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## ARTICLES

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**African Journal of Agricultural Research**

*Full Length Research Paper*

# Vegetation structure of naturally occurring areas of mangaba *Hancornia speciosa* Gomes in the mid-north region of Brazil

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**The unknown potential of the mangaba *Hancornia speciosa* naturally occurring areas in the mid-north region of Brazil has raised the risk of its extinction and contributed to its underutilization. The objective of this study was to characterize the vegetation structure with naturally occurring mangaba in Recanto, Patizal and Recurso, villages in Morros municipality, State of Maranhão to provide the species proper utilization and conservation. The floristic composition was determined by the quadrants method. Two individuals were selected per quadrant, an adult and regenerating. The phytosociological parameters computed were Relative Density, Frequency and Dominance, Importance Value, Cover Value, the Shannon and Weaver Diversity Index and the Sorensen Similarity Index. The species *H. speciosa* reached relevant position in all computed parameters in the three sampled villages with importance values varying from 25.15 to 29.38% for the regenerating and from 29 to 56.64% for the adult strata, indicating the species relative ecological importance.**

**Key words:** Diversity, Savannah-Restinga transition, phytosociology.

## INTRODUCTION

The Brazilian natural heritage is relevant for the global biodiversity conservation due to its territorial extension, diversity and endemism of species, genetic heritage and the ecosystem heterogeneity of its biomes (Maracahipes et al., 2011). However, the floristic richness of Brazil is constantly threatened, either by land speculation, deforestation or the predatory exploitation of natural resources.

According to notice of the Ministry of the Environment (2012) the Brazilian Savannah is considered the richest in the world, with 11,627 native plant species already catalogued. However, it has suffered significant loss of

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**Table 1.** Soil chemical characterization at 0-20 cm depth in the Recurso, Recanto and Patizal villages, P. A. Rio Pirangi, Morros municipality, State of Maranhão.

| Villages | O.M. | pH | P | K | Ca | Mg | H+Al | Na | Al | CTC | V% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | g/dm³ | $CaCl_2$ | mg/dm³ | ..........................mmol$_c$/dm³............................ | | | | | | | |
| Recurso | 5 | 4 | 1 | 0.7 | 3 | 6 | 20 | 1.7 | 0 | 31.4 | 36.3 |
| Recanto | 7 | 4 | 1 | 0.6 | 4 | 3 | 20 | 1.8 | 2 | 29.4 | 32.0 |
| Patizal | 14 | 5.8 | 1 | 0.5 | 5 | 2 | 20 | 2.8 | 2 | 28.3 | 29.3 |

O. M. = Organic Matter; P = Posphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; H+Al = Hydrogen plus Aluminum; Na = Sodium; Al = Aluminum; CTC = Cation Exchange Capacity; V% = Base saturation.

habitat and many native species with great socio-economic and environmental importance, as is the case of mangaba (*Hancornia speciosa* Gomes), are at risk of extinction.

The mangaba is an abundant species in the mid-north region of Brazil. It is typical of the Savannah and Restinga (sandbank) environments. The species has broad potential for use and high utility value for both the pharmacological industry including latex, leaves, stem bark and root for very specific purposes; and for the food industry, the fresh consumption of fruit and / or manufacture of juices, jams, pulps, ice cream among others (Lima et al., 2015). Countless families survive as mangaba collectors in the mid-north region of Brazil.

Nevertheless, mangaba production in almost all comes from the extraction collection, and despite their socio-economic importance, studies of the species are limited. This is a species still under domestication phase but with extinction risks, and little is known about its peculiarities in its naturally occurring environment, which is under accelerated devastation process. Therefore, issues related to the development, adaptation and arrangement of species, still need to be investigated further. Based on this approach, this study aimed to characterize vegetation structure of naturally occurring mangaba in the mid-north region of Brazil in order to support the development of a management plan justifying the conservation and proper utilization of the species.

## MATERIALS AND METHODS

This research was carried at the Settlement Project Rio Pirangi (P. A.) in Morros municipality, in the State of Maranhão, mid-north region of Brazil, from November, 2014 till April 2015. The climate in the region is sub-humid with average temperature ranging from 25 to 27°C, relative humidity is between 78 and 82% and rainfall is approximately 1900-2300 mm year$^{-1}$ (Nugeo, 2015).

The P. A. great richness is the mangaba tree composition in the villages of Recurso (2° 58’ 42.7” S and 43° 53’ 12.7” W), Recanto (2° 58’ 30.7” S and 43° 49’ 29.0” W) and Patizal (3° 00’ 25.4” S and 43° 54’ 22.9” W) where this study was conducted. In all villages extractive farmers conserve native mangaba trees and neither slash and burn nor cultivate the land, thus they make their living from the sale of the mangaba fresh and/or processed fruits, except in Recanto, where farmers use native mangaba areas for cultivation and pasture for extensive cattle farming, therefore, the use of mangaba for both the consumption and for marketing fresh and/or processed is minor compared to the other two villages.

Vegetation in the naturally occurring mangaba in the three villages is classified as Savannah-Restinga transition zone (Nugeo, 2015). The soil is classified as Quartzipsamment (Nugeo, 2015). Twenty soil sub-samples were randomly collected per village at 0 to 20 cm, bulked and sent to the Soils Laboratory of the Maranhão State University for performing chemical analysis according the Instituto Agronomico de Campinas methodology (IAC, 2001).

The structure and composition of the adult and natural regeneration strata from vegetation with naturally occurring mangaba was determined by the quadrants method with 20 m spacing between points and 50 m between transects. Four transects were distributed in the sampled vegetation in each village. All transects were georeferenced. Two individuals were sampled per quadrant, one adult with the plant stem diameter at soil level (DSL) of 5 cm or more and one individual from the regeneration community, with DSL of 5 cm or less. The distance point tree and total plant height were measured with an analogical pachymeter, a measuring tape and a graduated ruler, respectively.

The phytosociological parameters computed were density, frequency and dominance (absolute and relative), importance value, cover value, the Shannon Diversity Index (H') and the Sorensen Similarity Index (ISS), according to Mueller-Dombois and Ellenberg (1974). Data were analyzed by means of the software FITOPAC 2.1.2 (Shepherd, 2009).

One extractivist farmer contributed with the identification of the species common names. Thereafter, collection of the botanical material was made for determination of the species scientific names, plants were pressed to prepare exsiccates and were incorporated into the Rosa Mochel Herbarium of the Maranhão State University in São Luis. The floristic list of families and species was organized according to the Angiosperm Phylogeny Group III guidelines (APG III, 2009).

## RESULTS AND DISCUSSION

The soil chemical analysis results indicated that the soil in all villages were strongly acid except in Patizal where it was medium acid. Organic matter, P and K contents were low in all villages but Ca content was medium. The Mg and Al contents were low in all areas except in Recurso where their content was medium. The Al content was high in all soils except in Recurso where it was low Therefore soils in the occurring mangaba areas in this study are characterized by low natural chemical fertility (Table 1).

However, mangaba is not demanding in soil fertility because it grows well in poor and acidic soils which are

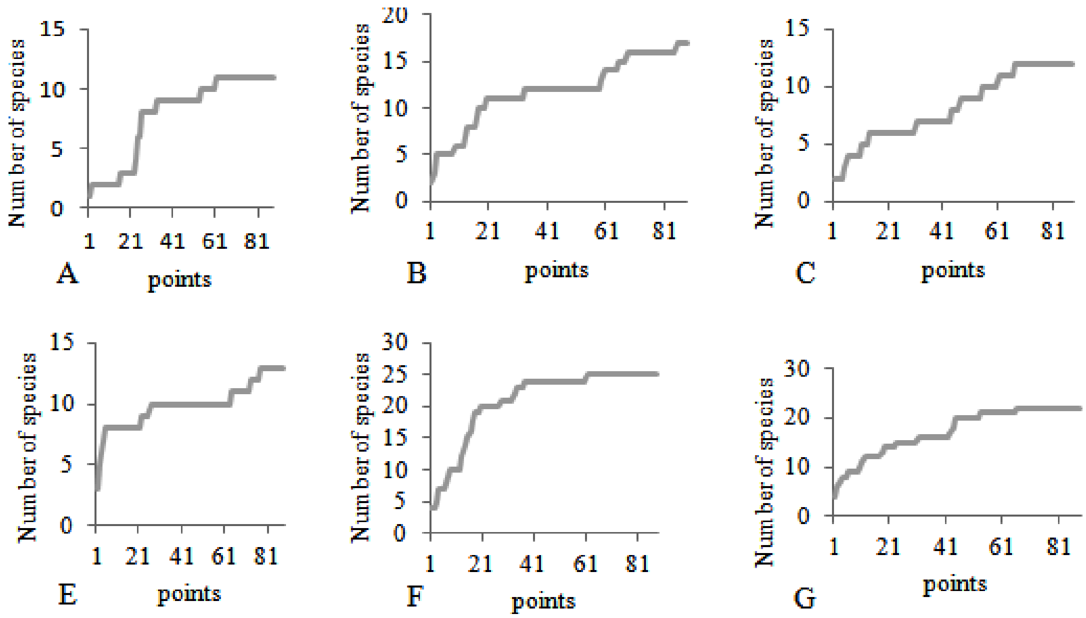


**Figure 1.** Sampling sufficiency curve for the regenerating (A, B, C) and adult (D, E, F) strata for vegetation sampled in Recanto, Patizal and Recurso villages respectively, in the P. A. Rio Pirangi, Morros municipality, State of Maranhão, mid-north region of Brazil.

major characteristics of the Brazilian savannah soils (Vieira-Neto, 1994). Silva et al. (2011) reported that mangaba emergency percentage, stem diameter and the length of the root system were not significantly affected by different substrates and Oliveira et al. (2014) studying the effect of different culture media on the in vitro germination of mangaba seeds observed that there was no difference in the values of germination average time.

The number of sampled points was determined by the stability of the collector's curve obtained with 61 points for the regenerating and with 85 points for the adult strata for vegetation assessed in Recanto; 66 and 67 points, respectively, for regenerating and adult strata in Patizal, and finally, with 77 and 61 points for regenerating and adult strata, respectively, in the Recurso village (Figure 1). Eighty eight points were sampled per study area despite field observations have shown that the collector's curve stabilized with a lower number of points, thus this suggests a broad flora representation in this study.

## Floristic composition of the adult and regenerating strata in naturally occurring mangaba areas

A total of 264 points distributed in 12 transects were sampled totaling 2,112 live individuals, from these, 1,056 individuals from 33 species and 20 families, were from the regenerating stratum and 1,056 individuals from 22 species and 10 families, were from the adult stratum (Table 2). The number of species and families sampled in both the regenerating and adult vegetation strata was higher in Recanto followed by Patizal and Recurso villages (Figure 2). The family Apoycnaceae was the most abundant, with the highest number of individuals in both adult and regenerating strata in all villages (Figure 3). The Shannon Diversity Index indicated that the sampled vegetation floristic diversity was higher in Recanto than Patizal and Recurso villages (Table 3). In general, the floristic diversity was higher in the regenerating than in the adult stratum in all villages (Table 3). The Shannon Diversity Index (H') indicates high species diversity for any type of vegetation when it varies from 3.83 to 5.85 nats. ind.$^{-1}$ (Knight, 1975). Thus, based on the results obtained in this study, it is possible to infer that both adult and regenerating strata from the naturally occurring mangaba areas in the Savannah-Restinga vegetation transition zone in Morros, State of Maranhão showed low species diversity. In a study on natural species regeneration carried out in the Savannah of the Federal District of Brazil, Medeiros et al. (2007), reported a value of 3.21 nats. ind.$^{-1}$.

Marmontel et al. (2014) assessing arboreal vegetation in the Savannah in the State of Minas Gerais, Brazil, described H' value of 2.5 nats. ind.$^{-1}$. Both reported H' values were higher than those obtained in this study. This is because mangaba management and the greater awareness of the mangaba food, nutritional and cultural values have resulted in the mangaba conservation in the villages from this study which contributed for the significant increase in the number of mangaba plants occupying the other species niches thus decreasing the overall species diversity.

**Table 2.** List of the species and families recorded in the regenerating and adult strata in Recanto, Patizal and Recurso villages, in the Savannah-Restinga transition vegetation zone in Morros municipality, State of Maranhão, mid-north region of Brazil.

| **Recanto village** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Regenerating stratum** | | | | | | | |
| **Familes** | **Species** | **NI** | **RD (%)** | **RF (%)** | **RDo (%)** | **CV (%)** | **IV (%)** |
| Apocynaceae | *Himatanthus sucuuba* (Spruce) Woodson | 100 | 28.41 | 24.35 | 25.59 | 27.07 | 26.12 |
| Apocynaceae | *Hancornia speciosa* Gomes | 89 | 25.28 | 20.87 | 29.3 | 27.36 | 25.16 |
| Fabaceae | *Hydrochorea* sp. | 3 | 8.52 | 9.13 | 5.4 | 6.98 | 7.68 |
| Malphigiaceae | *Byrsonima crassifolia* L. Rich | 20 | 5.68 | 6.09 | 5.79 | 5.75 | 5.85 |
| Fabaceae | *Parkia platycephala* Benth | 17 | 4.83 | 5.65 | 6.64 | 5.75 | 5.71 |
| Bixaceae | *Cochlospermum orinocense* (Kunth) Steud | 10 | 2.84 | 3.91 | 2.01 | 2.43 | 2.92 |
| Hypericaceae | *Vismia brasiliensis* Choisy | 12 | 3.41 | 3.04 | 2.0 | 2.71 | 2.82 |
| Fabaceae | *Stryphnodendron barbatiman* Mart. | 6 | 1.70 | 2.61 | 2.58 | 2.15 | 2.30 |
| Myrtaceae | Unidentified species | 7 | 1.99 | 3.04 | 1.71 | 1.85 | 2.25 |
| Clusiaceae | *Platonia insignis* Mart. | 8 | 2.27 | 2.17 | 2.22 | 2.25 | 2.22 |
| Fabaceae | *Andira* sp. | 6 | 1.7 | 1.74 | 2.24 | 1.72 | 2.89 |
| Myrtaceae | *Myrcia* sp. | 7 | 1.99 | 3.04 | 0.6 | 1.3 | 1.88 |
| Bignoniaceae | *Zeyheria* sp. | 7 | 1.99 | 1.74 | 1.58 | 1.79 | 1.77 |
| Sapindaceae | *Talisiaretusa* R. S. Cowan | 4 | 1.14 | 1.74 | 1.76 | 1.45 | 1.54 |
| Sapotaceae | *Manilkara* sp. | 4 | 1.14 | 0.87 | 2.48 | 1.81 | 1.49 |
| Myrtaceae | *Psidium firmum* Berg. | 3 | 0.85 | 1.3 | 1.76 | 1.31 | 1.31 |
| Theaceae | *Laplaceae fruticosa* | 4 | 1.14 | 1.74 | 0.94 | 1.04 | 1.27 |
| Myrtaceae | *Campomanesia* sp. | 4 | 1.14 | 1.74 | 0.88 | 1.01 | 1.25 |
| Apocynaceae | *Aspidosperma* sp. | 3 | 0.85 | 0.43 | 1.17 | 1.01 | 0.82 |
| Anacardiaceae | *Myracrodruom urundeuva* Fr. All. | 3 | 0.85 | 1.3 | 0.24 | 0.55 | 0.80 |
| Commelinaceae | *Commelina benghalensis* L. | 2 | 0.57 | 0.87 | 0.94 | 0.76 | 0.79 |
| Humiriaceae | *Humiria balsamifera* Jaume St. Hillaire | 2 | 0.57 | 0.87 | 0.82 | 0.7 | 0.75 |
| Rubiaceae | *Guettarda* sp | 2 | 0.57 | 0,87 | 0,59 | 0,58 | 0.68 |
| Rubiaceae | *Bathysa meridionalis* Smith & Downs | 1 | 0.28 | 0,43 | 0,43 | 0,36 | 0.38 |
| Salicaceae | *Casearia* sp. | 1 | 0.28 | 0.43 | 0.31 | 0.30 | 0.34 |
| **Adult stratum** | | | | | | | |
| Apocynaceae | *Hancornia speciosa* Gomes | 129 | 36.65 | 30.57 | 31.43 | 34.04 | 32.88 |
| Apocynaceae | *Himatanthus sucuuba* (Spruce) Woodson | 106 | 30.11 | 27.51 | 31.14 | 30.63 | 29.59 |
| Fabaceae | *Parkia platycephala* Benth | 34 | 9.66 | 10.48 | 8.12 | 8.89 | 9.42 |
| Fabaceae | *Hydrochorea* sp. | 28 | 7.95 | 10.04 | 4.68 | 6.32 | 7.56 |
| Fabaceae | *Andira* sp. | 15 | 4.26 | 5.68 | 6.78 | 5.52 | 5.57 |
| Clusiaceae | *Platonia insignis* Mart. | 4 | 1.14 | 1.31 | 10.37 | 5.75 | 4.27 |
| Fabaceae | *Stryhnodendron barbatiman* Mart. | 13 | 3.69 | 4.37 | 3.06 | 3.38 | 3.71 |
| Bixaceae | *Cochlospermum orinocense* (Kunth) Steud | 7 | 1.99 | 3.06 | 0.41 | 1.2 | 1.82 |
| Melastomataceae | *Bellucia* sp. | 2 | 0.57 | 0.87 | 2.33 | 1.45 | 1.26 |
| Anacardiaceae | *Anacardium occidentale* L. | 2 | 0.57 | 0.87 | 0.98 | 0.78 | 0.81 |
| Anacardiaceae | *Myracrodruom urundeuva* Fr. All. | 3 | 0.85 | 1.31 | 0.13 | 0.49 | 0.76 |
| Sapindaceae | *Talisia retusa* R. S. Cowan | 3 | 0.85 | 1.31 | 0.08 | 0.47 | 0.75 |
| Malphigiaceae | *Byrsonima crassifólia* L. Rich | 2 | 0.57 | 0.87 | 0.33 | 0.45 | 0.59 |
| Hypericaceae | *Vismia brasiliensis* Choisy | 1 | 0.28 | 0.44 | 0.06 | 0.17 | 0.26 |
| Sapotaceae | *Manilkara* sp. | 1 | 0.28 | 0.44 | 0.05 | 0.17 | 0.26 |
| Apocynaceae | *Aspidosperma* sp. | 1 | 0.28 | 0.44 | 0,04 | 0.16 | 0.25 |
| Myrtaceae | *Campomanesia* sp. | 1 | 0.28 | 0.44 | 0.03 | 0.16 | 0.25 |
| | | | **Patizal village** | | | | |
| | | | **Regenerating stratum** | | | | |
| Apocynaceae | *Hancornia speciosa* Gomes | 108 | 30.68 | 24.24 | 32.97 | 31.83 | 29.30 |
| Apocynaceae | *Himatanthus sucuuba* (Spruce) Woodson | 75 | 21.31 | 19.48 | 26.98 | 24.14 | 22.59 |
| Fabaceae | *Machaerium* sp. | 40 | 11.36 | 12.55 | 7.79 | 9.58 | 10.57 |

**Table 2.** Contd.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fabaceae | *Myracrodruon urundeuva* Fr. All. | 18 | 5.11 | 6.06 | 10.76 | 7.94 | 7.31 |
| Salicaceae | *Casearia* sp. | 26 | 7.39 | 8.66 | 2.14 | 4.76 | 6.06 |
| Fabaceae | *Hydrochorea* sp. | 13 | 3.69 | 3.9 | 5.84 | 4.77 | 4.48 |
| Sapotaceae | *Manilkara huberi* (Ducke) A. Chev. | 13 | 3.69 | 5.63 | 3.51 | 3.61 | 4.28 |
| Bixaceae | *Cochlospermum orinocense* (Kunth) Steud | 8 | 2.27 | 2.6 | 2.52 | 2.4 | 2.46 |
| Bignoniaceae | *Zeyheuria* sp. | 10 | 2.84 | 3.03 | 1.17 | 2.01 | 2.35 |
| Myrtaceae | *Myrcia* sp. | 10 | 2.84 | 3.03 | 0.36 | 1.6 | 2.08 |
| Malpighiaceae | *Byrsonima crassifolia* L. Rich | 4 | 1.14 | 1.3 | 1.83 | 1.48 | 1.42 |
| Rubiaceae | *Guettarda* sp. | 4 | 1.14 | 1.73 | 1.07 | 1.11 | 1.31 |
| Hypericaceae | *Vismia brasiliensis* Choisy | 5 | 1.42 | 0.87 | 0.53 | 0.98 | 0.94 |
| Caryocaraceae | *Caryocar villosum* (Aubl.) Pers | 4 | 1.14 | 0.87 | 0.54 | 0.84 | 0.85 |
| Fabaceae | *Hymenaea courbaril* L. | 3 | 0.85 | 1.3 | 0.39 | 0.62 | 0.85 |
| Fabaceae | *Parkia platycephala* Benth | 2 | 0.57 | 0.87 | 0.48 | 0.53 | 0.64 |
| Sapindaceae | *Talisia retusa* R.S. Cowan | 2 | 0.57 | 0.87 | 0.27 | 0.42 | 0.57 |
| Fabaceae | *Peltogyne* sp. | 2 | 0.57 | 0.87 | 0.26 | 0.42 | 0.56 |
| Theaceae | *Laplaceae fruticosa* | 2 | 0.57 | 0.87 | 0.14 | 0.36 | 0.52 |
| Apocynaceae | *Aspidosperma* sp. | 1 | 0.28 | 0.43 | 0.28 | 0.28 | 0.33 |
| Fabaceae | *Bauhinia forficata* Link | 1 | 0.28 | 0.43 | 0.08 | 0.19 | 0.27 |
| Anacardiaceae | *Anacardium occidentale* L. | 1 | 0.28 | 0.43 | 0.08 | 0.19 | 0.27 |
| **Adult stratum** | | | | | | | |
| Apocynaceae | *Hancornia speciosa* Gomes | 226 | 64.2 | 46.24 | 62.23 | 63.15 | 57.56 |
| Apocynaceae | *Himatanthus sucuuba* (Spruce) Woodson | 63 | 17.9 | 25.43 | 23.94 | 20.9 | 22.43 |
| Anacardiaceae | *Myracrodruon urundeuva* Fr. All. | 22 | 6.25 | 7.51 | 2.40 | 4.32 | 5.39 |
| Fabaceae | *Parkia platycephala* Benth | 8 | 2.27 | 4.05 | 4.91 | 3.59 | 3.74 |
| Fabaceae | *Machaerium* sp. | 8 | 2.27 | 2.89 | 2.20 | 2.24 | 2.46 |
| Bixaceae | *Cochlospermum orinocense* (Kunth) Steud | 8 | 2.27 | 4.05 | 0.4 | 1.33 | 2.24 |
| Fabaceae | *Hydrochorea* sp. | 6 | 1.70 | 3.47 | 0.39 | 1.05 | 1.85 |
| Malvaceae | *Pachira aquatica* Aubl. | 4 | 1.14 | 2.31 | 0.44 | 0.78 | 1.29 |
| Sapotaceae | *Manilkara huberi* (Ducke) A. Chev. | 3 | 0.85 | 1.73 | 0.86 | 0.85 | 1.15 |
| Malpighiaceae | *Byrsonima crassifolia* L. Rich | 2 | 0.57 | 1.16 | 0.45 | 0.51 | 0.72 |
| Anacardiaceae | *Anacardium occidentale* L. | 1 | 0.28 | 0.58 | 0.99 | 0.64 | 0.62 |
| Salicaceae | *Casearia* sp. | 1 | 0.28 | 0.58 | 0.79 | 0.64 | 0.55 |
| | | **Recurso village** | | | | | |
| | | **Regenerating stratum** | | | | | |
| Apocynaceae | *Hancornia speciosa* Gomes | 97 | 27.56 | 24.12 | 36.47 | 32.01 | 29.38 |
| Apocynaceae | *Himatanthus sucuuba* (Spruce) Woodson | 57 | 16.19 | 17.11 | 21.23 | 18.71 | 18.18 |
| Fabaceae | *Machaerium* sp. | 61 | 17.33 | 16.23 | 9.78 | 13.55 | 14.45 |
| Myrtaceae | Unidentified species | 53 | 15.06 | 15.79 | 4.84 | 9.95 | 11.9 |
| Bixaceae | *Cochlospermum orinocense* (Kunth) Steud | 41 | 11.65 | 12.72 | 11.01 | 11.32 | 11.79 |
| Malpighiaceae | *Byrsonima crassifolia* L. Rich | 27 | 7.67 | 8.33 | 12.26 | 9.97 | 9.42 |
| Unknown | Not identified 1 | 8 | 2.27 | 2.19 | 0.80 | 1.53 | 1.76 |
| Sapotaceae | *Manilkara* sp. | 2 | 0.57 | 0.88 | 0.58 | 0.57 | 0.67 |
| Rubiaceae | *Guettarda* sp. | 2 | 0.57 | 0.88 | 0.49 | 0.53 | 0.65 |
| Fabaceae | *Parkia platycephala* Benth | 1 | 0.28 | 0.44 | 1.05 | 0.66 | 0.59 |
| Fabaceae | *Hymenaea courbaril* L. | 1 | 0.28 | 0.44 | 0.92 | 0.6 | 0.55 |
| Anacardiaceae | *Myracrodruon urundeuva* Fr. All. | 1 | 0.28 | 0.44 | 0.55 | 0.41 | 0.42 |
| Hypericaceae | *Vismia brasiliensis* Choisy | 1 | 0.28 | 0.44 | 0.02 | 0.15 | 0.25 |
| **Adult stratum** | | | | | | | |
| Apocynaceae | *Hancornia speciosa* Gomes | 233 | 66.19 | 50.29 | 53.44 | 59.82 | 56.64 |
| Apocynaceae | *Himatanthus sucuuba* (Spruce) Woodson | 81 | 23.01 | 29.82 | 35.16 | 29.09 | 29.33 |
| Malpighiaceae | *Byrsonima crassifólia* L. Rich | 21 | 5.97 | 9.94 | 2.47 | 4.22 | 6.13 |
| Anacardiaceae | *Anacardium occidentale* L. | 4 | 1.14 | 2.34 | 4.77 | 2.96 | 2.75 |

**Table 2.** Cont'd.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fabaceae | *Parkia platycephala* Benth | 2 | 0.57 | 1.17 | 2.15 | 1.36 | 1.30 |
| Anacardiaceae | *Myracrodruon urundeuva* Fr. All. | 4 | 1.14 | 2.34 | 0.39 | 0.77 | 1.29 |
| Sapindaceae | *Talisia retusa* R.S. Cowan | 2 | 0.57 | 1.17 | 1.07 | 0.82 | 0.94 |
| Bixaceae | *Cochlospermum orinocense* (Kunth) Steud | 2 | 0.57 | 1.17 | 0.15 | 0.36 | 0.63 |
| Curcubitaceae | *Luffa operculata* Cogn | 1 | 0.28 | 0.58 | 0.24 | 0.26 | 0.37 |
| Sapotaceae | *Manilkara* sp. | 1 | 0.28 | 0.58 | 0.11 | 0.2 | 0.33 |
| Sapotaceae | *Machaerium* sp. | 1 | 0.28 | 0.58 | 0.50 | 0.17 | 0.31 |

NI = number of individuals, RD = Relative density, RF = Relative frequency, RDo = Relative Dominance, IV= Importance Value, CV = Cover Value.

