized seeding using a sower of continuous flowing, with a 90 cm spacing between the lines, with 5.4 seed per running meter, and sowing depth of 3 cm. The basic fertilization was conducted with the concentrated formulation 10 – 15 – 15 of NPK, at a dosage of 800 kg ha^{-1}.

The tested treatments were carried out with Zinc (10%), where the recommendation of the product is of 1.5 to 2 l/há-¹, between 30 to 20 days after emergency (DAE). The applications of Zinc were conducted manually diluted in 3 L of water, with a proportion of 35 ml to each treatment, applied on the plot using a machine for applying pesticide, using individual protection equipment. When performing the applications, the relative humidity of the air and the temperature were collected with the suitable equipment.

All the crop cares during the crop cycle were taken with pesticides registered at the Agriculture and Supply Secretary of Paraná (SEAB/PR) for the corn crop, pesticides to control pests, diseases and weeds, through a trailed sprayer. The harvest point was reached in July of 2014, coming to a total of 152 days of cycle.

The harvest was conducted manually, with four samplings being collected randomly in each plot, 1 m each, with five cobs. After the harvest, the sizes of the cobs were assessed, taking the measurements with a ruler. In the sequence, it was done the trail and the cleaning of these grains with a strainer, where all the samples had to undergo a humidity analysis of the grains with universal equipment, where there were no significant differences between them and all were within the commercial parameters.

A volume of 1.000 grain of each of the collected samples was weighted in a precision scale, taking notes of the obtained values on a spreadsheet in order to obtain the productivity in kg/ha^{-1} of each treatment, after getting the total weight of each collected sample.

Thus, the evaluated parameters were: productivity (kg/ha^{-1}), mass of 1.000 grains and cob sizes. The results were submitted to an analysis of variance and the averages compared with Tukey's test at 5% of probability, using the Assistat program 7.7 beta version.

RESULTS AND DISCUSSION

According to Table 1 we can analyze that to the size of tenon T2, T3 and T4 were statistically equal, the witness was significantly lower than the other treatments. For weight in thousand grains no difference significant between treatments, productivity T2 was what had the best result. All data were analyzed with 5% significance using Tukey.

By analysing Figure 1 we can see that there was a big increase in the size of the cobs regarding the treatment of the control and within the treatments with zinc applications at different times of the day, it is proven that there are statistical differences where the treatments produced more when compared to the control; and, by

Table 1. Cob size (cm), Weight of 1000 grains (grs) and productivity (kg /ha^{-1}) on the application of Zinc at different times on the day of the corn harvesting.

Treatment	Cob size (centimeters)	Weight of 1000 grains (grams)	Productivity (kg /ha^{-1})
(T1) Control	14.22^{b}	305^{a}	7.746^{b}
(T2) Zinc at 08 h:00 min	15.12^{a}	311^{a}	8.142^{a}
(T3) Zinc at 16 h:00 min	14.85^{a}	304^{a}	7.926^{ab}
(T4) Zinc at 20 h:00 min	14.96^{a}	305^{a}	7.986^{ab}
Overall average	14.78	306.25	130.4
CV	1.51	0.79	5.88

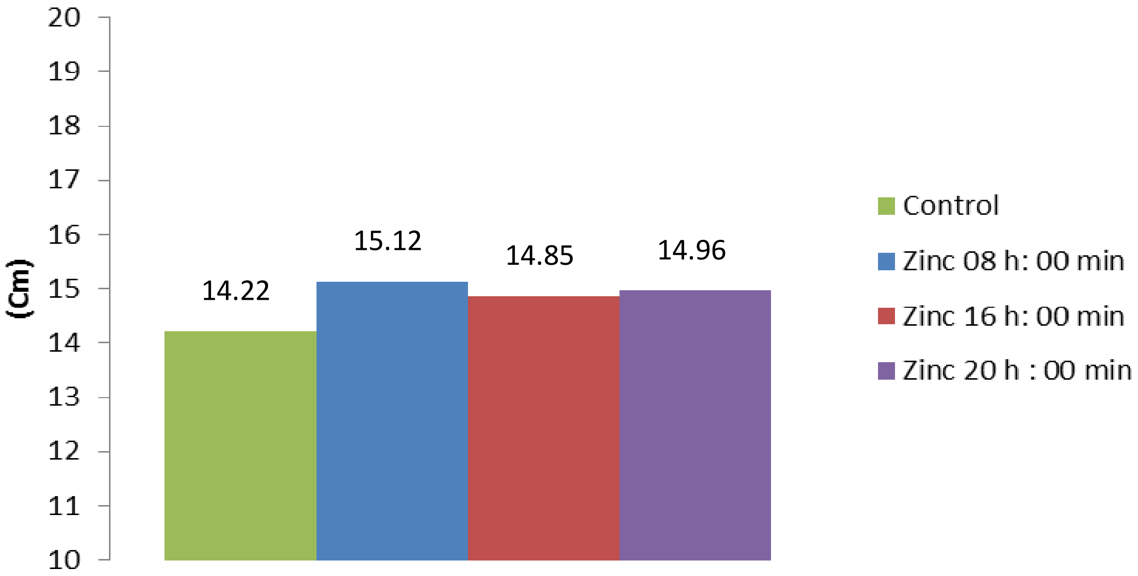

Figure 1. Cob size (cm) regarding the treatments conducted on the corn crop.

applying zinc at 08 h:00 min, the cobs reached to a larger size. These results if differ from the work done by Soares (2003) where there was no significant influence of application of boron and zinc on the cob size variable. According to Figure 2 we can analyze that none of the treatments showed a significant difference of 5%.