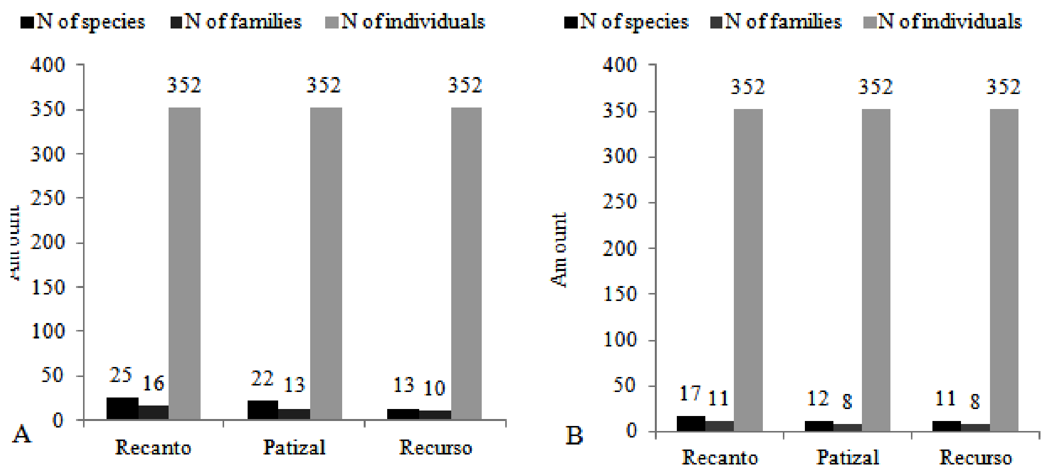


**Figure 2.** Number of species, families and individuals from both adult (A) and regenerating (B) strata recorded in sampled areas of Recanto, Patizal and Recurso villages in the P. A. Rio Pirangi, Morros municipality State of Maranhão, mid-north region of Brazil.

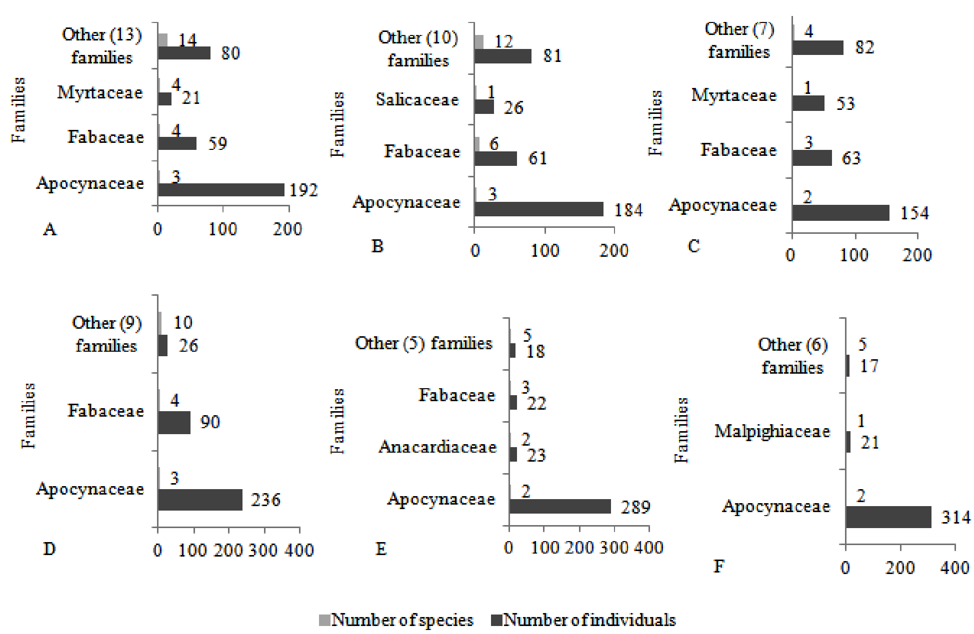


**Figure 3.** Number of individuals, species and families sampled in the vegetation regenerating (A, B, C) and adult (D, E, F) strata in Recanto, Patizal and Recurso villages respectively, in the P. A. Rio Pirangi, Morros municipality State of Maranhão, mid-north region of Brazil.

**Table 3.** Shannon Diversity Index of species sampled in the adult and regeneration strata in the Recanto, Patizal and Recurso villages in the Savannah-Restinga vegetation transition zone, Morros municipality, State of Maranhão, mid-north region of Brazil.

| Recanto | | Patizal | | Recurso | |
|---|---|---|---|---|---|
| **Sampling area (ha)** | **H'nats.ind.$^{-1}$** | **Sampling area (ha)** | **H' nats. ind.$^{-1}$** | **Sampling area (ha)** | **H' nats. ind.$^{-1}$** |
| **Vegetation regenerating stratum** | | | | | |
| 0.5 | 2.34 | 1.74 | 2.23 | 0.3 | 1.89 |
| **Vegetation adult stratum** | | | | | |
| 1.44 | 1.77 | 4.9 | 1.25 | 2.07 | 1.09 |

The Sorensen Similarity Index (SSI) was 30% for the regenerating and 40% and for the adult strata in the three villages. This indicates that, despite their proximity, the villages vegetation species composition in both regenerating and adult strata have low similarity, taking into account that only SSI values higher than 50% are considered as indicators of high similarity (Felfili and Resende, 2003).

Conversely, great similarity was observed among the three villages, with SSI values of 65, 62, and 58% for Patizal, Recanto and Recurso respectively, indicating vegetation stability.

## Density, frequency and relative dominance by sampled species in the naturally occurring mangaba areas

With regards to the regenerating stratum, *H. speciosa* occupied a relevant position for the phytosociological parameters Relative Density (RD), Relative Frequency (RF), and Relative Dominance (RDo) of the sampled vegetation in the Recanto, Patizal and Recurso villages. The species with higher RD in the Recanto were *H. sucuuba* (RD = 28.41%) with 100 individuals, followed by *H. speciosa* (RD = 25.28%) with 89 individuals. The other 23 species (92%) amounted 46.31% of the RD.

The species *H. speciosa* also occupied the first position in Patizal (RD = 30.86%) with 108 individuals followed by *H. sucuuba* (RD = 21.32%) with 75 individuals and *Machaerium* sp. (RD = 11.36%) with 40 individuals. The other 19 species (86.36%) responded for 36.65 % of the RD. The higher RD values in Recurso were recorded for *H. speciosa* (RD = 27.56%) with 97 individuals, followed by *Machaerium* sp. (RD = 17.33%) with 61 individuals, *H. sucuuba* (RD = 6.19%) with 57 individuals, one unidentified species of the Myrtaceae (RD = 15.06%) with 53 individuals, and *Cochlospermum orinocense* (Kunth) Steud (RD = 11.65%) with 27 individuals. The other eight species (61.53%) responded for only 12.21% of the total RD.

The higher Relative Frequency (RF) values in Recanto were recorded for *H. sucuuba* (RF = 24.35%) and *H. speciosa* (RF = 20.87%) The other 23 species (92%) represented 54.78% from the total RF. In Patizal, the higher RF values were 24.24, 19.48 and 12.55%, respectively for the species *H. speciosa*, *H. sucuuba* and *Machaerium* sp. The other 19 species (86.36%) amounted 43.73% from the total RF. The higher RF values in Recurso were observed for the species *H. speciosa* (RF = 24.12%), *H. sucuuba* (RF = 17.11%), *Machaerium* sp (RF = 16.23%), Myrtaceae (RF = 15.79%) and *C. orinocense* (RF = 12.72%). The other eight species (61.53%) represented only 14.03% of the total RF.

With regards to Relative Dominance (RDo), the most relevant species in Recanto village were *H. speciosa* (RDo = 29.30%) and *H. sucuuba* (RDo = 25.59%). Other 23 species (92%) amounted 45.11% from the total RDo. The higher RDo values recorded in Patizal were for *H. speciosa* (RDo = 32.97%), *H. sucuuba* (RDo = 26.98%) and *M. urundeuva* (RDo = 10.76%). The other 19 species (86.36%) reached 29.29% from the total RDo. In Recurso village the dominant species were *H. speciosa*, (RDo = 36.47%), *H. sucuuba* (RDo = 21.23%), *B. crassifolia* (RDo = 11.01%), and *C. orinocense*, (RDo = 69.23%). The other nine species (23%) amounted 19.03% from the total RDo.

Studies on natural species vegetation regeneration are still scarce, mainly due to the difficulty of regenerating species identification. Phytosociological surveys carried out on other naturally occurring mangaba environments had different results from those obtained in this study. For example, Barreira et al. (2002), studying floristic similarity between adult and regenerating strata in Savannh environment in the State of Minas Gerais, described for *H. speciosa* RD and RF values of 0.04 and 0.17% respectively. Similarly, Medeiros et al. (2007), in research carried out in Savannah environment in Central Brazil reported that the values of RD, RF and RDo for mangaba were so inexpressive that were not even cited by the authors.

With respect to the adult stratum sampled in Recanto village, the species with higher RD were *H. speciosa* (RD = 36.65%) with 129 individuals, followed by *H. sucuuba* (RD = 30.11%) with 106 individuals. The other 15 species (88.23%) amounted to 33.24% of the total RD. The higher RD values obtained in Patizal were for the species

*H. speciosa* (RD = 64.20%) with 226 individuals, and *H. sucuuba*, (RD = 17.9%) with 63 individuals. The other 10 species (83.33%) amounted to 17.9% of the total RD. The species with higher RD values in Recurso were *H. speciosa* (RD = 66.19%) with 233 individuals followed be *H. sucuuba* (RD = 23.01%) with 81 individuals. The other nine species (81.81%) amounted only 10.8% of the total RD.

With respect to RF, the species that reached higher values in Recanto village were *H. speciosa* (RF = 30.57%) and *H. sucuuba* (RF = 27.51%). Other relevant species were *P. platycephala* (RF = 10.48%) and *Hydrochorea* sp. (RF = 10.04%). The other 13 species (76.47%) amounted 21.40% of the total RF. The species with higher RF values in Patizal were *H. speciosa* (RF = 46.24%) and *H. sucuuba* (RF = 25.43%). The other 10 species (83.33%) represented 28.33% of the total RF. In Recurso the higher RF values were recorded for the species *H. speciosa* (RF = 50.29%) and *H. sucuuba* (RF = 29.82%). The other nine species (81.81%) represented only 19.89% of the total RF.

With regards to RDo, the species *H. speciosa* and *H. sucuuba* occupied the first and second positions respectively in all villages. For example, in Recanto *H. speciosa* (RDo = 31.43% and *H. sucuuba* (RDo = 31.14%. However *P. insignis* (RDo = 10.37%) also deserves to be highlighted. The other 14 species (82.35%) represented 27.06% of the total RDo. In Patizal, the higher RDo values were for *H. speciosa* (RDo = 62.23%) and *H. sucuuba* (RDo = 23.94%). The other 10 species (83.33%) totaled 13.83% of the total RDo. In Recurso, *H. speciosa* (RDo = 53.44%) and *H. sucuuba* (RDo = 35.16%) were prevalent species. The other nine species (81.81%) amounted 11.4% of the total RDo.

Marmontel et al. (2014) reported for *H. speciosa* RD the value of only 1.27% with occurrence of 40 individuals and RDo of 0.92% in sampling area of 1.5 ha. Similarly Castro and Conceição (2009) in a survey carried out in the Savannah vegetation at the Parque of Mirador, State of Maranhão, reported that *H. speciosa* did not stand out among the sampled species, with RD value of 0.31% with eight individuals, RF value of 0.69% and RDo of 0.36%.

Besides the proximity among the villages in the naturally occurring areas of mangaba in Morros, the results obtained in this research indicated remarkable differences with respect to vegetation structure and composition for both the adult and regenerating strata. Differences observed among species diversity and number of mangaba plants per area are probably due to the different use of the plant among the villages assessed in this study. Besides the greater diversity observed in Recanto village, the number of mangaba plants was lower in both the adult and regenerating strata when compared to the other villages. This can be explained by the intense use of the mangaba naturally occurring areas in agricultural activities by the surrounding community. Conversely, in Recurso and Patizal villages, greater awareness of the mangaba food, nutritional, economic and cultural values, resulted in the conservation of mangaba by the local population, which in fact, contributed to the significant number of mangaba plants in these villages.

**Importance value and cover value per species sampled in the mangaba naturally occurring areas**

The species *H. speciosa* and *H. sucuuba* reached relevant positions for the parameters Importance Value (IV) and Cover Value (CV) for both the adult and generating strata sampled in the three villages sampled in Morros. With regards to the regenerating stratum in Recanto village, the higher IV values were recorded for *H. sucuuba* (IV = 26.12%) and *H. speciosa* (IV = 25.16%) while the higher CV values were observed for *H. speciosa* (CV = 27.36%) and *H. sucuuba* (CV = 27.07%). The other 23 species (92%) amounted 48.72% of the total IV and 45.57% of the total CV. In Patizal, *H. speciosa* occupied the first position (IV = 29.3%) and (CV = 31.83%) followed by *H. sucuuba* (IV = 22.59%) and CV = 24.14%). The other 20 species (90.9%) amounted 48.11% of the total IV and 44.03% of the total CV. Finally, in Recurso, besides *H. speciosa,* (IV = 29.38% and VC = 32.01%); and *H. sucuuba* (IV = 18.18% and CV = 18.71%), other noteworthy species were *Machaerium* sp. (IV = 14.45% and CV = 13.55%), Myrtaceae (IV = 11.9% and VC = 9.95%); and *Cochlospermum orinocense* (IV= 11.79% and CV = 11.32%). The other eight species (61.53%) amounted 14.3% of the total IV and 14.46% of the total VC.

In the results reported by Barreira et al. (2002), *H. speciosa* obtained IV of only 1.39%, thus, it was not an important species to characterize the regenerating stratum of the assessed vegetation. This is very different from the results obtained in this study carried out in Morros. The more important species in the adult stratum in the Recanto village were *H. speciosa* (IV = 32.88% and CV = 34.04%); and *H. sucuuba* (IV = 29.59% and CV = 30.63%). The other 15 species (88.23%) of the total of 17 species amounted 38.12% of the total IV and 35.33% of the total CV. In Patizal, *H. speciosa* was the most important species (IV = 57.56%) and (CV = 63.15%), followed by *H. sucuuba* (IV = 22.43%) and CV = 20.9%). The other 10 species (83.33%) amounted 20.01% of the total IV and 15.95% of the total CV. In Recurso, the higher IV values of 56.64 and 29.33% and the higher CV values of 59.82 and 29.09%, were again for the species *H. speciosa* and *H. sucuuba*, respectively. The other nine species (81.81%) amounted 14.03% of the total IV and 11.09% of the total CV.

In contrast, Castro and Conceição (2009) described for *H. speciosa* (CV = 0.64% and IV = 1.33%). These authors observed that the species was not highlighted by these parameters. Similar results were obtained by

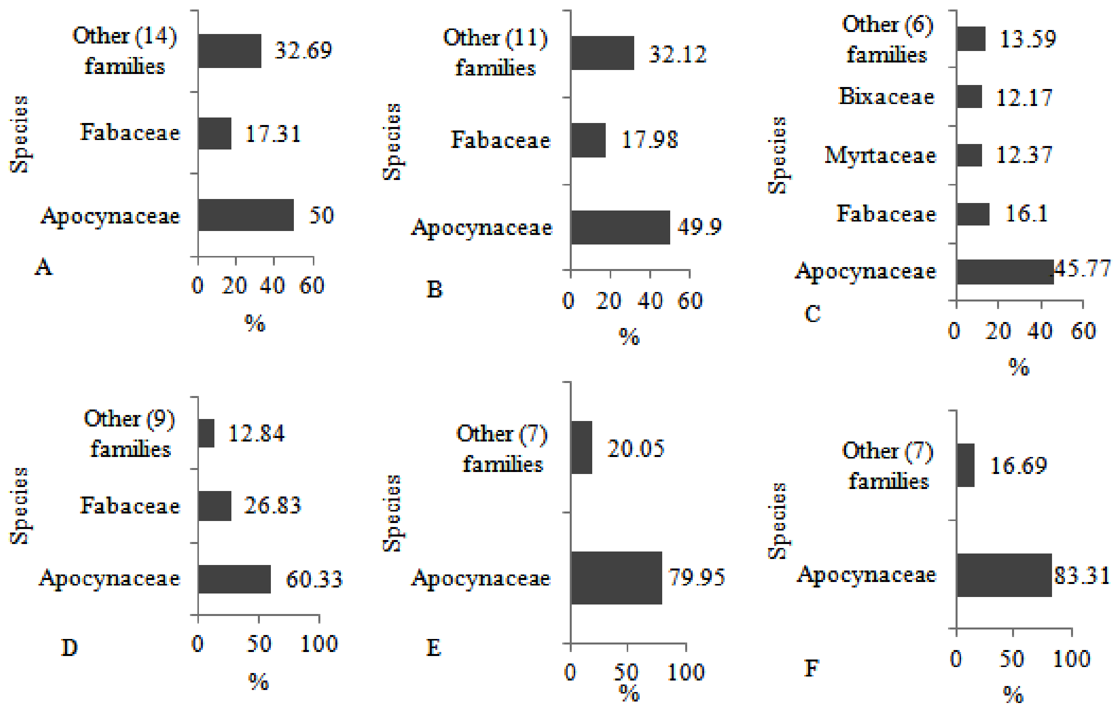


**Figure 4.** Importance Value per family sampled for the regenerating (A, B, C) and adult strata (D, E, F) of the vegetation assessed in Recanto, Patizal and Recurso villages respectively, in the P. A. Rio Pirangi, Morros municipality, State of Maranhão, mid-north region of Brazil.

Marmontel et al. (2014), who reported that the species reached IV value of only 3.27%; as well as in results described by Mota et al. (2014) in phytosociological survey carried out in Biribiri State Park, in Diamantina municipality, State of Minas Gerais where the mangaba did not stood out among the other species, reaching IV value of only 1.23%. It should be pointed out that the presence of the species *H. sucuuba* with IV values between 18.18 and 29.59% may be indicative of suitable area of growing and conservation of mangaba, however other studies are needed to quantify the relationship between the two species.

## Importance value (IV) per family sampled in the mangaba naturally occurring areas

The Apocynaceae family reached the higher IV values in three villages assessed. The IV values varied from 45.77 to 50% for the regenerating and from 60.33 to 83.31% for the adult strata (Figure 4). This suggests high ecological importance of this family for the vegetation assessed in this study.

These results are similar to those reported in research carried out by Castro and Conceição (2009) in Savannah vegetation in the Parque of Mirador in the State of Maranhão where the authors noted the same families described in Morros, although the highlights were for the families Myrtaceae (IV = 34.54%) and Malpighiaceae (IV = 28.17%).

## Conclusions

The more important species for the characterization of the Savannah-Restinga transition vegetation zone sampled in the mid-north of Brazil were *H. speciosa* and *Himatanhus sucuuba*, both had the higher importance value for the regenerating and adult strata. The *H. speciosa* importance value varied from 25.16 to 29.38% for the regenerating and from 32.88 to 57.56% for the adult strata among the vegetation sampled areas of Recanto, Patizal and Recurso villages, suggesting high ecological importance of this species for the sampled ecotone. The vegetation with naturally occurring mangaba showed low species diversity with H' varying from 1.89 to 2.34 $nats.ind.^{-1}$ for the regenerating and from 1.09 to 1.77 $nats.ind.^{-1}$ for the adult strata. The high Sorensen similarity indices among the vegetation strata in Recanto (65%), Patizal (62%) and Recurso (58%) suggest stability of the sampled vegetation in the naturally occurrence areas of mangaba.

## Conflict of interests

The authors have not declared any conflict of interests.

## ACKNOWLEDGMENTS

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*Full Length Research Paper*

# Soybean agronomic performance in narrow and wide row spacing associated with NPK fertilizer under no-tillage

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**The purpose of this research was to evaluate soybean agronomic traits performance under row spacing associated with NPK fertilizer. The experimental design was set up in a randomized complete block and the treatments were arranged with factorial concept, consisting of four NPK (02-20-18%) fertilizer rates (0; 200; 400 and 600 kg ha$^{-1}$) and five row spacing (0.35; 0.45; 0.50; 0.60 and 0.70 m), with three replications. The measurements were performed in two consecutive cropping seasons. The following variables were determined: time of canopy closure; plant height; the height of the first pod insertion; number of pods per plant; number of branches per plant; number of grains per pod; 1000-grain weight; and grain yield. The narrow row spacing (below than 0.40 m) may be a profitable alternative to reduce intraspecific plant competition resulting in improvement of soybean agronomic performance, resulting faster canopy closure and relative equidistance among soybean plants. Narrow rows promoted increase in soybean grain yield. The row spacing of 0.35 m associated with 600 kg ha$^{-1}$ of NPK fertilizer was the profitable combination to achieve the highest soybean grain yield. The wide row spacing demand more fertilizer to remain the same performance than in 0.35 m spacing row.**

**Key words:** *Glycine max* L., soil fertility, cropping season, soil science.

## INTRODUCTION

Soybean is largely cultivated in Brazil, which is the most important grain crop. This fact had as precedent the success of soybean cultivation in Brazilian Cerrado biome being result of a sum of important environmental factors, as appropriate photoperiod and favorable rainfall seasons. However, the development of studies and technologies in the correction and conservation of the soil, genetic improvement, selecting late cultivars for low latitude, and agricultural practices have been helpful in achieving so expressive productivity (Spehar and Trecenti, 2011). On average, the grain yield of soybean in the highest soybean producer State of Brazil (Mato Grosso) is 3,069 kg $ha^{-1}$, although grain yield can achieve values above 4,000 kg $ha^{-1}$ (Ensinas et al., 2015).

The challenge to increase crop yield is increasing around the world, to feed a growing population is necessary more than improvement of new cultivars. The possibility to increase the crop production with alteration in soybean plant arrangement can be a profitable alternative to obtain increment in grain yield with low investment for farmers. Sowing is one of the key factors that influence the success of any crop establishment and productivity. The optimization of row spacing and in-row plant density is a simple procedure with a low cost but has a significant influence on yield (Soratto et al., 2012) and is essential to maximize grain production.

A high plant density may result in overgrown plants and subsequently lodging, whereas a low plant population may enable weed infestation. Light interception by plants strongly influences the crop yield when other environmental factors are favorable, and it is modified by the plant spatial distribution in a given area. Soybeans have the ability to regulate growth and yield component production in response to changes in plant population and competition.

Increase in plant population density often results in higher soybean grain yield, but this is dependent on a number of factors, including climatic conditions of the growing region, plant size and leaf area, plant maturity and soil fertility. Higher soybean grain yields can be associated with the optimization of sunlight interception during the initial vegetative and breeding stage. The number of pods per plant may decrease in case of shadow during the bloom stage (Kurosaki and Yumoto, 2003), and consequently the grain yield decrease.

In Brazil and many other countries, the traditional row spacing in soybean is 0.45 m (Rosa et al., 2015; Freitas et al., 2016). The narrow row spacing can possibly improve the soybean performance and sunlight interception due to better plant distribution in the field. As reported by Moreira et al. (2015), wider rows spacing increases the soil temperature and decreases plant height, chlorophyll content and transpiration rates. Besides, the plant arrangement allows increasing soybean performance; another factor can be the improvement in soil fertility, because the alteration in row spacing can affect the nutritional demand of the plant.

Different approaches have been used to increase crop yield, such as increasing the amount of fertilizer, application of high-density resistant cultivars, uniformity of row spacing distribution (Liu et al., 2016). The soil fertility in Brazil shows low fertility, which is associated with the weathering in the process of soil formation. Highly weathered soils, such as most Brazilian soils are inherently infertile, with low cation exchange capacity, pH generally ranging around 4 to 5.5 and mineralogical assembly predominantly of iron oxides (Fe) and aluminum (Al). The immediate consequence of these intrinsic properties of tropical soils is the high sorption capacity of anions, which results in low concentration of P in soil solution (Pavinato et al., 2009; Abdala et al., 2015).

The knowledge about relationship between the row spacing and fertilizer on soybean development are insufficient, based on it, the purpose of this research was to evaluate soybean agronomic traits performance under row spacing associated with NPK (02-10-18) fertilizer in two consecutive cropping seasons.

## MATERIALS AND METHODS

### Location and soil description

This research was carried out in 2011/2012 and 2012/2013 cropping seasons in a Rhodic Hapludox classified according to Santos et al. (2013), sandy texture, and clay mineralogy constituted mainly by Al/Fe oxy-hydroxides. Located in the municipality of Ponta Porã, State of Mato Grosso do Sul, Brazil (approximately 22°34'09" S latitude, 54°48'2" W longitude, average altitude 553 m above sea level).

### Weather condition in the experimental location

The data of rainfall and temperature in the experimental location are shown in Figure 1. The period of data collection was initiated in January, 2010 and ended in December, 2013. The region is classified as tropical climate of type Cwa, with rainy summer and dry winter, according to (Köppen, 1948).

### Historic of the experimental area

The farm area has been cultivated or 10 years with crop succession of soybean in spring-summer and maize in fall-winter season. The fertilization was applied topdressing according to soil chemical analysis. The soil chemical properties analyzed before the establishment of the experiment in July, 2011 are in Table 1. The textural analysis showed the following results: 110, 70, and 820 g $kg^{-1}$ of clay, silt and sand respectively, according to Claessen (1997). Before the experiment implementation, the correction of soil acidity was performed in September, 2010. The recommendation of liming rate was based on the soil chemical analysis results (Table 1), which was necessary to apply 500 kg $ha^{-1}$ of liming in topdressing. The dolomitic lime showed calcium carbonate

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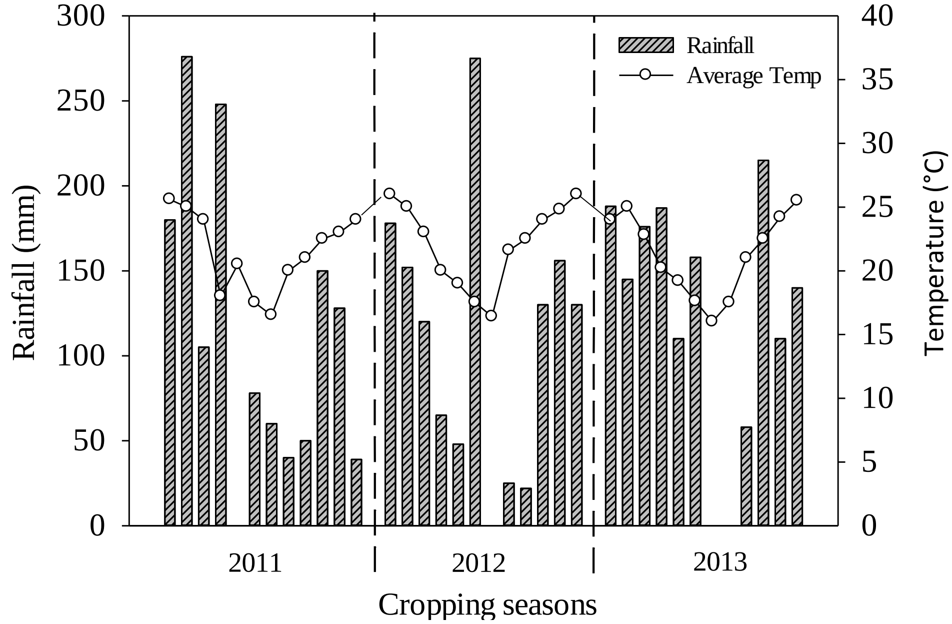


**Figure 1.** Rainfall and average monthly temperature in the period from January, 2011 to December, 2013.

**Table 1**. Soil chemical analysis under the experimental area before the experiment implementation, in 0-20 cm depth.

| pH | $P_{Mehlich-1}$ | OM | K | Ca | Mg | Ca+Mg | H | Al | H+Al | SB | CEC | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CaCl_2$ | mg $dm^{-3}$ | g $dm^{-3}$ | ------------------------------- $cmol_{(c)}$ $dm^{-3}$ ------------------------------------ | | | | | | | | | % |
| 5.69 | 46.26 | 15.33 | 0.07 | 2.00 | 1.00 | 3.00 | 1.68 | 0.00 | 1.68 | 3.07 | 4.75 | 64.63 |

OM_Organic Matter; Exchangeable (KCl 1 mol $L^{-1}$) $Ca^{2+}$, $Mg^{2+}$ and $Al^{3+}$; total acidity pH 7.0 ($H^{+}$+$Al^{3+}$); SB_Sum of bases=∑cations; CEC_Cation Exchange Capacity; BS_Base Saturation=(∑cations/CEC)x100.

equivalent (CCE) of 80% (33% calcium oxide and 15% magnesium oxide). Previously the soybean seeding, the desiccation of the cover crops was conducted with herbicide chlorimuron-ethyl (20 g a.i. $ha^{-1}$), 2.4-D (967 g a.i. $ha^{-1}$) and glyphosate (1,440 g a.i. $ha^{-1}$). After the soil fertilization and cover crops being dissected, the seeding period started in October (soybean) and February (maize).

### Experimental design and treatments

The experimental design was set up in a randomized complete block design and the treatments were arranged in factorial concept, consisting of four NPK (02-10-18) fertilizer rates (0; 200; 400 and 600 kg $ha^{-1}$) and five row spacing (0.35; 0.45; 0.50; 0.60 and 0.70 m), with three replications. The experimental units had dimensions of 15 m length by 9 m width. All operations were executed with a tractor wheel of 112 HP (Horsepower). The useful area to agronomic measurements was five central rows of each experimental plot, in which was disregarded 5 m initial and 5 m were ended in each row, in both cropping seasons. For the seeding procedure, the grain drill was used with the rows spaced according to experiment treatments. The fertilizer application in the experimental area was performed three days before the seeding. The drill had 26 rows and 0.17 m row spacing, and the application of fertilizer was deeper in soil at 8 cm depth, following the recommendation of the fertilizer treatments rates, which were allocated under and apart the seed to avoid contact. The seeding of soybean (*Glycine max* cv. BMX-Potência RR) crop was established on November 5$^{th}$, 2011 and November 10$^{th}$, 2012, both cropping season under no-till system. Soybean germination and purity of the seed were 95 and 99%, respectively. The seed density was 350,000 plants per hectare, the row spacing changed from 0.35 to 0.70 m according to the treatments of row spacing in soybean. The soybean seeds were treated with fungicide [Pyraclostrobin (25 g a.i. $ha^{-1}$) + Thiophanate-methyl (22.5 g a.i. $ha^{-1}$)], insecticide [Fipronil (25 g a.i. $ha^{-1}$)], micronutrients [cobalt (2.32 g $L^{-1}$) and molybdenum (40.6 g $L^{-1}$)], and these rates were in gram of active ingredient per 80 kg of seeds. Besides, the seeds were inoculated before the sowing with inoculant in turf, which contained the bacteria *Bradyrhizobium elkani* (Race Semia 5080) and *Bradyrhizobium japonicum* (Race Semia 5079) in the concentration of 5x$10^9$ viable cells per gram of inoculant. It was used 100 g of inoculate per 50 kg of soybean seed.

### Assessed parameters and statistical analysis

Ten days after plant emergence was evaluated the initial stand, through the plant counting in each row. The time of canopy closure was measured weekly by observation in the field, in which was

**Table 2**. Rule for interpreting the size of Person's correlation coefficients based on Hinkle et al. (2003).

| Size of correlation | Interpretation |
|---|---|
| 0.90 to 1.0 (-0.90 to -1.0) | Very high positive (negative) correlation |
| 0.70 to 0.90 (-0.70 to -0.90) | High positive (negative) correlation |
| 0.50 to 0.70 (-0.50 to -0.70) | Moderate positive (negative) correlation |
| 0.30 to 0.50 (0.30 to -0.50) | Low positive (negative) correlation |
| 0 to 0.30 (0 to -0.30) | Negligible correlation |

considered the number of days after soybean emergence to establish the time of canopy closure. When the soybean plant reached R8 reproductive stage (full maturation), 50 plants in each plot were measured and determined the following variables: plant height (PH); the height of the first pod insertion (HFPI); number of pods per plant (NPP); number of branches per plant (NBP); number of grains per pod (NGP); 1000-grain weight (1000-GW); and grain yield (GY).

The soybean grain yield was measured by the manual harvest in the experimental unit in a dimension of 5 m by 0.9 m in the center of each experimental unit. The grains were weighted and the grain yield was shown in kg $ha^{-1}$. Before the harvest, the final stand counting the plants in the useful row was evaluated. After the soybean harvest, the following variables were measured: number of failed pods; number of grains per pod; number of pods per plant; number of grains per plant (NGPl). The soybean grain yield was determined harvesting all the plants in 2 rows with 7 m length. The grain moisture and weight was determined at seed laboratory, and the moisture was corrected for 13%. In order to obtain the 1000-GW, it was collected 10 sub-samples with 100 grains per plot.

The variables evaluated in the experiment were submitted to the analysis of variance (ANOVA) by the *F*-test. The response surface was adjusted in case of significant interaction ($p \leq 0.01$) between row spacing with NPK rates. The correlation matrix of dependent variable was performed to obtain the degree of relationship between them. In case of significant correlation ($p \leq 0.01$ or 0.05), the strength was defined as Table 2. These statistical analyses were carried out with the assistance of ASSISTAT software.

## RESULTS AND DISCUSSION

### Statistical analysis of assessed variables

In order to assess and compare the results in two cropping seasons, it was measured the same soybean agronomic traits in both cropping seasons [2011/2012 (CS-1) and 2012/2013 (CS-2)]. In both cropping seasons, the variables studied were more affected by row spacing than NPK fertilizer rates or the interaction between both treatments. The number of failed pods per plant (NFPP) and 1000-grain weight did not show any significant difference ($p>0.05$) in the treatments evaluated in both cropping seasons (CS-1 and CS-2) (Table 3).

The significant interaction ($p<0.01$), between row spacing and NPK fertilizer, was noted just in CS-2, for the following variables: number of branches per plant (NBP), number of pods per plant (NPP), number of grains per plant (NGPl), and grain yield (GY) (Table 3). The cropping seasons affected the performance of soybean for the most variables assessed, as follow: time for canopy closure (TCC), plant height (PH), height of the first pod insertion (HFPI), number of failed pods per plant (NFPP), and number of grains per plant (NGPl). However, the grain yield did not alter between the cropping seasons (Table 3).

### Agronomic traits of soybean affected by rows spacing

The row spacing showed higher effects on soybean performance than NPK fertilizer rates in both cropping seasons (CS-1 and CS-2). The experiment was initially defined with 350,000 plants per hectare, which changed the initial and final stand (FS) increasing the number of plants per meter as the row spacing increased from 0.35 to 0.70 m (Figure 2A). In 0.35 m row spacing, the FS was 9.2 and 9.6 plants $m^{-1}$, for CS-1 and CS-2, respectively. On the other hand, in 0.70 m row spacing was noted the FS of 20.2 and 18.4 plants $m^{-1}$, for CS-1 and CS-2, respectively (Figure 2A). In comparison between cropping seasons, no significant difference ($p>0.05$) was observed in FS (Table 4).

Narrow rows (0.35 m) resulted in faster time of canopy closure (TCC) in both cropping seasons (Figure 2B), and the canopy with total closure by soybean plants occurred 72.9 and 66.5 days after emerged plant, in CS-1 and CS-2, respectively. On the other hand, in the wide rows (0.70 m) the total canopy closure occurred at 118.4 and 85.7 days after emerged plant, respectively for CS-1 and 2 (Figure 2B). The faster TCC by soybean plants may improve the capitation of sunlight and efficiency of nutrients and water used by soybean plants.

The increase in plant distribution in soil can avoid the intraspecific plant competition in narrow rows (less than 0.50 m), which may result in better plant performance. The faster canopy closure in narrow spacing contributes to decrease the incidence of weeds. As reported by Wells et al. (2014), in wider row spacing (0.76 m) the incidence of weeds were significantly higher in comparison to narrow row spacing (0.19 and 0.38 m). The plant height (PH) increased in wider rows in CS-1, but did not show any significant effect in CS-1 (Figure 2C). In CS-1 the PH average was 88.9 (CS-1) and 68.6 cm (CS-2), in both cropping seasons PH did not achieve the height for

**Table 3.** Summary of analysis of variance (ANOVA).

| Variables | ----------2011/2012 Cropping season-------- | | | | ----------2012/2013 Cropping season--------- | | | |
|---|---|---|---|---|---|---|---|---|
| | Source of variation | | | | | | | |
| | Block | NPK | RS | NPKxRS | Block | NPK | RS | NPKxRS |
| *df* | 2 | 3 | 4 | 12 | 2 | 3 | 4 | 12 |
| | ---------------------------------------Mean of squares-------------------------------------------- | | | | | | | |
| FS | $0.2^{ns}$ | $0.32^{ns}$ | 217.55** | $0.72^{ns}$ | $4.92^{ns}$ | $1.74^{ns}$ | 147.92** | $1.78^{ns}$ |
| TCC | $96.80^{ns}$ | $28.55^{ns}$ | 4589.40** | $16.33^{ns}$ | 29.26* | $28.68^{ns}$ | 732.73** | $16.9^{ns}$ |
| PH | $42.81^{ns}$ | $4.48^{ns}$ | 127.79** | $14.33^{ns}$ | $57.95^{ns}$ | $60.23^{ns}$ | $58.31^{ns}$ | $23.23^{ns}$ |
| HFPI | $0.05^{ns}$ | $0.23^{ns}$ | 5.29* | $0.44^{ns}$ | $6.11^{ns}$ | $2.95^{ns}$ | $0.64^{ns}$ | $0.88^{ns}$ |
| NBP | $0.01^{ns}$ | $0.03^{ns}$ | 0.21* | $0.04^{ns}$ | $0.09^{ns}$ | $0.01^{ns}$ | 0.14** | 0.9** |
| NFPP | $052^{ns}$ | $0.55^{ns}$ | $0.14^{ns}$ | $0.28^{ns}$ | $0.01^{ns}$ | $0.36^{ns}$ | $0.24^{ns}$ | $0.24^{ns}$ |
| NGP | 0.24* | 1.02** | 0.85** | $0.10^{ns}$ | $0.26^{ns}$ | $0.32^{ns}$ | $0.23^{ns}$ | $0.17^{ns}$ |
| NPP | $0.03^{ns}$ | $0.59^{ns}$ | 3.52** | $0.94^{ns}$ | 3.37* | 4.90* | 1.84** | 1.24** |
| NGPI | $0.06^{ns}$ | $1.47^{ns}$ | 9.21** | $2.52^{ns}$ | 8.66* | 13.42* | 4.75** | 3.19** |
| GY | $0.18^{ns}$ | $0.35^{ns}$ | 2.36** | $0.91^{ns}$ | $5.57^{ns}$ | 6.59* | 4.37** | 1.57** |
| 1000GW | $0.05^{ns}$ | $0.06^{ns}$ | $0.15^{ns}$ | $0.13^{ns}$ | $0.38^{ns}$ | $0.01^{ns}$ | $0.19^{ns}$ | $0.17^{ns}$ |

*df*_degree of freedom. *Significant at 0.05 probability level. **significant at 0.01 probability level by *F*-value. $^{ns}$no significant at 0.05 probability level by *F*-value. FS_final stand; TCC_time for canopy closure; PH_plant height; HFPI_height of the first pod insertion; NBP_number of branches per plant; NFPP_number of failed pods per plant; NGPI_number of grains per plant; GY_grain yield; 1000GW_1000-grain weight.

cultivar BMX-Potência RR, which implies that other factors reduced the plant development.

As reported by Freitas et al. (2016), the soybean cultivar BMX-Potência RR with height of 1.03 m is ideal for this cultivar development without water restriction. In CS-1 the average of plant height was 64.27 cm in the space between rows of 0.35 m, which was below the acceptable values of 0.91 to 1.03 m in average (Franchini et al., 2014; Rosa et al., 2015; Freitas et al., 2016). The relationship between plant heights measured at the end of plant cycle, the lowest plant height in narrow rows may be associated with reduction of intraspecific plant competition avoiding blanching resulting in smaller PH. The narrow rows, below 0.40 m, may decrease the plant height noting smaller lodgings and higher percentage of surviving plant. The higher plant height in CS-2 in relation to CS-1 probably occurred in function of better weather conditions in CS-2 (Table 4).

The optimization of row spacing and in-row plant density is a simple procedure with a low cost but has a significant influence on yield. However, Berger-Doyle et al. (2014) observed that row spacing did not have any effect on any major agronomic traits, indicating that specialty soybeans can be equally productive in either narrow or wide rows. However, soybeans planted in narrow-row spacing might be more profitable due to less herbicide and water costs than traditional wide-row spacing in the United States (that is, >70 cm). The narrow rows spacing promoted higher height of first pod insertion (HFPI) (Figure 2D). The HFPI did not show any significant difference (p>0.05) in both cropping seasons. The average HFPI was 11.65 cm, this height is in accordance to the expected for BMX-Potência RR. As reported by Ramteke et al. (2012), the adequate value for HFPI would be above 12 cm. Freitas et al. (2016) found in average 12.74 cm. The importance of HFPI in relation to the mechanical harvest of soybean, because in sloping land the loss of grain during the harvest is high due to the impossibility to harvest below 10 cm. Cunha et al. (2013) suggested 10 to 12 cm of HFPI in flat slope and above 15 cm in sloping land to avoid loss during the harvest.

The space between rows did not affect HFPI in both cropping seasons (Figure 2D). The number of failed pods per plant (NFPP) was statistically higher in CS-2, but in both cropping seasons no difference among the row spacing was noted. The CS-1 showed 2.5 times more failed pods per plant than in CS-2 (Table 4). The lowest NFPP in CS-1 may be associated with the drought stress occurred in this cropping season what maybe decreased the capacity of biomass accumulation by plant and grain fill. The narrow rows promoted higher number of branch per plant (NBP) (Figure 2E). No significant statistic difference (p>0.05) was noted for NBP between the cropping seasons, but HFPI was higher in CS-1 (Table 4). The higher values of number of branches per plant (NBP) noted in the narrow rows has been associated with many factors, as: the better water use due to the shelter of branches on soil surface, better root distribution in soil, decline of intraspecific plant competition, uniform exploration of soil fertility and higher sun radiation interception (Kuss et al., 2008). As reported by Rambo et al. (2004), the uniformity of the plant distribution may result in increasing the number of pods per square meter majority in R1 and R5 breeding stage. As reported by De

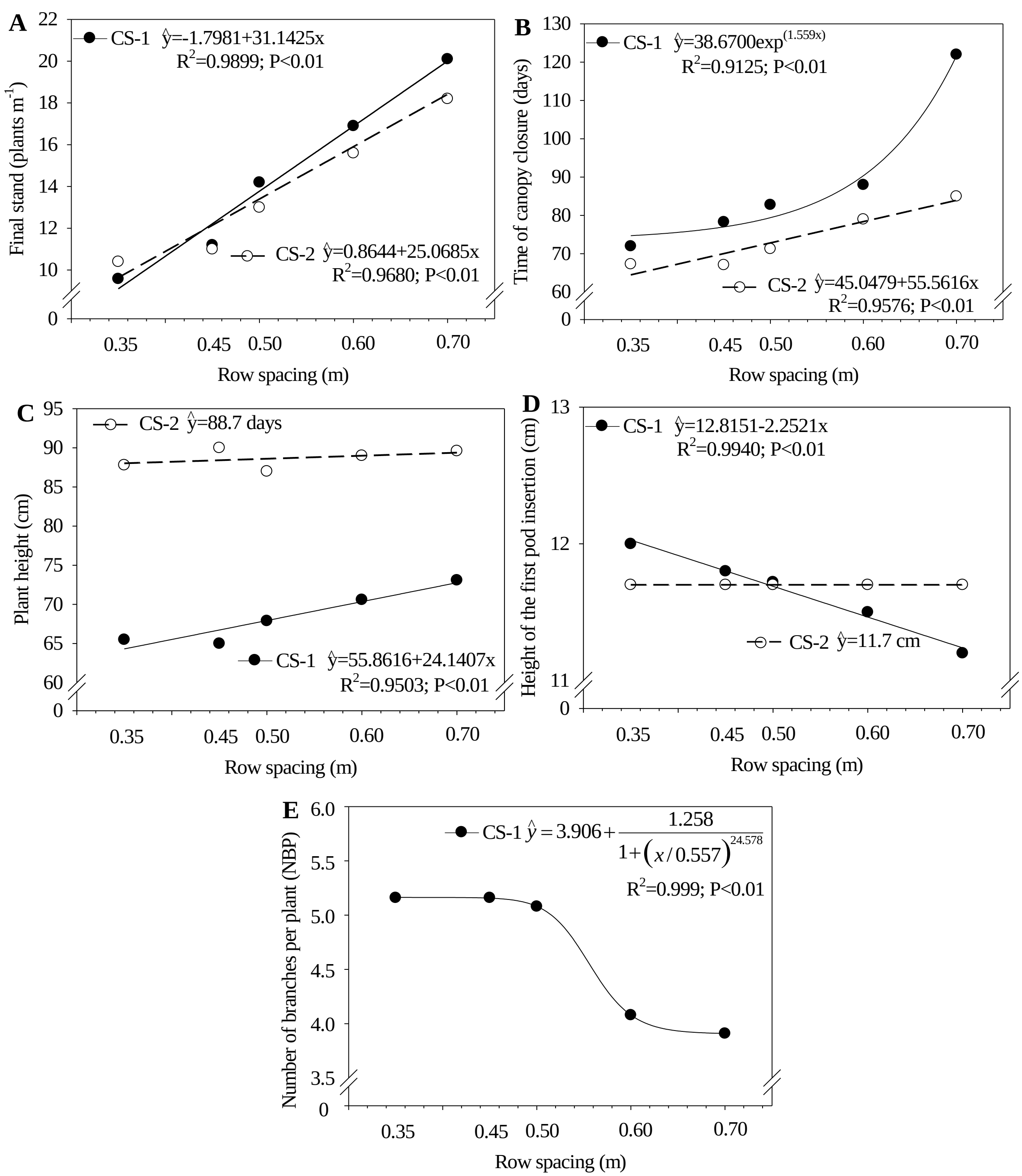


**Figure 2.** Row spacing in soybean affected soybean agronomic traits in two cropping seasons. CS-1 (2011/2012 cropping season) and CS-2 (2012/2013 cropping season); (A) final stand (FS); (B) time of canopy closure (TCC); (C) plant height (PH); (D) height of the first pod insertion (HFPI); (E) number of branches per plant (NBP).

Bruin and Pedersen (2008), the increase in row spacing can promote the decreasing in soybean grain yield.

## Row spacing and NPK fertilizer affected some agronomic traits of soybean

The number of grain per pod (NGP) was not affected by row spacing in CS-2 and no significant difference was observed between cropping seasons (Table 4), the average of NGP was 2.5 for both cropping seasons. On the other hand, in CS-1 was possible to adjust the logistic model for the data, which showed decreasing in NGP in wider row spacing (Figure 3A). NGP showed very high negative correlation with number of plants per meter (FS), TCC, and PH (Table 5). NPP, and NGPI decreased

**Table 4**. Test of mean for soybean agronomic traits in two cropping seasons.

| Cropping seasons | FS (pl m$^{-1}$) | TCC (days) | PH (cm) | HFPI (cm) | NBP | NFPP | NGP | NPP | NGPI | SGY (kg ha$^{-1}$) | 1000GW (g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2011/2012 | 14.4$^a$ | 88.7$^a$ | 88.9$^a$ | 11.7$^a$ | 4.7$^a$ | 5.9$^a$ | 2.5$^a$ | 56.4$^b$ | 146.6$^b$ | 3800$^a$ | 0.16$^a$ |
| 2012/2013 | 13.9$^a$ | 73.9$^b$ | 68.6$^b$ | 11.2$^b$ | 4.9$^a$ | 3.4$^b$ | 2.5$^a$ | 62.5$^a$ | 162.5$^a$ | 4200$^a$ | 0.16$^a$ |
| CV (%) | 26.0 | 17.5 | 6.5 | 10.6 | 9.8 | 22.1 | 7.8 | 12.1 | 12.1 | 25.6 | 2.4 |
| *F*-value | 0.5$^{ns}$ | 32.1** | 461.1** | 5.4* | 0.8$^{ns}$ | 26.2** | 0.1$^{ns}$ | 5.3* | 5.5* | 2.5$^{ns}$ | 0.1$^{ns}$ |

*Significant at 0.05 probability level. **significant at 0.01 probability level by *F*-value. $^{NS}$no significant at 0.05 probability level by *F*-value. FS_final stand; TCC_time for canopy closure; PH_plant height; HFPI_height of the first pod insertion; NBP_number of branches per plant; NFPP_number of failed pods per plant; NGPI_number of grains per plant; GY_grain yield; 1000GW_1000-grain weight.