Galrão and MesquitaFilho (1981) report that corn is one of the plants that most respond to the application of Zn, providing significant gains in the production of grains and in their weight. According to Ritchey et al. (1986), several studies conducted at greenhouses and on the field have shown that its addition promotes significant gains both in the dry matter and in the production of corn and sorghum grains. Showing that it is relevant the application of zinc on corn crop because it results in a productivity increase and weigth grain. According to Laun et al. (1987) the lack of zinc reaction may be related to liming since we culture had no problems during your cycle. It is shown that the treatment with zinc applied at 08 h:00 min had a better yield to productivity, when the treatments of zinc applications at 16h00 min and at 20 h:00 min obtained statistically equal results when compared their productivity. As for the control, its productivity decreased when compared to the other treatments.

Fageria (2000), when evaluating the seven levels of Zn, concluded that the Zn affected the production of dry matter in the aerial part and the final productivity in the rice, beans, corn, soybean and wheat crops, but the answer varied according to the crop.

Ritchey et al. (1986) obtained corn productions close to maximum yields in the first cultivation, and that yielding continued for four more consecutive harvests, consequence of the residual micronutrient left on the straw and the soil (Table 1 and Figure 3).

Conclusion

It can be concluded thatT2: the application of zinc at

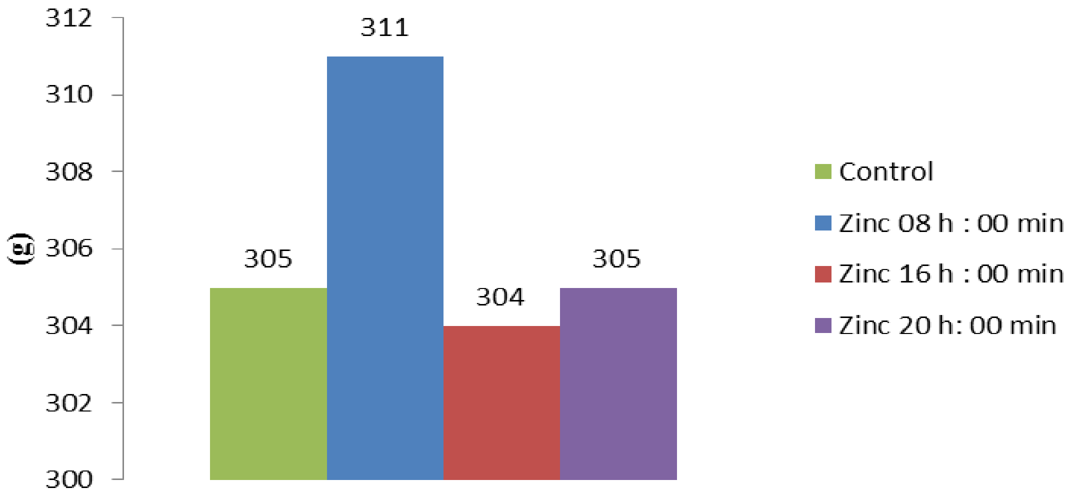

Figure 2. Weight of 1.000 grains (g) regarding the treatments conducted on the corn crop.

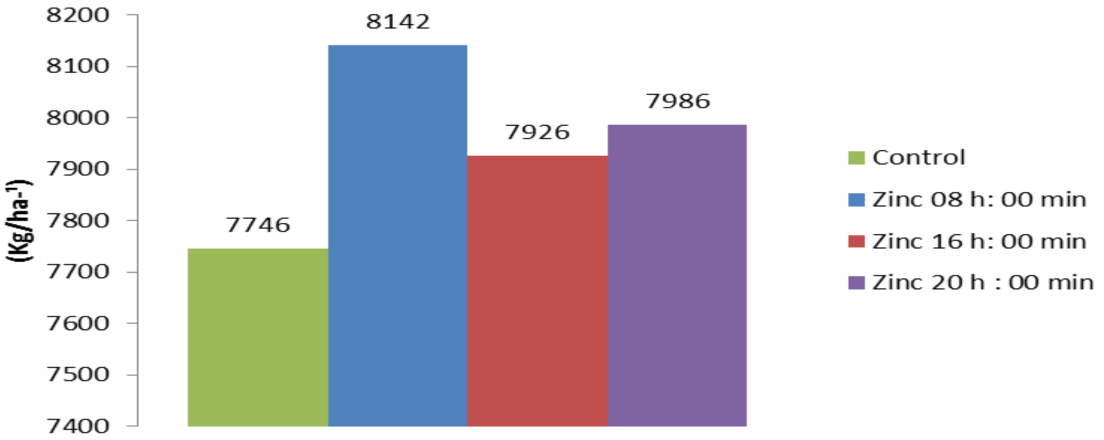

Figure 3. Productivity (Kg/ ha^{-1}) regarding the treatments conducted on the corn crop.

08h:00 min with a environment temperature 25°C at a RH of 71% with the the size of the larger tenon and higher productivity it was the best treatment, with a difference of 360 kg/ha^{-1} compared to the control. For the weight of 1000 grains all the treatments were statistically equal, on the evaluation of the cob size only the witness without the use of zinc has a size statistically below the other treatments.

Conflict of Interest

The authors have not declared any conflict of interests.

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