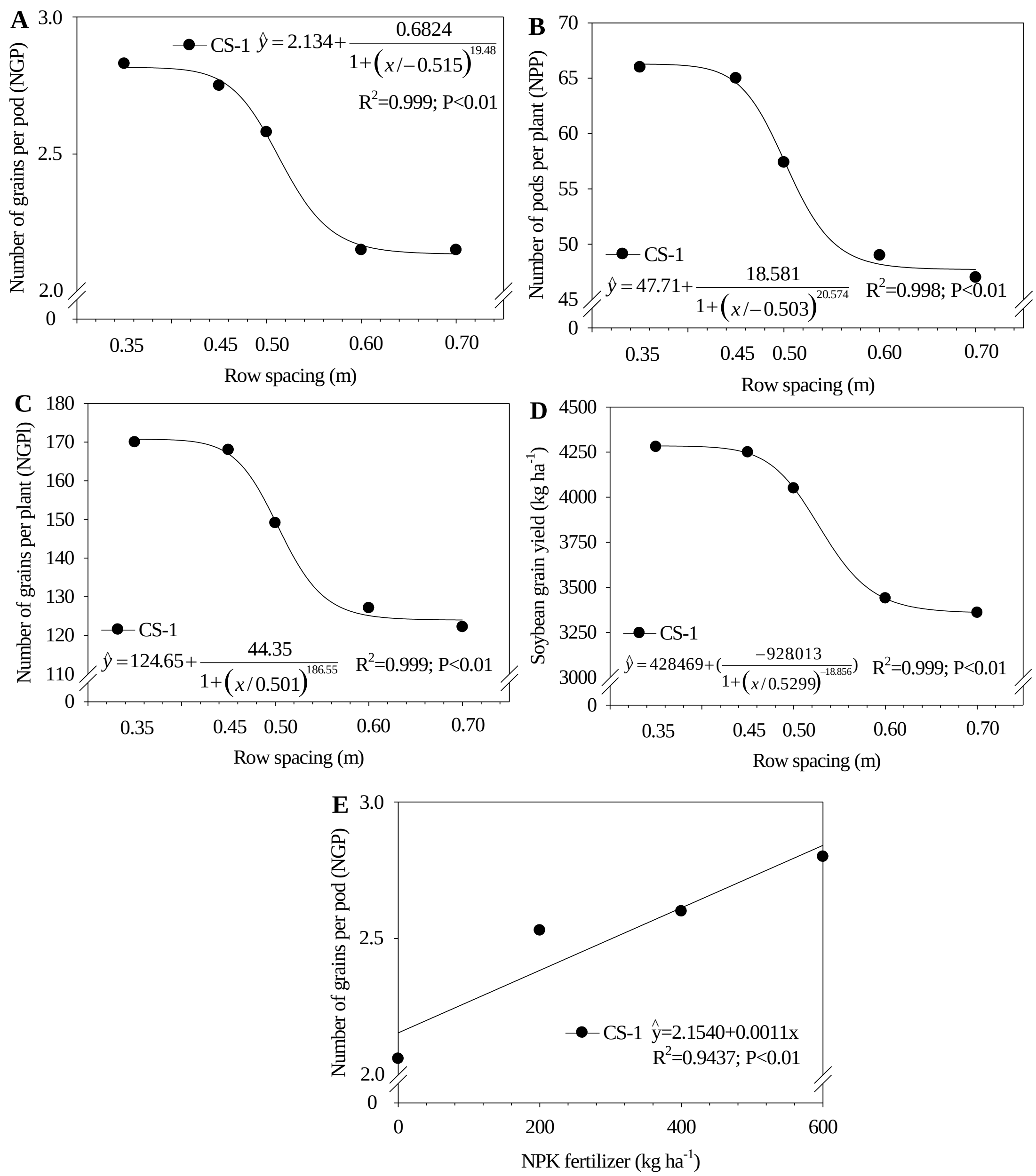


**Figure 3**. Row spacing in soybean and NPK fertilizer affected soybean agronomic traits. CS-1 (2011/2012 cropping season); (A) NGP_number of grains per pod; (B) NPP_number of pods per plant; (C) NGPI_number of grains per plant; (D) GY_grain yield; (E) NGPI_number of grains per plant.

**Table 5.** Simple matrix of Person's correlation between dependent variables.

| | FS | NGPl | TCC | NPPl | PH | NGP | HFPI | GY | NBP |
|---|---|---|---|---|---|---|---|---|---|
| FS | 1 | -0.955** | 0.913** | -0.932** | 0.981** | -0.929** | -0.987** | -0.921** | -0.921** |
| NGPl | | 1 | -0.787** | 0.999** | -0.975** | 0.955** | 0.872** | 0.955** | 0.938** |
| TCC | | | 1 | -0.791** | 0.9021** | -0.790** | -0.948** | -0.747** | -0.831** |
| NPP | | | | 1 | -0.976** | 0.957** | 0.876** | 0.956** | 0.939** |
| PH | | | | | 1 | -0.955** | -0.953** | -0.9365** | -0.948** |
| NGP | | | | | | 1 | 0.925** | 0.994* | 0.969** |
| HFPI | | | | | | | 1 | 0.885** | 0.910** |
| GY | | | | | | | | 1 | 0.976** |
| NR | | | | | | | | | 1 |

FS_final stand; NGPl_number of grains per plant; TCC_time for canopy closure; NPPl_number of pods per plant; PH_plant height; NGP_number of grains per pod; HFPI_height of the first pod insertion; GY_grain yield; NBP_number of branches per plant. Significance effects are at P<0.05 (*), <0.01 (**), and P>0.05 ($^{ns}$).

in wider row spacing in CS-1, and no significant difference was observed in CS-2. In CS-1, NPP, and NGPl were 10.82 and 9.74%, respectively, lower than CS-2 due to the drought stress occurred during the breeding stage (Table 5). The logistic model was adjusted to the data of NPP, NGPl, and GY (Figure 3B, C, and D). Observing the logistic model is quite evident the decreasing of NPP, NGPl, and GY in wider row spacing, which is not favorable to obtain high soybean production in same area and with the same economic budged.

In CS-1, NPK fertilizer rates showed significant effects on NGP (Figure 3E). NPK fertilizer rates did not affect the NGP in CS-2. The absence of effects in CS-2 for NGP might be associated with the optimal rainfall distribution (Figure 1), resulting in no effects of NPK fertilizer. With rainfall constraints the treatments with higher NPK dose may contribute to increase plant nutrition and higher capacity to resist to drought stress, thus in the highest NPK dose (600 kg ha$^{-1}$) NGP was 33.33% higher than in absence of NPK fertilizer (Figure 3E). As reported by Marschner (2012), plants with profitable nutrition may be more tolerate to environment factor, as the case of drought in breeding stage. NGP, NPP, and NGPL showed very high positive correlation with soybean GY (Table 5).

The reduction of NGP, NPP, and NGPl may be associated with intraspecific competition in row due to the higher number of plant per meter, obtained in wider row spacing than narrow row spacing (Figure 2A). On the other hand, the soybean GY showed very high negative correlation with FS, PH, and high negative correlation with TCC (Table 5).

The grain yield of soybean was negatively correlated with TCC, resulting in higher grain yield in narrow row spacing. With faster TCC, the radiation interception might be optimized during the vegetable and in the beginning of the breeding stage, thus avoiding flowers abortion in the stage R3. The grain yield decreased with the increasing in TCC, NGP, and NGPl. The grain yield in CS-1 showed better result in row spacing of 35 cm (4383.9 kg ha$^{-1}$) in comparison to 70 cm (3338.2 kg ha$^{-1}$). In CS-2, the significant (p<0.01) interaction between the row spacing and NPK fertilizer rates promoted the adjustment of the response surface, this way CS-2 is exposed in separate sub-heading and not discussed herein. The highest soybean GY in narrow row spacing may be associated with decreasing in intraspecific competition promoted by better spatial distribution of the plants in the area. Rambo et al. (2003) obtained higher grain yield in narrow row spacing of 20 cm when compared to 40 cm with the same plant population. Rambo et al. (2003) inferred higher GY are associated with decreasing in intraspecific plant competition. Possibly, the higher GY in narrow row spacing may be associated to higher radiation intercepted during the growth stage of the plant avoiding the abortion of flowers and pods, resulting in higher grain yield (Mattioni et al., 2008). Therefore, major agronomic traits may vary from year to year, but selection of proper varieties for a particular production environment is important in achieving high yield, proper seed size, and plant height (Berger-Doyle et al., 2014).

## Surface response for interactive effect of row spacing in soybean and NPK fertilizer rates

Only in CS-2 was observed significant (p<0.01) effect of the interaction between row spacing and NPK fertilizer rates for NBP, NGP, NPP, and soybean GY. The interaction between independent variables promoted the response surface adjustment to the data of NBP, NGP, NPP, and soybean GY (Figure 4). The highest NBP was observed in the highest NPK fertilizer dose and narrow row spacing (35 cm), resulting in 5.7 branches per plant, and 4.2 branches per plant in row spacing of 70 cm associate with NPK fertilizer rates of 161 kg ha$^{-1}$ of NPK (Figure 4A). Higher NGPl (170.10) and NPP (65.88) were

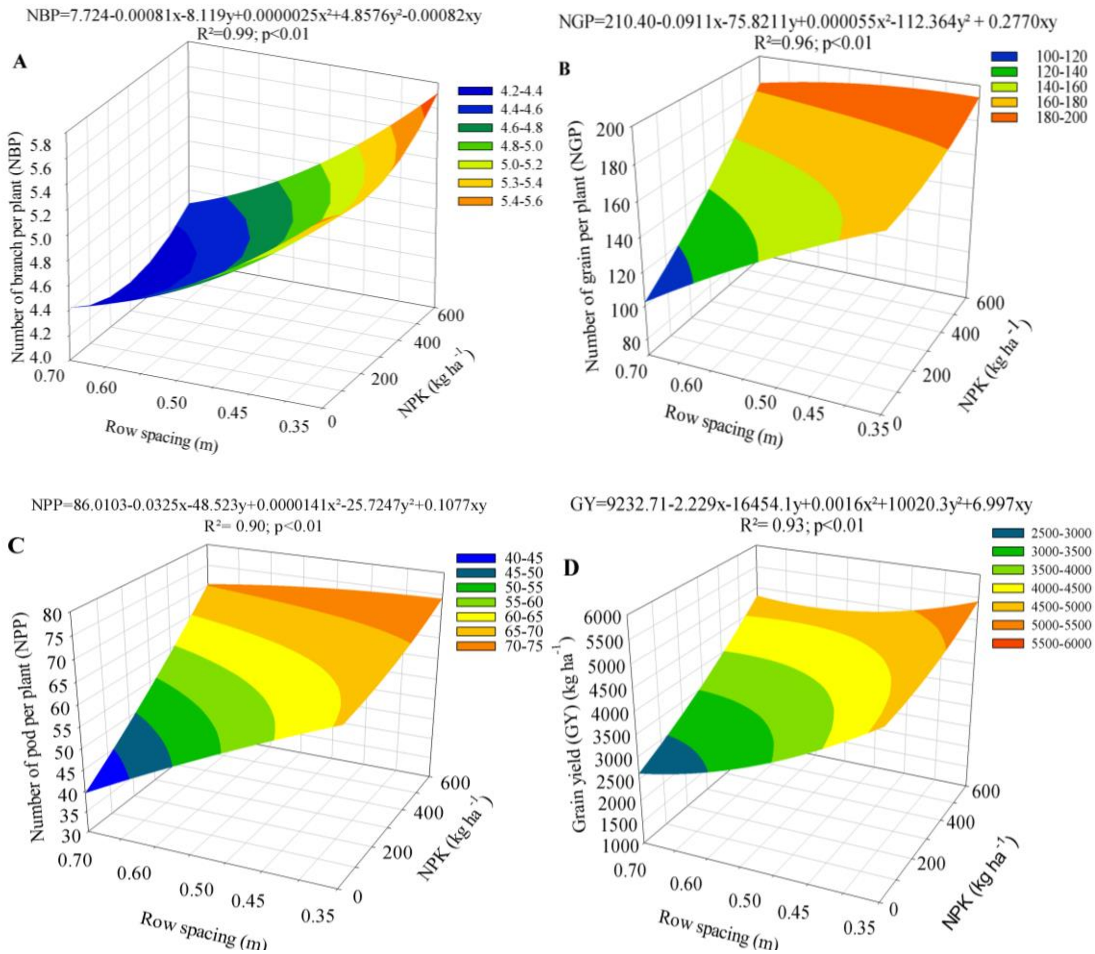


**Figure 4.** Agronomic traits of soybean under row spacing and NPK fertilizer. (A) number of branch per plant (NBP); (B) number of grain per plant (NGPl); (C) number of pod per plant (NPP); (D) grain yield (GY).

obtained in the narrowest row spacing (0.35 m) in the highest NPK fertilizer rates (Figure 4B and C).

In row spacing of 0.70 m in absence of NPK fertilizer the NPP and NGPl declined 40% and 40.19%, respectively, in comparison to row spacing of 0.35 m and absence of fertilizer. This decline was higher than in NPK dose of 600 kg $ha^{-1}$, which showed a little difference between the row spacing in soybean. To remain the same NPP and NGPl in row spacing of 0.35 and 0.70 m, it is necessary to apply 600 kg $ha^{-1}$ of NPK fertilizer rates. The grain yield increased in narrow row spacing and increment in NPK dose. The highest grain yield (5417.4 kg $ha^{-1}$) was obtained with the association of 600 kg $ha^{-1}$ of NPK dose with row spacing of 0.35 m. In the case of absence of NPK fertilizer and row spacing of 0.70 m the lowest yield obtained was 2624.7 kg $ha^{-1}$, which corresponded to 51.55% of decline in grain yield (Figure 4D). The increasing in grain yield in narrow row spacing may be attributed to higher water and nutrient use efficiency, lower weed competition relate to small time of canopy closure, decreasing in intraspecific plant competition, and higher light intercept (Pedersen, 2008).

## Conclusions

The narrow row spacing (less than 0.40 m) may be a profitable alternative to reduce intraspecific plant competition resulting in improvement of soybean agronomic performance, resulting faster canopy closure and relative equidistance among soybean plants. Narrow rows promoted increase in soybean grain yield. The row spacing of 0.35 m associated with 600 kg $ha^{-1}$ of NPK (02-20-18) fertilizer was the profitable combination of factors to achieve the highest soybean grain yield. The wider row spacing demands more fertilizer to remain the same performance than in 0.35 m spacing row.

## Conflict of Interests

The authors have not declared any conflict of interests.

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## Abbreviations

**NTS,** No-tillage system; **FS,** final stand; **TCC,** time for canopy closure; **PH,** plant height; **HFPI,** height of the first pod insertion; **NBP,** number of branches per plant; **NFPP,** number of failed pods per plant; **NGPl,** number of grains per plant; **GY,** grain yield; **1000GW,** 1000-grain weight.

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# Feed resource utilization and dairy cattle productivity in the agro-pastoral system of South Western Uganda

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**A cross-sectional study was carried out in six sub-counties of Kiruhura district, South Western Uganda with the aim of assessing feed resource utilisation and dairy cattle productivity. Individual interviews using a semi structured questionnaire were conducted in seventy five households. The mean land holding, grazing land and cultivated land were 74, 70 and 2 ha, respectively. Majority (61%) of the farms kept Ankole × Friesian crossbred cattle and the average daily milk production per cow per day for low grade and high grade crossbred cows was 5.4±1.3 and 7.4±2.6 L, respectively. The mean in months for age at first calving (AFC) was 30.7±9.8 and 25.9±4.9, calving interval (CI) was 12.6±3.2 and 11.4±1.1, and open period 3.5±2.7 and 2.3±1.2 for low grade and high grade cross bred cattle, respectively. A few farms (7%) maintained a constant herd size from the previous two years, while (67%) registered decreases in herd size and 27% increased their herd size. Natural pastures were the major feed resource throughout the year for all households and the majority (71%) did not provide any feed supplement during dry season or conserve the excess pasture produced in the rainy season. The average stocking rate was 1.4 ± 0.98 TLU/ha which was high and this was aggravated by increasing use of land for cultivation. The use of crop residues and agro-industrial by products was low. The average annual dry matter production on farms meets only 83% of the annual dry matter requirements for an average herd. The major constraints to livestock production were the high costs incurred in disease prevention and treatment (62%), feed shortage (40%) and drought related challenges (31%). It was concluded that feed availability could be improved by equipping the farmers with feed resource management techniques such as improved management of grazing lands, conservation of pastures in the form of hay, and proper utilization of crop residues and agro-industrial by-products, through training and provision of dedicated extension services.**

**Key words:** Dairy cattle, feed resource, crossbred, cattle productivity.

## INTRODUCTION

The dairy production sector is expected to make a significant contribution to Uganda's future economy through provision of employment in rural areas and frequent income to many resource poor households (Ekou, 2014). Milk production contributes about 50% of the total output from livestock sector in Uganda (DDA, 2009). While there is some milk production from goats, cattle are the sole producers of marketed milk and a considerable number of dairy cattle are reared in traditional systems with pasture as the main feed resource and minimal investment in feeding (Ekou, 2014). Extensive grazing is practiced in rangeland pastoral areas where dairy cattle are either continuously grazed or more rarely rotationally grazed where paddocks exist on farms (Roschinsky et al., 2012). Milk production in the rangelands is below potential. The low productivity of dairy cattle in these rangeland systems has been attributed to heavy dependence on natural pasture as a feed resource whose availability is influenced by the annual rainfall pattern (Grimaud et al., 2006, 2007; Ocaido et al., 2009), genetic type with Ankole cattle having low milk yields (Grimaud et al., 2007; Galukande, 2010) and poor adoption of productivity enhancing technologies and management practices (Elepu, 2006). However increased productivity has been registered in the western rangelands as a result of crossing the indigenous Ankole with Holstein Friesian cattle (Galukande, 2010). These crosses are producing more milk but compared to the Ankole cattle, they have larger daily milk yield fluctuations during the year which reduces their overall productivity (Galukande, 2010). The demand for milk on the local and regional market on the other hand continues to grow and in order to meet this demand; efforts have to be put into increasing productivity of dairy cattle. An improvement in the productivity of these crossbred cattle will require better management and utilization of the pasture resources (Grimaud et al., 2007; Roschinsky et al., 2012) and integration of other feed resources like agro-industrial by-products (Grimaud et al., 2007). Indeed the development of feed resources has been highlighted as one of the major areas that will contribute to increasing dairy cattle productivity in Uganda (Ekou, 2014). This study was aimed at assessing the feed resource utilisation for dairy cattle in the south western rangelands of Uganda.

## MATERIALS AND METHODS

### Description of study area

The study was conducted in the sub-counties of Kazo, Burunga, Kenshunga, Rwemikoma, Kinoni and Buremba in Kiruhura district, South Western Uganda. Kiruhura is located at 00° 12°S, 31° 00°E with an average elevation of 1800 m above sea level. The district experiences a bi-modal rainfall pattern where the two rain seasons normally run from March to May and mid- August to October and the average annual rainfall is 900 mm (KDLG, 2012). The dry seasons are pronounced with temperatures ranging from 17 to 30°C. It forms part of the south western rangelands of Uganda that are characterized by open and wooded savannah grassland vegetation. The area is typified by a light to moderate cover of feathery-leaved, thorny *Acacia* trees dominated by *Acacia gerrardii* and *Acacia hockii* species (Byenkya, 2004). The landscape is made up of flat areas with rolling hills interspersed with wide valleys. The hills rise to an average height of 100 to 200 m above the valley bottoms (Mulindwa et al., 2009). It is estimated that 58% of its population is engaged in livestock farming, while 32% is engaged in crop production and 10% in trade and service provision (KDLG, 2012).

### Farm selection and data collection

In each of the six sub-counties, farm households were contacted through farmer group leaders. A total of 75 farm households divided into 18, 14, 13, 11, 10 and 9 from Kazo, Burunga, Kenshunga, Rwemikoma, Kinoni and Buremba sub-counties, respectively were studied. Data was collected during the dry season period of July 2011 to August 2011 through individual interviews conducted using a semi structured questionnaire. In each household, the respondent was the household head, a wife or a key person involved in the daily management of cows. Data on household sociodemographic characteristics, land use, livestock production as well as feed resource utilisation was collected. The data for cattle production characteristics (cattle herd structure, milk yield, age at first heat and service, calving interval, weaning age) were obtained from the respondents' estimation at the time of the interview. Crossbred dairy cows were categorized into high grade cross for those with over 50% Holstein Friesian genes and low grade as those with 50% Holstein Friesian genes as evaluated by the respondents.

### Feed dry matter availability assessment

The annual dry matter available from pastures was determined by multiplying the average grazing area by the estimated dry matter yield of 2 t/ha (FAO, 1987). The annual dry matter from cultivated fodder was determined using the estimated dry matter yield of 8t/ha (Alemayehu, 2002) and the crop residue dry matter yield determined using the estimated yield (FAOSTAT, 2015) and estimated dry matter yield (FAO, 1987; Wilaipon, 2009).

The herd annual dry matter requirement was determined using the average herd TLU (73.26) and the daily dry matter requirements of 6.25 kg/TLU (Jahnke, 1982).

### Statistical analyses

The data were analysed using Stata for windows (version 11.2, 1989-2009). Descriptive statistics, analysis of variance and logistic regression were used for data analysis. The logistic regression was used to investigate the factors that influence pasture availibility on farms. Stocking rate expressed as hactares per tropical livestock unit (TLU) was used as the dependent variable indicating pasture availabilty. Stocking rate determines the proportion of pasture available for a cow to consume (Fales et al., 1995). The TLUs were computed using ratios attributed to estimated body weights as outlined in (LEAD, 1999) (bull ≈450 kg = 1.55, cow≈400 kg = 1.42, steer≈150 kg = 0.68, heifer≈100 kg =0.5, calf≈ 60 kg = 0.34, sheep≈35 kg = 0.23 and goat≈ 35 kg= 0.23). The computed stocking rate was coded into a binary viariable using the recommended optimum stocking rate of 0.7 TLU/Ha (Mulindwa et al., 2009) as the cut off. All those farms that had under 0.7 TLU/Ha

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**Table 1.** Socioeconomic characteristics of households.

| Variable | N | % |
|---|---|---|
| **Gender of household head** | | |
| Female | 6 | 8 |
| Male | 69 | 92 |
| | | |
| **Age of household head (years)** | | |
| 30-39 | 8 | 10.6 |
| 40-49 | 22 | 29.3 |
| 50-59 | 25 | 33.3 |
| 60-69 | 15 | 20 |
| 70-79 | 5 | 6.6 |
| | | |
| **Education of household head** | | |
| No formal education | 4 | 5.3 |
| Primary level | 27 | 36 |
| Secondary level | 39 | 52 |
| Tertiary level | 5 | 6.7 |
| | | |
| **Experience in livestock farming (years)** | | |
| 10-30 | 44 | 58.6 |
| 31-50 | 28 | 37.3 |
| 51-60 | 3 | 4 |
| | | |
| **Family size** | | |
| 0-10 | 15 | 20 |
| 11-20 | 55 | 73.3 |
| 21-30 | 5 | 6.6 |

**Table 2.** Land holding (ha) and land use pattern in the study area.

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Total land holding | 74 | 75.4 | 3.8 | 456 |
| Total grazing land | 69.5 | 75.1 | 2.2 | 444 |
| Cultivated land | 2.42 | 2.7 | 0.15 | 14.6 |

were considered to have low to optimum stocking rates, while those that had over 0.7 TLU/Ha were considered overstocked.

## RESULTS AND DISCUSSION

### Household description

The socioeconomic characteristics of households in the study area are shown in Table 1. The average age of the household head was 53 and ranged from 33 to 76 years. The years of experience in livestock farming ranged from ten to sixty with an average of 29 years. Of the 75 farms only 8% were female headed.

The average total farm landholding and grazing area were 74 and 69.5 hectares, respectively (Table 2). Majority (48%) of the farms had private landholdings as either freehold or leasehold tenure, while 45% had public landholdings of customary or rented tenure and 7% had both public and private landholdings. Bananas were the major crop grown (Figure 1). The other crops included cassava, maize, groundnuts and sweet potatoes in decreasing order of importance.

### Livestock production

All farms kept cattle for their milk and in addition 82.7, 56 and 35% farms reported keeping goats, chicken and sheep, respectively. The majority of the farms 61.3%

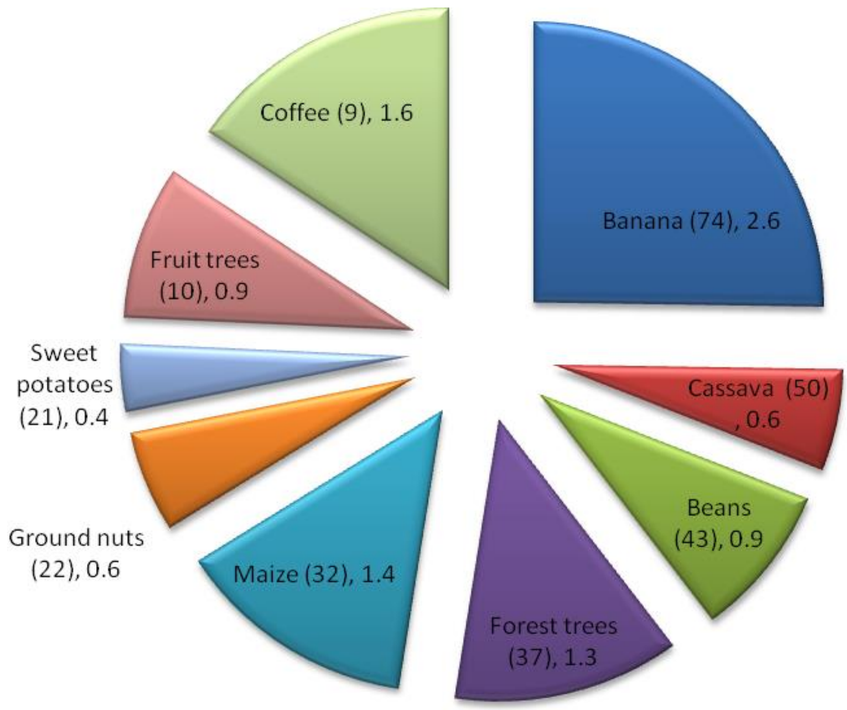


**Figure 1.** Average land area devoted to crops [(number of farms), hectarage].

**Table 3.** Cattle herd structure.

| Category | Farms | Mean | SD |
|---|---|---|---|
| Cows | 75 | 34 | 26.2 |
| Heifers | 75 | 22 | 17.1 |
| Bull calves | 73 | 14 | 10.3 |
| Bulls | 65 | 2 | 1.4 |
| Steers | 13 | 9 | 7.5 |

reported keeping only Ankole crossbred cattle while 38.7% reported keeping both Ankole and crossbred cattle. The average (±standard deviation (SD)) number lactating cows was 24.5±17.6. The mean (±SD) farm TLU was 62±40.6 and cattle herd structure comprised mostly milking cows followed by heifers and bull calves (Table 3). All but three farms reported using only natural mating. The three farms were using both natural mating and artificial insemination. Natural mating was preferred on many farms, because the alternative of artificial insemination was not readily available and was very expensive to use. The farms also found it relatively easy to acquire grade bulls for using on their farms. During the previous two years, majority of the farms registered a decrease in herd size (66.7%), while (26.7%) increased their herd sizes and (6.7%) maintained a constant herd size. Herd size reduction was mainly attributed to sale of animals to obtain cash for household use or farm development, but they were also sold in order to get rid of unwanted bulls on the farms. Disease related deaths were another reason that led to reduction in herd sizes. Increase in herd size was attributed to receipt of animal gifts, herd multiplication, improved management, and purchase of animals.

Ankole cows had the lowest average daily milk yield per cow and this was significantly different ($p \leq 0.05$) from that of both high and low grade cross cattle (Table 4). The average AFC, age of calves at weaning, open period and CI were significantly lower for high grade crosses compared to Ankole cattle, but were not different ($p > 0.05$) from those of low grade cattle (Table 4). The better performance of Ankole-Friesian crosses in terms of milk yield, AFC and CI compared to Ankole cattle is similar to what was reported in Galukande (2010) and Galukande et al. (2013). While the classification into high grade and low grade and estimation of daily milk yield may not be accurate since there are no written records on farms, it has been shown that improving cows beyond 50% results

**Table 4.** Milk production and reproductive performance of Ankole and crossbred cattle.

| Parameter | Farms | Mean | SD |
|---|---|---|---|
| **Milk production/cow/d (L)** | | | |
| Ankole | 20 | $3.0^{c}$ | 1.3 |
| Low grade cross | 22 | $5.4^{b}$ | 1.7 |
| High grade cross | 57 | $7.4^{a}$ | 2.6 |
| **AFC (months)** | | | |
| Ankole | 22 | $35.2^{b}$ | 6.96 |
| Low grade cross | 22 | $30.7^{b}$ | 9.8 |
| High grade cross | 57 | $25.9^{a}$ | 4.9 |
| **Age at weaning (months)** | | | |
| Ankole | 20 | $10.3^{b}$ | 3.6 |
| Low grade cross | 23 | $8.5^{ab}$ | 2.4 |
| High grade cross | 57 | $7.7^{a}$ | 2.3 |
| **Open period (months)** | | | |
| Ankole | 21 | $5.7^{b}$ | 3.4 |
| Low grade cross | 23 | $3.5^{a}$ | 2.7 |
| High grade cross | 57 | $2.3^{a}$ | 1.2 |
| **CI (months)** | | | |
| Ankole | 21 | $14.9^{b}$ | 3.6 |
| Low grade cross | 23 | $12.6^{a}$ | 3.2 |
| High grade cross | 57 | $11.4^{a}$ | 1.1 |

Figures with different superscripts in the column are significantly different at P ≤ 0.05

in higher daily milk yield. Cows are milked once or twice a day, milking usually starts as early as 05:00 h and ends at about 08:00 h depending on the number of milking cows in the morning and then again in the mid-morning from 11:00 to 13:00 h. The morning milking is what is apportioned for sale and is collected through local dairy coolers while the milk from the second milking is kept for home consumption. In a review on cross breeding for milk production in the tropics, Galukande et al. (2013) found that at 50% Bos Taurus crosses yielded 2.2 times higher milk compared to the local cattle in semi-arid areas. The average daily yield for 50% crossbred cows was 5.4 which is less than double that of the Ankole.

The mean (±SD) daily milk in litres per farm sold to dairy processors through the local cooling centres was 105±99, while the mean milk sold at the farm was 46±64. On some farms, the milk was split into two portions, one delivered to local cooling centres and the other sold at the farm to milk traders. The average farm gate price for a litre of milk was slightly better 376 UGX than that paid by the milk processor 365 UGX. Only thirteen farms were involved in commercial production of ghee. Besides milk and ghee, the other source of revenue was the sale of live animals. Cows and bull calves were the most frequently sold followed by heifers and in rare cases breeding bulls were sold. The mean (±SD) daily revenue in UGX from milk was 40551±48154 and the mean (±SD) revenue in UGX from sale of cows in the previous nine months was 12.6±1.2 million.

## Livestock feed resources and feeding system

### Pasture

Table 5 shows the major feed resources utilized on farms. Natural pastures are the major feed resource throughout the year and for most some farms it is the only feed resource. The predominant grass species on farms were *Brachiaria* species, *Hyparrhenia rufa, Cynodon dactylon, Themeda triandra, Sporobolus pyramidalis* and *Panicum maximum*.

The annual dry matter requirement for maintenance of an average herd was 167 tonnes /year while the annual dry matter availability from natural pasture was 139 tonnes (Table 5). The annual dry matter yield from pasture which is the only feed for most farms meets only 83% of the annual dry matter requirements of an average dairy herd. The farms therefore need to increase feed availability in order to fill the gap.

**Table 5.** Feed resource utilisation and estimated annual dry matter yield.

| Feed resource | Farms (%) | Average hectarage | Crop yield (tonnes/ha) | Conversion factor | Dry matter yield (tonnes/year) |
|---|---|---|---|---|---|
| **Herbage** | | | | | |
| Natural Pasture | 100 | 69.5 | - | 2[1] | 139 |
| Planted pasture grass and legume mixture | 20 | 1.7 | - | 8.0[2] | 13.6 |
| Planted pasture grass | 20 | 0.3 | - | 8.0[2] | 2.4 |
| Planted pasture legumes | 11 | 0.5 | - | 8.0[2] | 4.0 |
| Planted fodder trees | 6.7 | 0.1 | - | - | - |
| **Crop residues** | | | | | |
| Banana peels | 40 | 2.6 | 4.25[3] | 0.25[4] | 1.1 |
| Maize stover | 1 | 1.38 | 2.75[3] | 2[1] | 5.5 |
| **Agro-industrial by-products** | | | | | |
| Cotton seed cake | 1 | - | - | - | - |
| Maize bran | 2.7 | - | - | - | - |
| **Cattle herd annual dry matter requirements** | | | | | |
| | **TLU** | **Annual (tonnes)** | | | |
| Cows | 48.28 | 110 | | | |
| Heifers | 11 | 25 | | | |
| Bulls | 3.1 | 7 | | | |
| Steers | 6.12 | 14 | | | |
| Calves | 4.76 | 11 | | | |
| Total | 73.26 | 167 | | | |

[1](FAO, 1987) [2](Alemayehu, 2002) [3](FAOSTAT, 2015) [4](Wilaipon, 2009).

Planted forage was not common on farms, 20% had planted pasture as a mixture of legume and grass stands, 20% had grass only stands and 11% had legume only stands, and 6.7% had planted fodder trees. The average acreage for all types of planted forage was less than 2 ha yielding a small amount (4.4 kg) of dry matter annually. These estimates indicate that the pasture resources, both natural and planted did not yield sufficient dry matter to sustain an average dairy herd in this system. The farms would need to improve their management of natural pasture and invest in planting more pasture to increase the dry matter yield from pasture.

## Crop residues and agro-industrial by-products

Besides natural pasture, the other feed resource that was used was crop residues from bananas (peels) 30 farms (40.5%) and only one farm reported using maize stover. Only one farm reported using maize bran while another farm used a ration made from cotton seed cake and maize bran when prices were favourable. The major reasons for not using agro-industrial by-products on farms were unavailability, the high expense involved, low returns from milk making their use uneconomical or lack of facilities like milking parlour where they can be fed individually to animals.

With bananas as the major crop grown, widespread use of the residues both peels and pseudo stems as a dry season supplement would have been expected in this system, but this was not the case. Even on farms that reported use of banana peels, only a few cows were fed rather than the whole milking herd. Banana plant residues have been reported as important basal and supplementary feed for dairy cows in the tropics (Kimambo and Muya, 1991; Katongole et al., 2013; Lumu et al., 2013). Previous studies have found that the dry matter digestibility of banana pseudo stems and fruit peelings were 59 and 61%, respectively (Kimambo and Muya, 1991), while crude protein of banana peels was 6% (Nambi-Kasozi et al., 2014), 7.9% (Aregheore and Ikhatua, 1999) and metabolisable energy was 8.7 MJ/kg of dry matter (Aregheore and Ikhatua, 1999). Banana pseudo stems and fruit peelings could therefore provide additional energy and protein on farms even though supply may be limited in prolonged dry seasons. Extensive systems in east and southern Africa that rely on crop residues as livestock feed during the dry season often have to deal with limited supply during prolonged dry seasons (Valbuena et al., 2012; Takele et al., 2014).

**Table 6.** Dry season feeding strategies and utilization of excess pasture.

| Strategy | Percentage response |
|---|---|
| **Dry season feeding strategy** | |
| Cattle feed on grazing land | 71 |
| Supplement with crop residues | 16 |
| Supplement with planted fodder | 13 |
| Rent land | 9 |
| Provide hay supplement | 8 |
| Utilise reserve paddock | 4 |
| | |
| **Utilization of excess pasture** | |
| Left for grazing | 85 |
| Conserved as baled or standing hay | 12 |
| Never have excess | 2.7 |

Other crops that would provide residue supplements are maize, beans, ground nuts or sweet potatoes but their respective average hectarages were too small to yield substantial dry matter besides the fact that with the exception of beans, the other crops were grown by less than half of the households. Crop residue utilization for feeding livestock can be enhanced through increasing biomass production per unit area by strategic application of organic manure and developing technologies for efficient collection, processing and storage (Tui et al., 2013).

The absence of grain mills or oil processing facilities in this area makes agro-industrial by-products expensive to use because of the additional transport costs involved. However, poultry farmers in peri-urban areas of Kampala opted for bulk purchasing of feed ingredients when supply was plenty as a way of coping with feed scarcity (Katongole et al., 2013), a strategy that could be adopted on agro-pastoral dairy farms.

The majority of the farms (71%) did not provide any feed supplement for cattle in the dry season (Table 6); the cattle scavenged on whatever was left of the pasture. Excess herbage during the rainy season was not conserved on most (85%) farms. The lack of preservation of pasture will only perpetuate the dry matter deficit for dairy cows unless the farms adopt strategies like fencing off part of their rangeland during the rainy season to be used in the dry season when pasture availability is low as is being practised in some (Solomon et al., 2007; Abate et al., 2010; Selemani et al., 2012) rangeland systems. Another alternative that has been practised is to plant and preserve fodder banks of planted grass and legume pasture in the form of standing hay (Campbell et al., 1996).

## Management of grazing land

The average stocking rate on farms was 1.4 ± 0.98 TLU/ha. This stocking rate is high when compared with the optimum stocking rate of 0.71TLU/Ha for the area according to a study by (Mulindwa et al., 2009). Semi arid rangelands tend to favour lower optimal stocking rates 0.61 TLU/ha (Maposa, 2012), 0.71 TLU/ha (Mulindwa et al., 2009) in order to maintain good levels of forage biomass production (Maposa, 2012). The amount of pasture available in relation to the number of grazing animals in the rangeland has a bearing on the intake, animal performance and long term ecological health of the rangeland (Fales et al., 1995; Mulindwa et al., 2009). High stocking rates have a greater impact on the ability of the animal to meet its nutrient requirements when rangeland pastures are in poor condition and rainfall is scarce (Fynn and O’Connor, 2000).

Farmer’s assessment of herbage availability on their farms revealed that it followed the rainfall pattern with the highest amount available during the long rains from September to December and least during the dry period of June to August (Figure 2). Planted pastures had the highest availability followed by natural pastures and the least available was the herbage from planted fodder trees.

Many of the farms (78%) reported having cleared the bush on over 75% of their total grazing land. Bush clearing in the study area involves manual cutting down of shrubs during the dry season. The shrubs are often not completely destroyed so they are able to sprout again and therefore require regular clearing in order to maintain bush free pasture. Bush encroachment if left unchecked can lead to loss of grass cover and thus degradation of the rangeland (Macharia and Ekaya, 2005). Extensive management of bush encroachment on farms in south western Uganda was shown to offer economic benefit through improving herbage dry matter yield, gross income, milk yield and body condition score of cows (Mugasi et al., 2007).

All farms had some form of fencing on their grazing land, 44% reported complete perimeter fencing with paddocks, 42% perimeter fence only, 13% perimeter

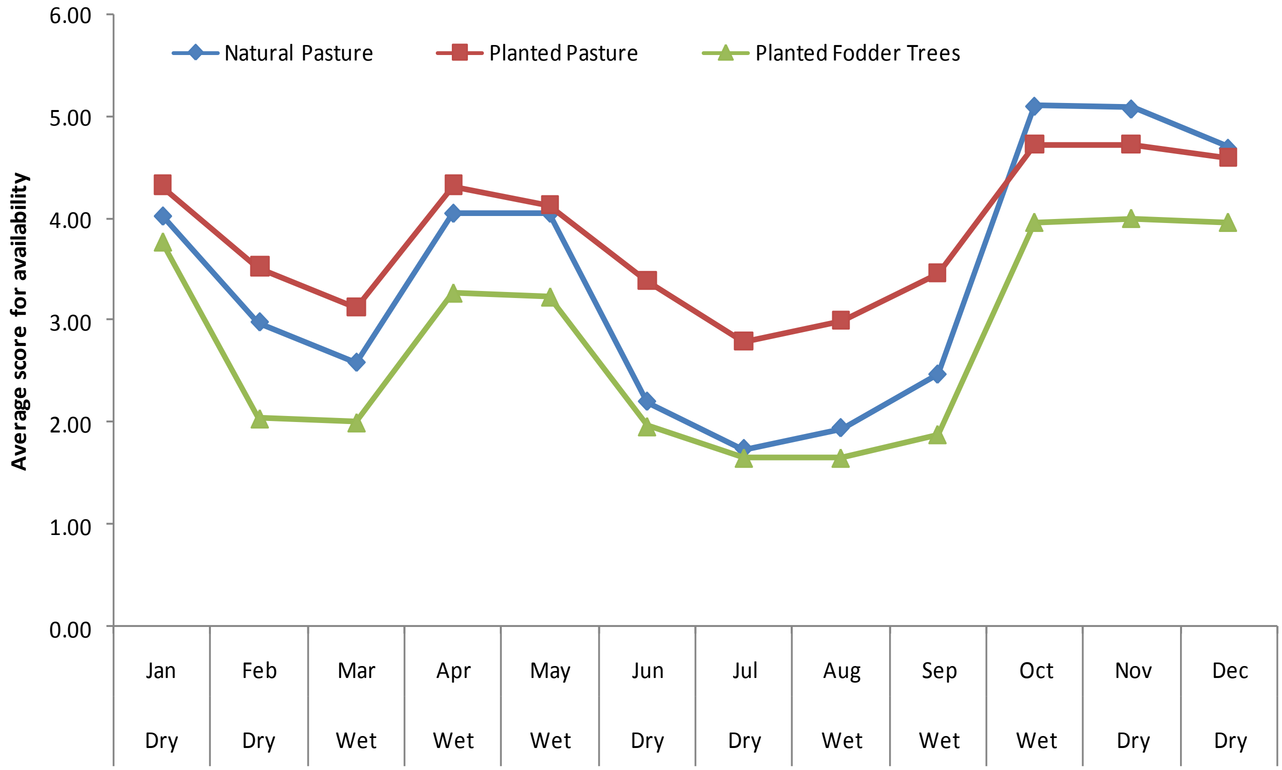


**Figure 2.** Annual trend for herbage availability. Scores: 1- very little available, 2- little available, 3- available in moderate quantities, 4- sufficient availability, 5- available in large quantities, 6- available in very large quantities

fence with only part of it paddocked and only one reported having an incomplete perimeter fence with no paddocks. Fencing is done using live fences of *Euphorbia tirucalli* species (oruyenje, local name) or timber poles obtained from the farms together with barbed wire. The labour costs for splitting the timber poles, digging holes and the cost of barbed wire makes it expensive to construct fences with barbed wire while the live fences are effective only during the first few years of growth before the hedges overgrow and become woody losing their ability to close in. Fencing in the rangelands permits protection of the grazing area, fodder banks and with paddocks it facilitates rotational grazing and implementation of pasture improvement technologies (Mwebaze, 2003). However, it has been argued that planned grazing can be done without fenced paddocks (Kirychuk and Fritz, 2010). According to Kirychuk and Fritz (2010), a grazing plan can be developed and documented so that animals are herded to specific areas at set times and their distribution controlled. This is a good alternative for reducing fencing costs on farms with large grazing areas, but requires ensuring that the herder adheres to the plan. Well fenced farms would incur less labour costs for herding, but have higher costs for infrastructure set up and maintenance while the reverse would be true for farms with a grazing plan that includes no paddocks.

Water for animals is got from water wells located in the valleys within the farms. The type of water wells and watering frequency are shown in Table 7. Majority of the farms water their cows two to three times a day. Watering is done by driving cows to the water wells from where water is drawn into troughs for the animal to drink. On most farms this is done immediately after morning milking before the cows are taken for grazing and just before mid morning milking. All farmers provided minerals in the form of rock salt and in addition 12% of the farms provided artificial mineral licks.

### Factors affecting availability of natural pastures

The logistic regression model to determine the influence of household size, age, education level, land tenure, fencing, bush clearing, cattle breeds, cultivated land and livestock revenue on the likelihood of overstocking was statistically significant $\chi^2$ (11) = 27.67, p < 0.005 (Table 8). Farm households that had received some form of training in livestock management tended to have lower stocking rates while a higher proportion of cultivated land to total land was associated with overstocking (p<0.1). This highlights the need to provide training on optimal utilization of pasture resources through reducing the herd size to match pasture resources, pasture improvement

**Table 7.** Water wells on farms and watering frequency.

| | Farms | % |
|---|---|---|
| **Well type** | | |
| Manually dug | 32 | 46 |
| Tractor dug | 31 | 44 |
| Both manual and tractor dug | 7 | 10 |
| | | |
| **Number of water troughs** | | |
| 1-3 | 63 | 93 |
| 4-6 | 5 | 7 |
| | | |
| **Watering frequency** | | |
| Once | 2 | 3 |
| Two - three | 55 | 80 |
| Four – six | 12 | 16 |

**Table 8.** Logistic regression model for prediction of overstocking on study farms.

| Variable description | Coefficient | SE | Significance |
|---|---|---|---|
| Number of persons living in the household | 0.144 | 0.145 | 0.321 |
| Age of household head | -0.018 | 0.055 | 0.740 |
| Number of years the household head had been practicing livestock farming | 0.045 | 0.050 | 0.373 |
| Number of years household head spent in formal education | -0.112 | 0.136 | 0.411 |
| Private (Freehold or leasehold tenure) or public (customary or rented tenure) | 0.922 | 0.776 | 0.235 |
| Proportion of bush cleared land | -1.524 | 1.435 | 0.288 |
| Whether the grazing land is fenced with paddocks or not | 1.435 | 0.965 | 0.137 |
| Revenue from daily sale of milk | 5.1e-06 | 9.2e-06 | 0.578 |
| Whether the household had had any training in livestock management | -2.119 | 1.215 | 0.081 |
| Revenue from sale of live cattle during the previous nine months | -2.3e-08 | 4.3e-08 | 0.589 |
| Proportion of total land holding that is cultivated | -0.674 | 0.267 | 0.012 |
| Constant | -0.098 | 4.459 | 0.982 |
| $\chi^2(11) = 27.67$, Prob > $Chi^2 = 0.0036$ | - | - | - |
| Pseudo $R^2 = 0.4013$ | - | - | - |
| N = 59 | - | - | - |

The dependent variable was stocking rate and was coded 0 = low to optimum and 1= high

and adjusting cultivated area in relation to total land area.

## Constraints to livestock production

The major constraints to livestock production were the high costs incurred in disease prevention (62%) and treatment, feed shortage (40%) and drought related challenges (31%) (Table 9). Other constraints to production included low and fluctuating milk prices, limited resources for investing in improved feeding, high costs of labour and labour shortage. Water and feed shortages in the dry season was the major constraint to livestock feeding. Bush encroachment and high cost of supplementary feeding were the other constraints mentioned. While feed shortage in the dry season was a major constraint to livestock feeding, many farms had no alternative feeds for their cattle during periods of pasture scarcity; the cattle depended on whatever was left on the range. The farmers saw the need to invest in improved feeding but cited insufficient resources as a hindrance probably due to the relatively low returns from sale of milk.

## Conclusion

This study has shown that annual feed availability is not

**Table 9.** Major constraints to livestock production and feeding.

| Constraint | Percentage response |
|---|---|
| **Livestock production** | |
| High costs of disease prevention and treatment | 62 |
| Feed shortage | 40 |
| Drought related problems | 31 |
| Low and fluctuating milk prices | 21 |
| Limited resources for investment in improved feeding | 12 |
| High cost and shortage of labour | 9 |
| High cost of inputs (e.g. barbed wire) | 8 |
| **Livestock feeding** | |
| Water and feed shortage especially in the dry season | 86 |
| Bush encroachment on grazing land | 5 |

sufficient to meet the dry matter requirements for dairy cattle seeing that natural pasture is the main feed resource with minimal use of crop residues and agro-industrial by products. The average annual dry matter production on farms meets only 83% of the annual dry matter requirements for an average herd. This could be the reason why milk production and age at first calving of both low grade and high grade crossbred cattle are not good enough. Feed availability could be improved by equipping the farmers with feed resource management techniques such as improved management of grazing lands, conservation of pastures in the form of hay, and proper utilization of crop residues and agro-industrial by-products, through training and provision of dedicated extension services.

## Conflict of interests

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# Effect of combined doses of gamma ray and sodium azide (mutagenic agents) on the morphological traits of some varieties of okra (*Abelmoschus esculentus)*

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***Abelmoschus esculentus*** **(okra) is a popular health food because of its high fiber, vitamin C and folate content. It is also rich in antioxidants, a good source of calcium and potassium. Three varieties of okra: Jokoso, NHAe47-4 and Beru (a local variety) were irradiated with 20, 40, 60, 80 and 100 kr doses of gamma rays then soaked in 2.0 mM and 3.0 Mm of Sodium azide for 2h with the aim of determining the effects of the combined mutagens on their morphology. There were significant differences between the control and the treated seeds used in their germination, seedling survival, seeding length, survival to maturity and height at maturity. The effective concentrations and doses of combined mutagens for Beru and NHAe47-4 varieties were: 2.0 mM + 20 kr, 2.0 mM + 40 kr, and 2.0 mM + 60 kr and 3.0 mM + 20 kr, 3.0 mM + 40 kr, and 3.0 mM + 60 kr) while the effective concentrations and doses for Jokoso variety were: 2.0 mM + 20 kr, 2.0 mM 40 kr 2.0 mM 60 kr and 3.0 mM + 20 kr only. Jokoso variety was worse affected than any other. Sodium azide and gamma rays can be used for inducing mutation that will produce genetic variability in Okra.**

**Key words:** *Abelmoschus esculentus,* germination, genetic variability.

## INTRODUCTION

Okra (*Abelmoschus esculentus)* is a perennial, often cultivated annually in temperate climates, and it grows to around 2 m tall. It is a flowering plant in the mallow family. It is related to such species as cotton, cocoa, and hibiscus. The leaves are 10 to 20 cm long, broad, palmately lobed with 5 to 7 lobes. The flowers are 4 to 8 cm in diameter, containing five white or yellow petals, with a red or purple spot at the base of each. The fruit is capsule-like and the length can be up to 18 cm long with pentagonal cross-section, containing numerous seeds. The crop is cultivated throughout the tropical and warm temperate regions of the world for its fibrous fruits or pods containing round, white seeds. It is among the most heat- and drought-tolerant vegetable species in the world and it tolerates soils with heavy clay and intermittent moisture, but frost can damage the pods (Wikipedia, 2016).

Okra is a popular health food due to its high fiber,

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vitamin C, and folate content. It is also known for being high in antioxidants. The crop is rich in lutein which is an antioxidant found in several areas of the body including the skin and eyes. It is also a good source of calcium and potassium (Duvauchelle, 2012). Okra, known in many English-speaking countries as ladies' fingers, ochro or gumbo is valued for its edible green seed pods (https://en.wikipedia.org/wiki/OkraWikipedia, 2016).

A study carried out in 2009 revealed that okra oil suitable for use as a biofuel (Farooq, et al., 2010). It fibers were traditionally used to make rope for fish lines and game traps. It is suitable for paper and cardboard manufacture. Roasted okra seeds are used in some places as a substitute for coffee. The grounded pulp of *A. Caillei* stems is used as a stabilizer when making Pita beer in Ghana. Okra is a good source of calcium and oil. Oil from it seeds contains about 20% amino acid thus, it compares favorably with the oil found in poultry, eggs, and Soya beans. In genetics, a mutagen is a physical or chemical agent that changes the genetic material, usually DNA, of an organism and thus, increases the frequency of mutations above the natural background level (https://www.ndsu.edu/pubweb/~mcclean/plsc431/mutation/mutation3.htm 21/4/2016). Mutation breeding has been done on okra by Norfadzrin et al. (2007) Manju and Gopimony (2009), Phadvibulya et al. (2009), Hegazi and Hamideldin (2010) and Muralidharan and Rajendran (2013) using different doses of gamma rays. Induced mutations have played a pivotal role in enhancing world food security, as new food crop varieties with various induced mutations have brought about a significant increase in crop production at locations people could directly access (Kharkwal and Shu, 2010). Induced mutations are significant as novel mutations are being isolated for enhanced nutrition quality of crop plants, for ex. micronutrients, protein, amino acids, fatty acids and vitamins (Navnath and Mukund, 2014).

Mutation, whether induced or natural, has played an important role in increasing variability leading to production of varieties of crop. Plant breeders induce mutation in crop varieties in order to produce high yielding and superior genotypes. In the process of breeding crop plants, the progress achievable tends to be limited by the variability present in nature, so that further progress in breeding becomes difficult. When mutation or change occurs in chromosomes, pure breeding lines occasionally give rise to cultivars having a different allele of a particular gene. Ionizing radiation produces a range of effects on DNA both through free radical effects and direct action: breaks in one or both strands can lead to rearrangements, deletions, chromosome loss, death if unrepaired; this is from stimulation of recombination, damage to/loss of bases (mutations) and crosslinking of DNA to itself or proteins. Induced mutations are significant as novel mutations are being isolated for enhanced nutrition quality of crop plants: micronutrients, protein, amino acids, fatty acids and vitamins (Navnath and Mukund, 2014). Another source of nutrition provision is from the neglected and underutilized crops. These and the major crop to enhance nutrition provision for the ever-growing human population (Jain and Suprasanna, 2011). Among physical mutagens, gamma radiation has been widely used for mutation induction for both seed and vegetative propagated crops. Recently, ion energy technology- heavy ion beam (HIB) and low energy ion beam (LIB) - is being used for mutation induction in wide ranging crops. HIB is predominantly used for inducing mutations in plants (Jain, 2010). This investigation seeks to induce profitable mutation and select the concentrations and doses of the mutagens that will enhance production of okra. Indeed, such a study is needful to unveil any desirable features for quantitative traits, agronomic, Phytochemical and pharmaceutical benefits.

## MATERIALS AND METHODS

### Plant source and mutagen treatment

Three varieties of okra NHAe47-4, Jokoso and a local variety called Beru were used for this research. Two improved varieties (NHAe47-4 and Jokoso) of Okra *A. esculatus* seeds were collected from Institute of Agricultural Research (Plant Science Department) Ahmadu Bello University, Zaria ($11^0$ 04'N and $7^0$42'E) and a local variety was purchased in Sabo Main Market Zaria The Sodium azide used for this research was collected from Biochemistry Department A.B.U. Zaria. Soaking of the seeds was done in the Biological Sciences laboratory, Ahmadu Bello University, Zaria.

Standard agronomic practices (Good Agricultural Practices for Okra, 2008, "Thai Agricultural Standard (TAS)") during the experimental period were adopted in accordance with the enforcement of the Agricultural Standards Act B.E. 2551 (2008). National Bureau of Agricultural Commodity and Food Standards Ministry of Agriculture and Cooperatives.

### Treatment of seeds with the mutagens

The okra seeds were air-dried and each variety divided into five sets of five hundred seeds and taken to the Centre for Energy Research and Development, Obafemi Awolowo University Ile-ife ($7^0$ 28'N and $4^0$ 32'E) for radiation with Gamma cell 220 Cobalt 60 ($Co^{60}$).The doses of the Gama ray were 20 kr, 40 kr, 60 kr, 80 kr and 100 kr. The same sets of seeds were also soaked in 2.0 and 3.0 milimolar solution of Sodium azide respectively for one hour. The seeds were then washed with tap water to remove excess chemicals and exudates.

### Planting of the seeds

Planting of both treated and the control seeds were done in Botanical Garden, Ahmadu Bello University Zaria, using the open garden to study the combined effect of the two mutagens. Each plot consisted of five rows and each row was four meters long and the intra row spacing of 50 cm and inter row spacing of 75 cm apart in three replications. Twenty seeds were planted per row. The layout follows 3×5 Randomized Complete Block Design (RCBD). The seeds were observed daily until maximum germination was achieved. Field studies were undertaken to determine the effects of

**Table 1.** Morphological characteristics of treated and untreated seeds of Beru variety (mean length in centimeter).

| Mutagen | % Germination | Seedling height | Stem height at maturity | Leaf length | Fruit length |
|---|---|---|---|---|---|
| Control | 97[a] | 9.5[a] | 28.00[a] | 10.50[a] | 5.60[a] |
| 2.0mM + Gamma Rays 20Kr | 50[b] | 10.9[a] | 11.37[c] | 5.30[b] | 5.50[a] |
| 2.0mM + Gamma Rays 40 Kr | 30[b] | 5.3[c] | 10.00[c] | 5.10[b] | 5.50[a] |
| 2.0mM + Gamma Rays 60 Kr | 40[b] | 6.6[b] | 12.25[c] | 6.00[b] | - |
| 2.0mM + Gamma Rays 100 Kr | 10[b] | 3.2[d] | - | - | - |
| 3.0 mM + Gamma Rays 20Kr | 10[b] | 9.3[a] | 12.17[c] | 5.10[b] | 4.50[a] |
| 3.0 mM + Gamma Rays 40 Kr | 20[b] | 8.5[b] | - | - | - |
| 3.0 mM + Gamma Rays 60 Kr | 40[b] | 6.6[b] | 14.00[c] | 5.30[b] | 4.50[a] |
| 3.0 mM + Gamma Rays 100 Kr | 20[b] | 5.1[c] | - | - | - |

Means followed by the same letter in the column are not significantly different (P>0.05).

the combined mutagens on lethality and morphological injury. The growth of the plant was estimated in relation to the time of flowering, maturity and variability in plant development within and between treatments.

The following data were collected: germination percentage, survival, and average plant height, seedling height, and root length, survival at maturity, time of flowering, fruit length and height at maturity.

**Germination rate and percentage:** Due to induced injury and delayed germination/ emergence of the treated seeds, the estimate was recorded at the time when the control population was considered 50 to 90%, that is, germination after a week of planting. The percentages of different treatment doses were then compared.

**Seedling height:** Seedling heights were measured in centimeter, using ruler from the ground level to the tips of the highest leaves.

**Seedling survival:** The estimates of seedling survival were taken to ascertain the relative emergence of seedling survival of the treatment population. The plants were considered dead if no photosynthetic tissue was observable. The seedling survival was observed after four weeks of the seedling emergence.

**Survival to maturity:** Estimates of the percentages of plants in each treatment at the time of maturity provided information on the severity of the injury induced by the mutagens. Treatment doses were then classified into low, medium, and high or lethal dose.

**Delayed development:** The recorded growths of the mutants were estimated in relation to the time of flowering of the plants as well as the variability in plant development within and between treatments. The time of emergence of flower buds was also recorded.

**Heights at maturity:** Measurements were done in centimeter. Whole plants, from the ground level to the highest point of the plants were measured. 50% of the population of each treatment (including the control) was selected at random and the mean of each taken. The percentage reductions in heights were also compared.

### Statistical analysis

The data collected were subjected to the following statistical methods used to analyze the data: Mean (average) percentages, Analysis of variance (ANOVA) and t-test. The aim was to determine if there was any significant difference between the two mutagens.

## RESULT AND DISCUSSION

### Mean performance of the morphological characters of okra

Tables 1 to 3 show the mean performance of the morphological characteristics of okra (*Abelmuscus esculantus.)*

### Percentage germination

There were reductions in the germination and survival percentages with increasing concentrations of combined mutagens. Reductions in germination and survival percentages due to the effect of mutagens on various crop plants have earlier been documented by Mensah, (1977); Mensah and Akomeah (1997) and Mensah et al. (2005).

Beru, Jokoso and NHAe47-4 varieties were treated with 20 krad and 2 mM had 50% germination, and 100 krad and 2 mM had 10% germination. The seed sets were treated with 20 krad and 3 mM had 10% germination and100 krad and 3 mM had 20% germination. (Tables 1 and 3)

### Seedling survival

The Beru variety treated with 2.0 mM+100 kr, 3.0 mM+40 kr, and 3.0mM +100 kr was not able to survive beyond three weeks after germination. Jokoso variety treated with 2.0 mM +100 kr, 3.0 mM + (40 kr, 60 kr, 100 kr) also did not survive beyond the seedling stage. NHAe47-4 variety treated with 2.0 mM +100 kr, 3.0 mM +100 kr did not survive beyond the seedling stage (Tables 1 and 3).

### Seedling height

Seeds treated with combined mutagens that is, 2.0 mM +

**Table 2.** Morphological Characteristics of Treated and Untreated Seeds of Jokoso Variety (Mean in Centimeter).

| Mutagen | % Germination | Seedling height | Stem height at maturity | Leaf length | Fruit length |
|---|---|---|---|---|---|
| Control | 96[a] | 6.70[a] | 21.00[a] | 10.00[a] | 7.60[a] |
| 2.0mM + Gamma Rays 20Kr | 50[a] | 8.5[a] | 10.67[c] | 5.90[b] | 4.75[c] |
| 2.0mM + Gamma Rays 40 Kr | 20[b] | 8.3[a] | 8.00[c] | 4.40[c] | 4.00[c] |
| 2.0mM + Gamma Rays 60 Kr | 40[b] | 6.0[a] | 7.50[d] | 7.30[b] | 5.50[b] |
| 2.0mM + Gamma Rays 100 Kr | 10[b] | 4.1[b] | - | - | - |
| 3.0 mM + Gamma Rays 20Kr | 50[a] | 8.0[a] | 14.25[b] | 5.50[b] | 4.00[c] |
| 3.0 mM + Gamma Rays 40 Kr | 30[b] | 8.0[a] | - | - | - |
| 3.0 mM + Gamma Rays 60 Kr | 40[b] | 6.3[a] | - | - | - |
| 3.0 mM + Gamma Rays 100 Kr | 10[b] | 4.7[b] | - | - | - |

Means followed by the same letter in the column are not significantly different (P>0.05).

**Table 3.** Morphological Characteristics of Treated and Untreated Seeds of NHAe47-4 (Mean in Centimeter).

| Mutagen | % Germination | Seedling height | Stem height at maturity | Leaf length | Fruit length |
|---|---|---|---|---|---|
| Control | 95[a] | 9.10[b] | 24.00[a] | 9.80[a] | 5.70[a] |
| 2.0 mM + Gamma Rays 20Kr | 50[a] | 9.00[b] | 11.67[d] | 5.70[b] | 4.00[b] |
| 2.0 mM + Gamma Rays 40 Kr | 40[b] | 5.00[e] | 5.75[f] | 3.60[c] | 3.00[b] |
| 2.0 mM + Gamma Rays 60 Kr | 20[b] | 6.60[d] | 8.00[e] | 4.00[c] | 2.50[c] |
| 2.0 mM + Gamma Rays 100 Kr | 10[b] | 3.60[f] | - | - | - |
| 3.0 mM + Gamma Rays 20Kr | 30[b] | 7.80[c] | 12.17[d] | 6.90[b] | 4.70[a] |
| 3.0 mM + Gamma Rays 40 Kr | 40[b] | 9.40[b] | 9.17[e] | 5.80[b] | 2.75[c] |
| 3.0 mM + Gamma Rays 60 Kr | 20[b] | 9.50[b] | 6.75[f] | 6.90[b] | 5.00[a] |
| 3.0 mM + Gamma Rays 100 Kr | 10[b] | 4.50[e] | 6.00[f] | 4.33[c] | 1.00[d] |

Means followed by the same letter in the column are not significantly different (P>0.05).

gamma rays of different concentrations have mean seedling heights as follows: 20 kr +2.0 Mm (10.50 cm); 40 kr +2.0 mM (4.97 cm); 60 kr +2.0 mM (6.50 cm), 100 kr +2.0 mM (3.25 cm), while those treated with 3.0 mM +the various doses of gamma rays were: 20 kr +3.0 mM ( 9.17 cm), 40 kr +3.0 mM (7.90 cm); 60 kr +3.0 mM (6.63 cm) and 100 kr +3.0 mM (5.13 cm) (Tables 1 and 3)

### Stem height

Okra plants treated with combined mutagens showed decrease in stem height with increase in dose of the combined mutagens.

### Leaf length

The seeds treated with the combined mutagens showed decrease in leaf length with increase in concentration of sodium azide and decrease in dose of Gamma rays.

### Fruit length

The combination of both mutagens showed decrease in length with increase in the concentrations of Sodium azide solution and the doses of Gamma rays. Generally, the height of the seedlings, stem of the mature plants, length of the leaves and fruits length were inversely proportional to the doses of the two mutagens. (Tables 1 and 3)

### Survival to maturity

Okra seeds treated with the two mutagens, (20 krad +2 mM, 40 krad + 2 mM, 60 krad + 2 mM and 20 krad and 3 mM) survived to maturity flowered but had stunted growth. Jokoso however, showed different characteristics. All those treated with 40 krad + 3 mM, 60 krad + 3 mM, died but those treated with 3 mM + 20 kr that survived (Tables 1 and 3). Beru variety treated with 20 krad + 3 mM survived till the flowering stages but those treated with 100 krad and 3 mM did not survive till the flowering stage. The NHAe47-4 variety treated with 20 krad + 2 mM, 40 krad + 2 mM, 60 krad + 2 mM survived till flowering stage but those treated with 100 krad + 2 mM died before reaching flowering stages. Those treated with 20 krad +3 mM, 40 krad + 3 mM, 60 krad + 3 mM survived till their flowering stages just as those treated with 100 krad +3 mM. It is worthy of note that all the sets of seeds of NHAe47-4 treated with all the various doses and concentrations of the combined mutagens survived to maturity budded but had stunted growth.

### Development of fruits

When treated with combined mutagens, Beru variety delayed in flowering for up to three weeks even when the control plants was budded and flowered. The plants all attempted to bud but the majority of buds were aborted. Some tried to fruit but only one fruit or the maximum of four fruits developed. Jokoso variety delayed in flowering for more than three weeks but the control plants flowered and fruited. The plants had plenty buds but only few flowered and fruited. Some have just one fruit while those plants treated 20 kr +2 mM, and 20 kr+3 mM, had about five fruits. NHAe47-4 variety also had delay in producing flower buds for about three weeks while the control produced flower buds. In fact, these plants had numerous flower buds but only few buds were flowered and fruited. Those treated with 20 kr+2 mM and 20 kr+ 3 mM had up to six fruits but the rest had one or two fruits. Most of the buds died and fell off. This may be due to the combined effect of the two mutagens on the plants. This resulted in destroying the carpel. When some of the flower buds were opened, the carpels were seen like scattered red dots in the buds. The carpels probably were destroyed and no site for fertilization hence, on fruit formation. This may explain why there were a lot of bud formations but those buds did not develop into fruits.

## DISCUSSION

It has been established that both radiation and chemical mutagens (Sodium azide and Gamma ray) play a role in enlarging genetic variable of quantitative character. This creates a scope for selection (Adamu et al., 2004). Mutations, or heritable alterations in the genetic material, may be gross, this may be at the level of the chromosome, or point alterations. This technically refers to mutations not visible as cytological abnormalities and/or those which map to a single "point" in experimental crosses. Point mutation can involve just a single nucleotide pair in DNA. Mutagens may be of physical, chemical or biological origin. They may act directly on the DNA, causing direct damage to the DNA, and most often result in replication error. Some however may act on the replication mechanism and chromosomal partition. Many mutagens are not mutagenic by themselves, but can form mutagenic metabolites through cellular processes; for example, through the activity of the cytochrome P450 system and other oxygenases such as cyclooxygenase (Kim and Guengerich, 2005). Such mutagens are called promutagens (http//www-personal.ksu.Edu/-bethmont/mutdes.htm\ mutagens, 2016).

In this research, Okra (*Abelmuscus esculantus* L.) showed differences in their response to gamma rays and sodium azide solutions even though phenotypic changes were observed. The techniques used could not demonstrate any specific chromosomal aberration. This however, does not mean that mutation did not take place since obvious morphological changes were recorded. Very interesting results have been obtained for many polygenic characters such as plant height, leaf length, fruit length and maturity and it was envisaged that combined mutagens will induce more variability in crops. In general, treatment with the mutagens (gamma rays and sodium azide) reduced germination, seedling survival, seedling height and plant height. This is possibly associated with dose. These observations were in agreement with earlier findings (Jagajanantham et al., 2013; Ashish et al., 2011 and Adamu et al., 2004).

There is high sensitivity with respect to germination and seedling injury. The seeds treated with highest dose of gamma ray and combined mutagens showed the highest reduction in percentage germination. Similar observation was made by Jadhav et al. (2012), who reported reduced germination percentage in all the M1 generation of okra treated with gamma ray and EMS. Ashish et al (2011) also observed reductions in the germination and survival percentages with increasing concentrations of two mutagens. Also, treatment with combined mutagens showed reduction in seedling height which may be due to a high frequency in induced deletions or translocations. Jagajanantham et al. (2013) reported the impact of chemical mutagens in germination percentage, plant height and number of leaves decreased with increasing concentration of DES. The plants treated with combined mutagens produced varieties with taller seedling height than the control. This showed that the combined mutagens can help to produce beneficial and desirable qualities. Jagajanantham et al. (2013) observed that the duration of the first flower increased with increasing concentration of DES and EMS. Those treated with 2 mM + 60 kr and 2 mM +100 kr showed reductions in seedling heights, which may be due to the inability of the Sodium azide to suppress the effect of the high doses of gamma radiation on the crops. Treatment with 3 mM + 20 kr also showed taller varieties than the control in Beru and Jokoso varieties but shorter seedling height in NHAe47-4 variety. With increase in dose of gamma rays on the three varieties of okra used in this research, the suppressing effect of sodium azide reduced with increases in dose of gamma rays. These rays were able to suppress the effect of sodium azide on the plants but in NHAe47-4 variety, the mean seedling height increased with combined treatment of 3 mM + 60 kr, then dropped remarkably when treated with 3 mM + 100 kr.

There were late flowering and maturity of the plants with increase in the dose of the combined mutagens. This may be due to the changes in genetic and physiological composition resulting from treatment with the two mutagens. This result is at variance with the works of Adamu et al. (2004) but in agreement with Jagajanantham et al. (2013). The result here may be due to the dose of the radiation and the effect of the chemical mutagens which suppressed early development of the crops.

The seeds treated with the highest dose of combined mutagens showed the highest reductions in the stem height, leaf length and fruit length. This is possibly associated with the doses and concentrations of the two mutagens. This is in agreement with the findings of Ashish et al. (2011) and Jagajanantham et al. (2013).

## Conclusion

The result of this research showed that the effective concentrations of combined mutagens in Beru and NHAe47-4 varieties are 2.0 mM + 20 kr, 2.0 mM + 40kr, and 2.0 mM 60 kr and 3.0 mM + 20 kr, 3.0 mM + 40 kr, and 3.0 mM + 60 kr while in Jokoso variety, the effective doses are 2.0 mM + 20 kr, 2.0 mM + 40 kr, and 2.0 mM + 60 kr and 3.0 mM + 20 kr. Analysis of variance of the morphological characters indicated that there is a significant difference between the control plants and the plants treated with the two mutagens in all the three varieties of okra used. Genetics and cytogenetics analysis of induced mutation could contribute much to a deeper understanding of the mutation events in higher plants especially with the knowledge of the genetic contents of the chromosomes of crops. This finding offers very valuable material for physiological investigations of a single gene effects and the investigation of the process deserves more attention.

## Conflict of Interests

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# Characteristic of an Oxisol post-cultivation of the corn using tannery sludge vermicompost and irrigation with domestic wastewater

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**The use of organic solid waste/effluent has currently been increasingly enhanced. A waste and effluent currently produced on a large scale that have potential for use in agriculture refers to sludge tannery and wastewater, respectively. However, in Brazil these residues are still little used and there is great reluctance to use them in general agriculture. Thus, this study aimed to evaluate the characteristics of an Oxisol after maize cultivation (*Zea mays* L.) using tannery sludge vermicompost and irrigation with wastewater. After 120 days of cultivation, soil samples were collected for analysis of the: pH, electrical conductivity (EC), total organic carbon (TOC), base saturation (BS), organic matter (OM), N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn. The values for these parameters were compared between the various treatments, as well as the values observed in the soil prior to cultivation. It was observed that the tannery sludge vermicompost and irrigation with wastewater, provided little increase in pH, EC, TOC, base saturation, OM, N, P, K, Cu and Fe compared to their concentrations originally identified in the soil. Moreover, tannery sludge vermicomposts and wastewater constitute good sources of Ca, P, Mg, Mn and Zn, being able to increase the content of these elements in the soil.**

**Key words:** Agro-industrial waste, tannery, *Zea mays* L., Oxisol.

## INTRODUCTION

Industrial processes and human activities, in general, have the effect of generation of specific waste, among which we mention those produced by industrial activities, such as bovine skin processing. While this activity generates significant profits, it present problems when is found that the waste and effluent produced by many tannery industries are disposed incorrectly, representing risks to health and to the environment as highlighted by Batista and Alovisi (2010), the sludge tannery, even after receiving treatment in a sewage treatment plant it

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contains significant organic and inorganic fillers such as acids, phenols, sulfates, sulfides, and especially toxic elements such as chromium, which is used during the tanning process.

Tanning is the chemical process that converts animal hides and skin into leather and related products. More than one hundred different chemicals nearly (3,50,000 tonnes/year of inorganic and heavy metal salts, soaps, oils, waxes, solvents, dyes, etc.) used in tanning processes are found in process wastes and wastewaters (Godecke et al., 2012). The major components of the sludge include sulfide, chromium, volatile organic compounds, large quantities of solid waste, suspended solids like animal hair and trimmings. For every kilogram of hides processed, 30 L of effluent is generated and the total quantity of effluent discharged by Indian industries is approximately 45000 to 50,000 $m^3$/day. Tannery industry plays an important role with respect to environmental pollution due to disposal of large volume of solutions of tanning baths. The discharge of chromium rich tannery sludge is a serious threat for environment with high concentrations of organic and inorganic component that they create risk to human health and environmental aspects (Cetin et al., 2013). Tannery industry is one of the important industries in India (Kushwaha and Upadhyay, 2015) and in many regions of Brazil (Godecke et al., 2012; Meunier and Ferreira, 2015), for example, which earns large foreign exchange through the leather export.

When it comes to corn culture, several studies have shown that the use of *in natura* tannery sludge added to soil cultivated with maize plants is viable, the sludge being a good nutrient source for the development of the plant and yield. However, better results have been achieved when high doses of tannery sludge are applied together with mineral fertilizers. Borges et al. (2007) pointed out that the higher production of grains and green phytomass are observed when 144 Mg $ha^{-1}$ of tannery sludge are applied together with NPK (400 kg $ha^{-1}$). In turn, Konrad and Castilhos (2002) and Ferreira et al. (2003) show that higher corn grain yields are obtained with 20.5 and 21.3 Mg $ha^{-1}$ of tannery sludge applied with phosphorous and potassium fertilizers, respectively. If on one hand these concentrations are interesting under the agronomic point of view, on the other hand, a certain difficulty is imposed to rural producers when it comes to transportation of large amount of tannery sludge and the costs of such transportation. Besides, the necessity of additional chemical fertilization increases production costs.

Thus, the development of studies that contribute with forms to treat or reuse such materials has been stimulated. An interesting option is the use of substrates from vermicomposting (a process that not only is a form of tanning sludge treatment (Carlesso et al., 2011)), but is also a biotechnology able to transform these residues in noble composts, feasible to be used in other sectors, such as agriculture (Suthar, 2010). As discussed by Varma et al. (20115), during vermicomposting, different important nutrients that are present in the residues are converted, by means of the joint action of earthworms and their intestinal microbiota, in many soluble and available forms to plants than the forms presented *in natura* residues.

Another interesting option is the wastewater reuse in agriculture. There are great demands for the use of wastewater, coming from domestic sewage, especially in water scarcity scenario, we live in today. Different studies have pointed to the potential use of this water in agriculture, due to the fact these has nutrients that are beneficial to the development of plants (Fonseca et al., 2005a, b; Fonseca et al., 2007; Leal et al., 2011; Andrade-Filho et al., 2013; Bonini et al., 2014; Silva et al. 2014). To Hespanhol (2003), the wastewater arising from domestic sewage, contain nutrients whose content meet, if not all, at least most of the nutritional needs of plants in general.

Despite the obvious benefits of using vermicompost and wastewater in agriculture, it is important to assess the impact of these uses on the soil. The study of the characteristics of the soil post-cultivation of the corn using tannery sludge vermicompost and irrigation with domestic wastewater is as important as the impact of waste on crop productivity. Thus, this study aimed to evaluate the characteristics of a Oxisol after corn crop, using the vermicomposting from tannery sludge in association with irrigation of domestic wastewater, considering the lack of studies involving this issue, as well as the need to combine agronomic interest to the environmental.

## MATERIALS AND METHODS

The present study was carried out in a protected environment located in the experimental area of the Unidade Educacional de Produção (UEP) de Olericultura of the Instituto Federal Goiano (IF Goiano) – Urutaí Campus (Goiás, Brazil). The protected environment was a simple arc with east-west direction. A metallic structure of 30 m in length, 7 m in width, 3.0 m in height, and 1.2 m in arc height was built and covered with a 0.15 mm-thick low-density polyethylene film. The sides were made of 2.0 × 2.0 mm clarity screen. Corn was planted in samples of a superficial layer (0 to 20 cm) of an Oxisol, collected in an area close to the protected environment. The physical-chemical and chemical characterization of the soil samples (Table 1) was made following the method described in Embrapa (1997). The vermicompost used in this study were those produced from vermicomposting substrates made up of 20% of liming and primary tannery sludge types and 80% of cattle manure (Malafaia et al., 2015) (Table 1).

Before the installation of the experimental units, both soil and vermicomposts were dried and sieved (2-mm mesh). The treatment arrangement consisted of a 2×6 factorial (two irrigation types and six fertilization treatments), in completely randomized design, with five repetitions, totalizing sixty experimental units, are shown in Table 2.

The dose of NPK used in treatments labeled “soil + NPK” (Table 2) was calculated on the basis of the culture nutritional necessities, nutrient concentrations present in the soil, and in the crop yield expectation, according to Sousa and Lobato (2004), resulting in 10

**Table 1**. Main characteristics of the initial soil and tannery sludge vermicompost used in this study.

| Variable | Results | | |
|---|---|---|---|
| | Soil | Vermicompost (Lc20)* | Vermicompost (Lp20)* |
| pH ($CaCl_2$) | 5.30 | 8.8 | 8.8 |
| N (%) | 0.11 | 1.5 | 1.2 |
| P (Melich – $mg.dm^{-3}$) | 5.00 | 700.0 | 400.0 |
| K ($mg.dm^{-3}$) | 240.00 | 18,000.0 | 20,000.0 |
| Ca ($cmolc.dm^{-3}$) | 2.60 | 14.0 | 14.0 |
| Mg ($cmolc.dm^{-3}$) | 0.80 | 18.0 | 15.0 |
| CTC ($cmolc.dm^{-3}$) | 6.20 | 82.4 | 85.4 |
| Na ($mg.dm^{-3}$) | 8.00 | 1,000.0 | 1,200.0 |
| Cu ($mg.dm^{-3}$) | 2.50 | 5.0 | 2.9 |
| Fe ($mg.dm^{-3}$) | 63.00 | 244.0 | 122.0 |
| Mn ($mg.dm^{-3}$) | 47.00 | 68.0 | 55.0 |
| Zn ($mg.dm^{-3}$) | 4.40 | 36.0 | 39.0 |
| Organic matter (%) | 2.30 | 29.9 | 24.2 |
| Sat Al (%) | 0.00 | 0.0 | 0.0 |
| Base Sat (%) | 65.00 | 100.0 | 100.0 |
| Total Organic Carbon (%) | 1.30 | 17.3 | 14.0 |
| Cr ($mg.dm^{-3}$) | <5.00 | <5.0 | <5.0 |

*Vermicompost (LC20): tannery sludge vermicompost made up of 20% sludge tannery liming type and 80% of cattle manure. Vermicompost (LP20): tannery sludge vermicompost made up of 20% tannery sludge from the primary type and 80% of cattle manure. Soil analysis were performed according to Embrapa (1997) and vermicompost, according to Tedesco et al. (1995).

**Table 2**. Experimental units set for corn (*Zea mays* L.) culture treated with tannery sludge vermicompost and irrigated with domestic wastewater.

| Treatment | Types of irrigation water | |
|---|---|---|
| | Supply water (A) | Wastewater (R) |
| Soil - control, without chemical fertilizer and without vermicompost (T1) | x | |
| Soil + NPK (T2) | x | |
| Soil + 20% of primary tannery sludge vermicompost (VLp20) (T3) | x | |
| Soil + 20% of primary tannery sludge vermicompost (VLp20) + P (T4) | x | |
| Soil + 20% of liming tannery sludge vermicompost (VLc20) (T5) | x | |
| Soil + 20% of liming tannery sludge vermicompost (VLc20) + P (T6) | x | |
| Soil - control, without chemical fertilizer and without vermicompost (T1) | | x |
| Soil + NPK (T2) | | x |
| Soil + 20% of primary tannery sludge vermicompost (VLp20) (T3) | | x |
| Soil + 20% of primary tannery sludge vermicompost (VLp20) + P (T4) | | x |
| Soil + 20% of liming tannery sludge vermicompost (VLc20) (T5) | | x |
| Soil + 20% of liming tannery sludge vermicompost (VLc20) + P (T6) | | X |

Mg $ha^{-1}$. NPK sources were urea, simple superphosphate and potassium chloride, respectively. The doses of tannery sludge vermicompost to be added to the soil were calculated based on the concentration of K, high concentration element in vermicomposts used (Table 1) and $K_2O$ basal dose of 50 kg $ha^{-1}$. The amount of 60 kg $ha^{-1}$ simple superphosphate was provided via topdressing in two plots of 30 kg $ha^{-1}$, at 40 and 60 days after sowing. Furthermore, the amount of 130 kg $ha^{-1+}$ urea (nitrogen source) was provided via topdressing in two plots of 65 kg $ha^{-1}$, at 40 and 60 days after sowing. The dose of liming sludge vermicompost (VLc20) added to the soil corresponded to 6.1 Mg $ha^{-1}$ and the dose of primary sludge vermicompost (VLp20) was 5.5 Mg $ha^{-1}$. It was not necessary to perform the soil pH correction.

Soil samples to which tannery sludge vermicompost and fertilizers were previously incorporated were placed in 15-L polyethylene pots (volumetric capacity of 12.5 kg). Soon after the installation of the experimental units, the pots were sown with three maize (*Zea mays* L.) seeds (commercial variety LG 6036) (LG Semente®). After 15 days, thinning took place, remaining one plant in each pot. Whenever necessary, phytosanitary treatments were

**Table 3.** Physical-, chemical- and physico-chemistry-characterization of irrigation water used in the present study.

| Attributes | Water supply* | Wastewater* |
|---|---|---|
| pH at 25°C | 7.38 | 7.73 |
| Fe dissolved (mg.L$^{-1}$) | 0.31 | 1.26 |
| N total (mg.L$^{-1}$) | 2.43 | 54.57 |
| N organic | ND | 4.90 |
| N ammoniacal (mg.L$^{-1}$) | 0.07 | 43.67 |
| Nitrate (mg.L$^{-1}$) | 0.33 | 6.00 |
| Electric conductivity at 25º C (µs.cm$^{-1}$) | 67.20 | 746.33 |
| P total (mg.L$^{-1}$) | 0.14 | 9.10 |
| Orthophosphate (mg.L$^{-1}$) | 0.33 | 20.86 |
| BOD (mg.L$^{-1}$) | 0.67 | 572.11 |
| Total Solids (mg.L$^{-1}$) | 73.33 | 1,290.00 |
| Cu dissolved (mg.L$^{-1}$) | 0.35 | 0.44 |
| Zn (mg.L$^{-1}$) | 0.37 | 0.26 |
| Na (mg.L$^{-1}$) | 25.59 | 56.63 |
| Mn dissolved (mg.L$^{-1}$) | 0.57 | 1.80 |
| Mg dissolved (mg.L$^{-1}$) | 1.78 | 12.16 |
| Ca (mg.L$^{-1}$) | 6.28 | 37.41 |
| K (mg.L$^{-1}$) | 7.45 | 19.16 |
| TOC (mg.L$^{-1}$) | 14.95 | 43.47 |

ND: Parameter not measured. *The values refers to the average of four samples collected throughout the experimental period. For the characterization of irrigation water monthly samples were collected throughout the experimental period (n = 4) for evaluation of physical-chemical- and physico-chemical parameters, according to the methodology proposed by APHA (1997).

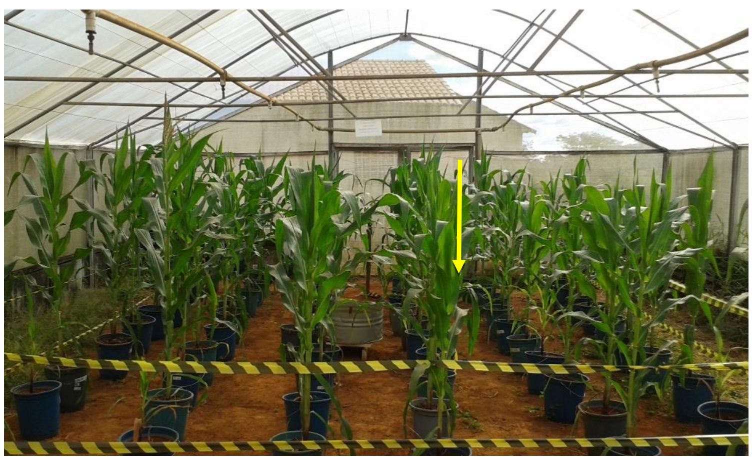

**Figure 1.** General view experiment and location of the evaporimeter tank used in the study. The yellow arrow indicates the evaporimeter tank

performed.

Irrigation waters came from the water supply system of the Instituto Federal Goiano (IF Goiano) – Urutaí Campus, treated at the Water Treatment Station (ETA) of the campus itself, and from the domestic sewage treatment system (composed of a stabilization pond), also located in IF Goiano. To characterize the irrigation waters, four samples were collected during the experimental period for the determination of physical, chemical and physico-chemical parameters, according to the method proposed by Apha (1997).

The analyses of irrigation waters (supply and wastewater) were carried out by HIDROSERV – Serviços em Recursos Hídricos e Saneamento Ltda. (Goiânia, GO, Brazil). Table 3 presents the characteristics of the irrigation waters used in the present study.

Irrigation was carried out by means an evaporimeter tank developed by Salomão (2012), circular in shape, with internal diameter of 52 cm and (internal) height of 24 cm, mounted under a 15 cm-high wooden pallet and installed inside the protected environment, between the experimental units (Figure 1).

**Table 4.** Summary of F test of variance analysis for pH, electrical conductivity (EC), total organic carbon (TOC), based saturation (BS), organic matter (OM), N, P, K, Ca, Mg, Cu, Fe, Mn and Zn variables from the studied soil, depending on the type of irrigation water and fertilizer treatments.

| Factors | pH ($CaCl_2$) | EC ($\mu S.cm^{-1}$) | TOC (%) | BS (V%) | OM (%) |
|---|---|---|---|---|---|
| Factor 1 (irrigation types) | 106.66** | 26,338.23** | 268.52** | 172.53** | 3.75$^{ns*}$ |
| Factor 2 (treatments) | 16.66** | 825.35** | 292.91** | 65.07** | 93.75** |
| Interaction (factor 1 × factor 2) | 7.66** | 132.60** | 300.26** | 39.28** | 93.75** |
| CV (%) | 1.93** | 1.51** | 2.03** | 2.66** | 6.35** |
| **Factors** | **N (%)** | **P ($mg.dm^{-3}$)** | **K ($mg.dm^{-3}$)** | **Ca ($cmolc.dm^{-3}$)** | **Mg ($cmolc.dm^{-3}$)** |
| Factor 1 (irrigation types) | 179.79** | 4,317.90** | 2,083.38** | 2.36$^{ns}$* | 60.00** |
| Factor 2 (treatments) | 2.12$^{ns}$ | 181.11** | 198.53** | 63.42** | 11.40** |
| Interaction (factor 1 × factor 2) | 1.63$^{ns}$ | 123.25** | 149.85** | 56.68** | 10.22** |
| CV (%) | 008,55$^{ns}$ | 0.007,17** | 0.002,71** | 04,18** | 16,36** |
| **Factors** | **Cu ($mg.dm^{-3}$)** | **Fe ($mg.dm^{-3}$)** | **Mn ($mg.dm^{-3}$)** | **Zn ($mg.dm^{-3}$)** | |
| Factor 1 (irrigation types) | 1,11$^{ns}$ | 1,222.82** | 2,139.24** | 127.55** | |
| Factor 2 (treatments) | 3.77** | 170.92** | 227.37** | 649.18** | |
| Interaction (factor 1 × factor 2) | 1.11$^{ns}$ | 216.84** | 241.93** | 317.10** | |
| CV (%) | 8.65** | 1.94** | 2.59** | 2.14** | |

*Significant at 5% probability; **Significant at 1% probability; ns: not significant; CV: variation coefficient in %. Irrigation types: supply water and domestic wastewater.

The calculation of the water volume to be irrigated daily, in order to keep the water retention capacity of the soil in 70% (243.1 ml $kg^{-1}$) during the experiment, took into account the pot area to be irrigated (0.06 $m^2$) and evapotranspiration (ETc). The water volume to be restored was measured with a graduated cylinder. To determine ETc, the following equation was used:

$$ETc = kc\ (LT \cdot Kt_c) \qquad (1)$$

where *ETc* = crop evapotranspiration; *kc* = crop coefficient, specific to the phonological cycle phase;
*LT* = evaporated water layer observed in the evaporimeter tank; $Kt_c$ = corrected tank coefficient (0.94), specific for the evaporimeter tank used in our study.

The water retention capacity of the soil ($C_{100\%}$=347.4 ml $kg^{-1}$) was determined by means of the soil soaking power, according to Embrapa (1997).

At the end of the experiment (120 days), soil samples from each treatment (five samples of each experimental unit (which corresponds to the five replicates), totaling 60 soil samples (Table 1)) were collected and were analyzed the pH, electrical conductivity (EC), total organic carbon (TOC), based saturation (BS), organic matter (OM), N, P, K, Ca, Mg, Cu, Fe, Mn and Zn, according to the method proposed by Embrapa (1997). Soil analyses were carried out in the Laboratório Terra (Goiânia, GO, Brazil).

The resulting data were treated by means of the analysis of variance, following the factorial model (two-way ANOVA), the factors being “treatment” (six levels) and “irrigation” (two levels), with five repetitions. In the cases of significant F, Tukey test was applied at 5% probability. The residual normality was checked by means of the Shapiro-Wilk test and the Bartlett test was used to check residual homoscedasticity, by means of the software R version 3.0.3 (R Core Team, 2014). Analysis of variance was performed using the software ASSISTAT, version 7.7 beta (free copy).

## RESULTS AND DISCUSSION

In this study, it was observed that there was interaction between the sources of variation "irrigation" and "treatments" for the concentration of all parameters in the samples, except for the N and Cu contents (Table 4).

Regarding the soil pH, it was observed that all treatments irrigated with wastewater, with the exception of T2R treatment (which received chemical fertilizer) had a significant increase for this parameter compared to treatments irrigated with water supply (Table 5). It was also observed that the treatments irrigated with water supply (T3A the T6A) which had soil added with tannery sludge vermicomposts also showed an increase in pH, compared to the control treatment (T1A) and gave values of pH similar or superior to treatment T2A (which received chemical fertilizer) (Table 5). These results validated different works developed in different agricultural systems with diverse cultures, which found an increase in soil pH by irrigation with domestic sewage (Andrade-Filho et al., 2013; Oliveira et al., 2014). It is believed that in the present study, the increase of soil pH value can be attributed, among other factors. The addition of exchangeable cations and anions by the effluent, and the addition of organic residues to the soil originated from vermicompost, followed by decarboxylation and deamination, proton consuming processes.

Regarding the base saturation (SB) parameter, the observed values does not follow a defined pattern (that is, associated with a treatment in particular), observed

**Table 5.** Mean values of the interaction between type of irrigation water x fertilization treatments for pH, electrical conductivity (EC), total organic carbon (TOC), base saturation (BS), organic matter (OM), P, K, Ca and Mg from studied soil.

| Types of irrigation | Trataments | | | | | |
|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T5 | T6 |
| | | | pH ($CaCl_2$) | | | |
| A | 4.80bC[2] | 5.00aB | 5.20bA | 5.10bAB | 5.00bB | 5.2bA |
| R | 5.30aA | 5.00aB | 5.40aA | 5.40aA | 5.40aA | 5.4aA |
| **BS (V%)** | | | | | | |
| A | 50.00bD | 57.00bC | 65.00aB | 69.00aA | 59.00bC | 60.00bC |
| R | 69.00aAB | 62.00aC | 67.00aB | 71.00aA | 62.00aC | 63.00aC |
| **EC (μS.cm$^{-1}$)** | | | | | | |
| A | 68.00bB | 47.80bE | 54.00bD | 73.00bA | 59.00bC | 49.00bE |
| R | 126.00aB | 105.00aD | 120.00aC | 131.00aA | 98.00aE | 97.00aE |
| **OM (%)** | | | | | | |
| A | 1.00bD | 1.20bC | 1.45bB | 2.70aA | 1.60aB | 1.60aB |
| R | 1.60aA | 1.60aA | 1.60aA | 1.60bA | 1.60aA | 1.60aA |
| **TOC (%)** | | | | | | |
| A | 0.57bD | 0.66bC | 0.92aB | 1.10aA | 0.93aB | 0.93aB |
| R | 0.93aA | 0.93aA | 0.93aA | 0.93aA | 0.93aA | 0.93aA |
| **P (mg.dm$^{-3}$)** | | | | | | |
| A[1] | 1.00bB[2] | 1.00bB | 2.00bA | 2.00bA | 2.00bA | 2.00bA |
| R | 5.00aD | 6.00aC | 8.10aB | 11.00aA | 5.00aD | 6.00aC |
| **K (mg.dm$^{-3}$)** | | | | | | |
| A | 92.00bA | 72.00bD | 48.00bE | 84.00bB | 76.00bCD | 80.00bBC |
| R | 100.00aB | 120.00aA | 92.00aC | 88.00aC | 104.00aB | 120.00aA |
| **Ca (cmolc.dm$^{-3}$)** | | | | | | |
| A | 2.20bD | 2.60aC | 3.30aA | 3.50aA | 3.30aA | 3.00aB |
| R | 3.40aA | 2.70aCD | 3.10bB | 3.50aA | 2.90bBC | 2.60bD |
| **Mg (cmolc.dm$^{-3}$)** | | | | | | |
| A | 0.60bA | 0.60bB | 0.60bB | 1.20aA | 0.60bB | 1.00aA |
| R | 1.30aA | 1.00aBC | 1.10aABC | 1.20aAB | 0.90aC | 0.90aC |
| **Fe (mg.dm$^{-3}$)** | | | | | | |
| A[1] | 43.00Bd[2] | 62.00bA | 48.00bC | 54.00bB | 56.00aB | 50.00bC |
| R | 58.00aD | 64.00aB | 75.00aA | 61.00aC | 54.00bE | 61.00aC |
| **Mn (mg.dm$^{-3}$)** | | | | | | |
| A | 32.00bD | 46.00bC | 32.00bD | 60.00bA | 62.00aA | 52.00bB |
| R | 62.00aC | 69.00aA | 66.00aB | 71.00aA | 58.00bD | 62.00aC |
| **Zn (mg.dm$^{-3}$)** | | | | | | |
| A | 6.10aC | 8.20bA | 6.10bC | 5.20bD | 8.40aA | 7.40aB |
| R | 5.90bC | 9.30aA | 7.10aB | 5.50aD | 5.50bD | 5.60bD |

[1]A: Supply water; R: wastewater; T1: Soil (control); T2: Soil + NPK; T3: Soil + VLp20; T4: Soil + VLp20 + P; T5: Soil + VLc20; T6: Soil + VLc20 + P.
[2]Means followed by the same lowercase letter in the column and uppercase in line do not differ by Tukey test at 5% probability.

than higher values in T1R, T2R, T5R and T6R irrigated with wastewater treatments (Table 5). Analyzing only the treatments irrigated with the water supply, it was observed that the highest values for SB were found in T3A and T4A treatments. Among the treatments irrigated with wastewater, the highest values were identified in T1R, T3R and T4R treatments (Table 5). It is noteworthy that all the results for SB were considered average (51 to 70%), with the exception of T4R treatment, as well as to the vast majority of pH values (5.1 to 5.5).

With regard, EC parameter observed increase in their values in irrigation with wastewater treatments (Table 5), as evidenced by Nichele (2009), in which the corn was conducted in soil irrigated with domestic wastewater. Analyzing separately, irrigation with wastewater and supply treatments, no pattern set for this parameter was observed. It is believed that the observed EC increase in irrigation with wastewater treatments which can be attributed to the addition of salts present in the effluent.

About the OM, an increase was found only in treatments irrigated with wastewater, T1R, T2R, and T3R (Table 5). Among the treatments irrigated with wastewater, there was no significant difference for this parameter. In this case, it is likely that there has been fast mineralization of OM, in all experimental treatments, caused by the high temperatures associated with constant moisture, the result of continuous irrigation experiment with domestic wastewater. Beyond the high percentage of OM observed in T3A, T4A, T5A, and T6A treatments irrigated with the water supply, compared to other treatments, is possibly associated with high organic content present in the vermicompost used, and the high values of OM present in them (Table 1). TOC increase was observed only in T1R and T2R treatments, depending on the application of wastewater (Table 5). These results differ from previous studies that showed increase according to the TOC addition of domestic sewage in the soil (Friedel et al., 2000; Suárez-Abelenda et al., 2013). However, T3A, T4A, T5A, and T6A treatments, irrigated with the water supply, stand out which showed statistically higher TOC values than those found in the T1A and T2A treatments' soils (Table 5). In this case, it is believed that the addition of tannery sludge vermicomposts has directly influenced the level of this parameter in the soil, as both types of vermicomposts used had a high concentration of TOC (Table 1). Moreover, it can be assumed that irrigation with wastewater in soil plus vermicompost treatments (T3R to T6R) did not cause an increase of TOC, due to the fact that the amount of C consumed by microorganisms has been reset by C-effluent or microorganisms have a preference for using the OM of the effluent or vermicomposting as an energy source.

The variation factor "irrigation" with N concentration in soil was the only observed effect (Table 4). The treatments irrigated with wastewater were those that had higher N-total concentrations in soil (Table 4), a result that may be directly related to the high concentration of N-total present in this type of water (Table 3). The N contained in the wastewater used in the present study is 91.02% in its mineral form ($N\text{-}NH_4^+$ + $N\text{-}NO_3^-$), predominantly as $N\text{-}NH_4^+$ (Table 3), form that has commonly been identified in domestic effluents (Fonseca et al., 2005a; Andrade-Filho et al., 2013). Silva (2009), studying the effects of irrigation of corn with treated effluent, also noted a significant increase in N-ammoniacal and nitrate content in the soil after the experiment.

It was observed that irrigation with wastewater provided increment in P-element in the soil (Table 5) when compared with soils irrigated with the water supply, although this increase was very small in relation to the initial content of P in the soil profile (5 mg $dm^{-3}$) (Table 1). As shown in different studies that evidence the addition of domestic waste to soil, significantly increases the P-content in its surface layer (Costa et al. 2012, Bame et al. 2014), although there are studies that do not show changes in P-concentrations in soils irrigated with wastewater (Fonseca et al., 2005a; Silva, 2009; Nichele, 2009). Analyzing separately the treatments irrigated with the water supply, can show that T3A, T4A, T5A, and T6A treatments showed higher P-concentrations in relation to T1A (control) and T2A (which received chemical fertilizer) treatments. Such results can possibly be explained by the large amount of P present in the used tannery sludge vermicompost (Table 1), which possibly had been made available to the soil, besides the addition of P in T4 and T6 treatments.

Regarding K, although there was sharp decrease of the element relative to its initial concentration in the soil (Table 1), this was a significant increase of the element in soil irrigated with wastewater treatments (Table 5) compared to soils irrigated with the water supply. This data can be directly related to the high concentration of this element in the wastewater used (Table 3). At the end of the experiment, no set pattern was observed in analyzing separately the treatments irrigated with wastewater or not. In the treatments irrigated with the water supply, there is T1A treatment (control), with the highest K-concentration (Table 5), a result that can be explained by the low consumption of the element by the plant, since, crop did not have a good development in this experimental unit. Analyzing only the treatments irrigated with wastewater, T6R treatment (soil + VLc20 + P) was the one with the highest concentration of the element (Table 5).

Regarding Ca and Mg macronutrients, no well-defined standards were identified specifically in relation to any treatment, about their concentrations identified in the soil after cultivation of maize (Table 5). However, there was an increase of elements in the soil after the experiment when their concentrations were compared to the initial concentration observed in the cultivation of the soil profile (Table 1). Among the treatments irrigated with the water supply, it was observed that the T3A, T4A, T5A and T6A treatments (which had soil increased with tannery sludge vermicompost) showed higher Ca-concentrations in relation to T1A treatment (control) and T2A (which received chemical fertilizer). These results are possibly to the element increase provided by the tannery sludge vermicompost used, since such compounds show concentrations, nearly 5.5 times greater than the initial Ca-concentration observed in the soil used to cultivate (Table 1).

At the end of the experiment, it was observed that in soil irrigated with wastewater, the micronutrient Cu did show higher values compared to soils irrigated with water supply (Table 4). In addition, it is emphasized that there were no element additions to the soil in the treatments, when analyzing the initial concentration of the element in soil profile (Table 1). As for Fe, Mn and Zn elements, it was found at the end of the experiment. The soil of most treatments irrigated with wastewater has the highest values of the elements when compared with soils irrigated with water supply (Table 5).

For the Mn element, there was an increase in the soil compared to its initial concentration present in soil used to cultivate. While initially there was a concentration of 47 mg $dm^{-3}$ (Table 1) at the end of the experiment, the average element-concentration in soil irrigated with wastewater treatments was 64.66 mg $dm^{-3}$, increase which corresponds to almost 1.5 times. Furthermore, increase of Mn was observed, when compared with its initial concentration (Table 1) in all treatments with addition of tannery sludge vermicompost, which is probably due to the contribution provided by compounds used.

On the other hand, relative to their initial concentration in the soil, the soil of all treatments had the Zn-concentration increased (Tables 1 and 5). In this case, it is believed that the component of the contribution provided by the irrigation water supply or wastewater, has been responsible for this increase. From Table 3, it is possible to note that both types of water, especially the water supply, showed Zn values greater than the upper limit permitted by Brazilian law (Brazil, 2005). Moreover, the Zn concentration in the tannery sludge vermicompost used is at least eight times higher than the concentration in soil initially verified (Table 1). The increase of this element in the soil plus vermicompost may also be related to the high concentration of Zn present in coprolites of earthworms. Increases in Zn-levels in coprolites have been observed in previous studies (Cheng and Wong, 2002; Bartz et al., 2010) for various species of worms.

## Conclusion

It is concluded that the tannery sludge vermicompost, added to soil and irrigated with wastewater from households, provided little increase in pH, EC, COT, BS, MO, N, P, K Cu and Fe concentrations compared to their initially identified concentrations in soil and does not provide, therefore, changes in the soil for these parameters. On the other hand, tannery sludge vermin-compost and domestic wastewater constitute good sources of Ca, P, Mg, Mn and Zn, being able to increase the content of these elements in the soil. It was suggested that further research be conducted to assess the impact of treatment on aspects of crop production.

## Conflict of interests

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# Sugarcane cultivation submitted to water replacement via irrigation bar

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**From the hypothesis that during the development of sugarcane, the water regime affects the morphological performance and this affects the productivity. The objective of this work was to evaluate the growth, development, productivity and yield of sugarcane during the cycle the planting sugarcane (variety SP83-5073), under different water replacements. The experiment was established in the Boa Vista mill located in Quirinópolis – GO, Brazil, on a distroferric Red Latosol cerrado phase. The experimental design was a randomized complete block, analyzed in a split plot scheme with four replications. Irrigation was carried out by a hose-drawn traveller sprinkler systems coupled to an irrigation bar. The evaluated variables were plant height, stem diameter, number of leaves and leaf area of two plants located in the useful area of each plot. The results were submitted to analysis of variance by F test at 5% probability, and in cases where significant difference were observed, regression analysis was performed on the water replacement levels and the evaluation dates, using the statistical software SISVAR. The growth of sugarcane was influenced positively by water replacement, depending on the season and applied blade, for plant height variables, stem diameter, leaf number and leaf area. The sugarcane yield obtained maximum increases of 61.07% and 81.52 t ha$^{-1}$ on the blade 86.16% of water replacement with a productivity of 133.5 t ha$^{-1}$.**

**Key words:** Irrigation depth, biometry, water deficit, yield.

## INTRODUCTION

Brazil is the world's largest producer of sugarcane and its derivatives, sugar and alcohol. The expansion of the sugarcane area is arguably growing, so is the demand for knowledge encompassing the adaptability and the production of this crop in new cultivation areas (Silva et al., 2015). Such agricultural areas regularly have specific climatic conditions, especially water scarcity, which interferes with the growth and development of plants, due

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to the biochemical, physiological and morphological changes (Silva et al., 2007).

Dantas et al. (2006), Farias et al. (2008) and Wiedenfeld and Enciso (2008) stated that the use of the irrigation technology is essential to achieve high productivities, reaching the genetic potential of the crop. According to Inman-Bamber and Smith (2005), the morphological and physiological characteristics modified by water stress are of great importance to achieve high plant yield. Thus, an appropriate knowledge of how plants respond to such abiotic stress is one of the prerequisites to choose both the best variety and the best management practices, aiming mainly at improving the exploitation of natural resources (Smit and Singels, 2006).

Inman-Bamber (2004) pointed out that the time of exposure to drought adversely affects the shoot growth, especially the leaf production, accelerating the essence of the leaf and of the plant as a whole. This exposure may also lead to a reduction in the interception of radiation, in the water use efficiency and in the photosynthesis, as well as to an increase in the radiation transmitted to the ground surface.

The production of sugarcane can be affected significantly when there is a reduction in the emission and survival of tillers (Silva et al., 2014). Decrease in the expansion of leaves and stem usually occur before the reduction of leaves and subsequently affects the accumulation of dry matter and soluble solids in the juice (Inman-Bamber, 2004). On the other hand, cultivars that maintain better performance of these variables under water stress have the potential to be more productive under this water regime (Silva et al., 2008).

According to Arantes (2012), the water deficit is not limited only to arid and semi-arid regions of the world, since even in areas considered climatically humid, the uneven distribution of rainfall may, in some periods, limit growth. For the efficient use of water by sugarcane, it is essential to identify the water requirement responsible for maximum production (Wiedenfeld and Enciso, 2008).

In this context, from the hypothesis that during the development of sugarcane, the water regime affects the morphological performance and this affects the productivity. The objetive this work was evaluate the growth, development, productivity and yield of sugarcane during the cycle the plant cane (variety SP83-5073), under different water replacements.

## MATERIALS AND METHODS

The experiment was carried out in July 2013, during the crop cycle the plant cane of the variety SP83-5073 in the Boa Vista mill located in the municipality of Quirinópolis - GO. The experimental area comprises the Glebe 10.211 belonging to the Vilela farm located in the neighboring municipality of Paranaiguara - GO, at the margins of the Lago Azul (Blue Lake) owned by CEMIG, which has a soil classified as distroferric Red Latosol cerrado phase, according to Embrapa (2013). The climate is (according to Köppen climate classification) classified as tropical savanna with dry winter and rainy summer (Aw), with an annual average rainfall between 1430 and 1650 mm, and drought period well defined between May and October (Table 1).

The experimental design was randomized complete block, analyzed in a split plot scheme with four replications. The factors evaluated in the plots consisted of five water replacement depths (100, 75, 50, 25 and 0% of the required irrigation). The subplots were represented by six evaluation periods (30, 90, 150, 210, 270 and 330 days after planting - DAP). The internode length variable was measured from 90 to 270 DAP and the number of plants from 150 to 330 DAP. The variables total recoverable sugars and stem productivity were evaluated punctually at the end of the cycle to 330 DAP.

The experimental plots, that is the proportion of the area wetted by the irrigation equipment, were 50.0 m long and 50.0 m wide (33 crop lines with 1.5 m spacing), with a total area of 2500.0 $m^2$. The subplots were composed of 5.0 m of 2 lines, located in the center of the plot.

The planting fertilizer was recommended based on the soil analysis and the application process was made according to the management method adopted in every commercial cultivation area cultivation of the mill. During soil preparation, spread fertilization was carried out by incorporation of average grade of about 15 cm deep. The recommendation was 200 Kg $ha^{-1}$ of $P_2O_5$ in the form of single superphosphate. As for the K and N sources, they were used in a concentrated stillage enriched with urea, totaling equivalent to 180 kg $ha^{-1}$ $K_2O$ and 100 kg $ha^{-1}$ nitrogen. For micronutrients, it was used in a dose of 100 kg $ha^{-1}$ in the form of granulated FTE, being used as 4kg $ha^{-1}$ zinc, 2 kg $ha^{-1}$ boron and 2 kg $ha^{-1}$ copper. The nitrogen coverage fertilization was performed 60 days after planting. 120 kg $ha^{-1}$ N (urea) was applied on both sides of the lines combined with the “break-back” operation.

Irrigation was carried out by a hose-drawn traveller sprinkler systems of Irrigabrasil brand, model 140/GSV/350-4RII. The sprinkler was coupled to an irrigation bar brand Irrigabrasil, model 48/54; MDPE tube with 140 mm outer diameter and length of 350 m; wall thickness of 10.3 mm, with lattices 24.5 m long on each side, totaling 49.0 m of adjustable structure, thus allowing the irrigation of the sugarcane to about 4.0 m high. With height compensation system through telescopic wheels installed along the lattices, the central car of the bar was operated with 3.0 m width. Senniger emitters spaced at 1.85 m were used, totaling 26 emitters; the working pressure in the bomb was 10 Kgf $cm^{-2}$ while it was 5 Kgf $cm^{-2}$ in the reel. The reel was operated with an average wind speed of 14.5 m $s^{-1}$.

In software, the weather monitoring was used to estimate daily water consumption of sugarcane generating daily water balance and calculating the water depth to be applied, allowing the control of the appropriate time to irrigate. The readings were taken daily, enabling the assessment of crop water consumption with respect to the used water depth (100% of the available water), and the reference evapotranspiration (ET0) was calculated according to Penman-Monteith-FAO / 56 (Allen et al., 1998) (Table 2).

At the end of the irrigation period, a detailed report of the irrigation management was generated, calculating the accumulated water deficit and the irrigation depths applied during the irrigation period of the experiment (Table 3).

In the central lines of the subplots, the following morphological characteristics were evaluated in relative to plant height (PH); diameter of stem (DS); number of leaves (NL); leaf area (LA); number of internodes (NI); number of tillers (NT) and number of plants (NP). The plant height was measured, with a tape measure, from the ground to the collar of the +1 leaf (+1 leaf is that in which the collar can be completely visualized); and then expressed in cm. The stem diameter was determined with a caliper rule in the middle third of the plant, and expressed in mm.T

The number of leaves was determined by counting the fully expanded leaves with a minimum of 20% of green area, they were counted from the +1 leaf; then the leaf area was determined by

**Table 1.** Physical, water and chemical characteristics of the soil in the experiment area.

| Physical and water characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Layer** | **FC** | **PWP** | **Micro** | **Macro** | **TP** | **PD** | | **PR** |
| **m** | **%** | | | | **$cm^3$** | **$g.cm^{-3}$** | **Sd** | **Mpa** |
| 0.00-0.20 | 66.5 | 45.39 | 67.28 | 24.30 | 42.97 | 2.24 | 1.28 | 5.04 |
| 0.10-0.20 | 70.75 | 41.14 | 71.16 | 23.68 | 47.47 | 2.39 | 1.25 | 3.17 |
| 0.20-0.40 | 56.5 | 34.92 | 56.84 | 13.33 | 43.51 | 2.27 | 1.28 | 5.19 |

| | Granulometry | | | Textural Class |
|---|---|---|---|---|
| | **Clay (%)** | **Silt (%)** | **Sand (%)** | |
| 0.00-0.20 | 27.50 | 6.90 | 65.60 | Sandy |
| 0.20-0.40 | 45.06 | 4.04 | 50.90 | Sandy |

| Chemical characteristics | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Layer** | **pH** | **O.M** | **P** | **K** | **Ca** | **Mg** | **Al** | **H+Al** | **SB** | **T** | **V** |
| **(m)** | **in $H_20$** | **($g\ kg^{-1}$)** | **($mg\ dm^{-3}$)** | | | **($mmol\ dm^{-3}$)** | | | | | **(%)** |
| 0.00-0.20 | 6.1 | 60.42 | 8.16 | 3.04 | 21.30 | 15.70 | 0.0 | 55.75 | 45.80 | 95.50 | 45.90 |
| 0.20-0.40 | 6.3 | 45.47 | 2.15 | 4.19 | 15.40 | 14.20 | 0.0 | 45.55 | 35.69 | 75.20 | 40.50 |

FC, Field capacity; PWP, Permanent Wilting Point; Micro, Microporosity; Macro, Macroporosity; TP, Total Porosity; PD, Particle Density; Sd, Soil density; PR, Penetration Resistance; pH in distilled water. P and K, extractor Mehlich$^{-1}$. O.M, Organic Matter; T - Cation exchange capacity; SB - Sum of bases and V, Saturation per base.

**Table 2.** Monthly averages of agrometeorological data during the irrigation period.

| Year | Month | Tmax | Tmin | Tave | RH | Rainfall | $ET_0$ |
|---|---|---|---|---|---|---|---|
| | | ºC | | | % | mm | mm $day^{-1}$ |
| 2013 | 6 | 31.08 | 17.94 | 24.51 | 66.91 | 11 | 4.12 |
| | 7 | 29.11 | 13.94 | 21.53 | 60.90 | 0 | 3.99 |
| | 8 | 31.12 | 14.02 | 22.57 | 45.47 | 0 | 4.61 |
| | 9 | 33.41 | 18.60 | 26.00 | 58.44 | 13 | 5.05 |
| | 10 | 33.47 | 20.92 | 27.20 | 55.66 | 121 | 5.18 |
| | 11 | 32.20 | 21.07 | 26.64 | 79.25 | 105 | 4.88 |
| | 12 | 32.52 | 22.30 | 27.41 | 84.13 | 235.6 | 5.00 |
| 2014 | 1 | 29.4 | 20.4 | 23.21 | 77.99 | 206.0 | 5.3 |
| | 2 | 30.4 | 19.7 | 23.64 | 74.39 | 376.0 | 5.1 |
| | 3 | 28.7 | 19.14 | 23.11 | 82.54 | 315.0 | 4.8 |
| | 4 | 27.9 | 18.8 | 23.20 | 81.37 | 165 | 4.7 |
| | 5 | 26.7 | 18.4 | 21.37 | 70.49 | 40 | 4.5 |

Tmax, Maximum temperature; Tmin, Minimum temperature; Tave, Average temperature; RH - relative humidity; $ET_{0,}$ Reference evapotranspiration (Penman-Monteith-FAO/56 (Allen et al., 1998)).

counting the number of green leaves (fully expanded leaf with minimum of 20% green area, counted from the +1 leaf) (Benincasa, 2003).

The number of plants was determined by counting all plants containing more than six fully expanded leaves. The number of tillers was determined from the count of all plants containing less than six fully expanded leaves; the number of internodes was obtained by counting throughout the stem of the plants from the posting of the first stems.

The monitoring of the sugarcane ºBrix was conducted in the field, in the last three weeks prior to the harvest in each crop cycle. When the Maturation Index (MI = Top °Brix/ Base °Brix) was between 0.9 and 0.95, samples of three stems of each plot were collected, totaling twelve complete stems per treatment; and submitted for evaluation in the industrial quality laboratory of the mill, for the determination of total recoverable sugars (TRS), which was expressed in kg $ton^{-1}$.

Stem productivity was determined by the total weight of stems present in the respective subplots. In order to quantify the weight of the stems present in 1.5 m of the two central lines, whose value was extrapolated to ton $ha^{-1}$, the cut was performed as close as possible to the ground. The straw was then removed from stems and the index was highlighted. Then the stems were weighed on a hook-type digital scale, brand Soil Control (precision = 0.02 kg), with capacity of 50 kg.

The results were submitted to analysis of variance by F test at 5% probability, and in cases where significant differences were observed, regression analysis was performed on the water replacement levels and the evaluation dates, using the statistical software SISVAR (Ferreira, 2011).

**Table 3.** Fortnight averages of accumulated water deficit and irrigation depths applied during the irrigation period of the experiment.

| Month | Phase* | Kc** | Accumulated water déficit (mm) | | | | Applied depths (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 25% | 50% | 75% | 100% | 25% | 50% | 75% | 100% |
| 06 | II | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 06 | III | 0.40 | 2.40 | 4.79 | 7.19 | 9.58 | 10.00 | 20.00 | 30.00 | 40.00 |
| 07 | III | 0.70 | 4.18 | 8.35 | 12.53 | 16.71 | 10.00 | 20.00 | 30.00 | 40.00 |
| 07 | | 0.70 | 4.94 | 9.87 | 14.81 | 19.74 | 10.00 | 20.00 | 30.00 | 40.00 |
| 08 | III | 0.70 | 10.02 | 20.03 | 30.05 | 40.07 | 11.00 | 22.00 | 33.00 | 44.00 |
| 08 | | 0.70 | 9.51 | 19.02 | 28.53 | 38.04 | 11.00 | 22.00 | 33.00 | 44.00 |
| 09 | III | 0.70 | 10.53 | 21.06 | 31.60 | 42.13 | 11.00 | 22.00 | 33.00 | 44.00 |
| 09 | | 0.70 | 7.16 | 14.32 | 21.48 | 28.64 | 0.00 | 0.00 | 33.00 | 44.00 |
| 10 | III | 1.25 | 12.54 | 25.07 | 37.61 | 50.14 | 13.00 | 26.00 | 39.00 | 52.00 |
| 10 | | 1.25 | 12.56 | 25.12 | 37.69 | 50.25 | 13.00 | 26.00 | 39.00 | 52.00 |
| 11 | III | 1.25 | 6.49 | 12.98 | 19.47 | 25.96 | 13.00 | 26.00 | 39.00 | 52.00 |
| 11 | | 1.25 | 12.54 | 25.07 | 37.61 | 50.15 | 13.00 | 26.00 | 39.00 | 52.00 |
| 12 | IV | 1.25 | 17.64 | 35.28 | 52.92 | 70.56 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | | 1.25 | 22.06 | 44.12 | 66.19 | 88.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Total | | 132.57 | 265.08 | 397.68 | 530.23 | 115.0 | 230.0 | 378.0 | 504.0 |

*According to Diola and Santos (2012), wherein the stages of development of sugarcane are divided into four, namely: (i) Budding and establishment of the culture; (II) Tillering: Extends from the end of the budding up to 120 days after planting; (III) Vegetative development and stem growth; begins immediately after the tillering phase up to 270 days after planting; (IV) Maturation: Phase of synthesis and accumulation of sugar, which lasts from 270 to 300 up to 360 days after planting. **Kc - Culture coefficient, described by Doorenbos and Kassam (1994).

**Table 4.** Summary of the analysis of variance for plant height (PH), diameter of stem (DS), number of leaves (NL) and leaf area (LA) as a function of water replacement factors (WR) and days after planting (DAP) of sugarcane, Quirinópolis - GO, 2013/14.

| SV | DF | MS | | | |
|---|---|---|---|---|---|
| | | PH | DS | NL | LA |
| WR | 4 | 12400.53** | 20.79** | 1.00* | 1109746.96** |
| Block | 3 | 1001.21* | 1,88$^{ns}$ | 0.66$^{ns}$ | 127177.53$^{ns}$ |
| Residue$^a$ | 12 | 207.52 | 3.56 | 0.28 | 137706.32 |
| DAP | 5 | 218432.90** | 398.67** | 21.68** | 44993206.77** |
| WR x DAP | 20 | 522.63* | 15.62** | 0.70$^{ns}$ | 593389.05* |
| Residue$^b$ | 75 | 285.41 | 5.22 | 0.44 | 295129.95 |
| CV a (%) | | 8.62 | 7.24 | 8.06 | 10.29 |
| CV b (%) | | 10.11 | 8.77 | 10.14 | 15.06 |

$^{ns}$ non-significant; **,* significant, respectively, at 1 and 5% probability by F test. SV, Sources of Variation; DF, Degree of Freedom; MS, Mean Square; CV, Coefficient of Variation.

## RESULTS

In summary, in the variance analysis, it is observed that there was a significant interaction between the factors: water replacement (WR) and days after planting (DAP) for the variables: plant height (PH), diameter of stem (DS) and leaf area (LA), and there was isolated significant effect on number of leaves (NL) (Table 4).

In analyzing the unfolding of the interaction of PH as a function of WR, the observation was a linear increase at 90 and 150 DAP, with increasing up to 0.54 and 0.56 m, respectively, with 100% WR. Yet at 210, 270 and 330 DAP, there was a quadratic behavior of maximum increase obtained with 100.0, 93.50 and 79.50% WR, respectively, corresponding to values 2.75, 3.22 and 2.81 m as in Figure 1A. For the PH as a result of DAP, it was observed that there was a linear increase of up to 2.93, 2.57, 3.13, 3.06 and 3.10 m at 330 DAP for 0, 25, 50, 75 and 100% WR, respectively (Figure 1B). Thus, the highest PH increase due to WR was observed at 210 DAP with 103.0% of the required irrigation. For PH due to WR, the highest values were observed at 270 DAP, reaching 3.22 m. For PH as a function of DAP, it was observed the highest increase and value of PH with 50% WR, reached 3.13 mm.

In the analysis of the interaction of the DS as a result of

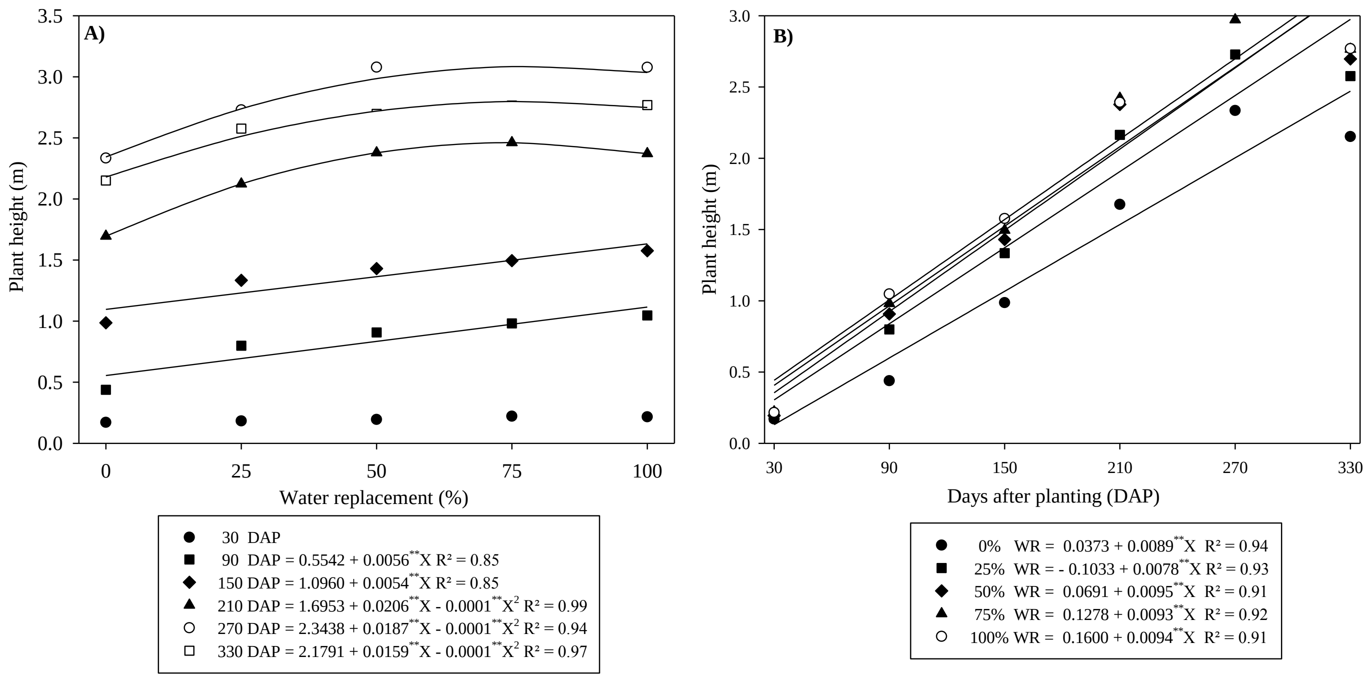


**Figure 1.** Plant height of sugarcane as a function of water replacement (A) and days after planting (B), Quirinópolis - GO, 2013/14.

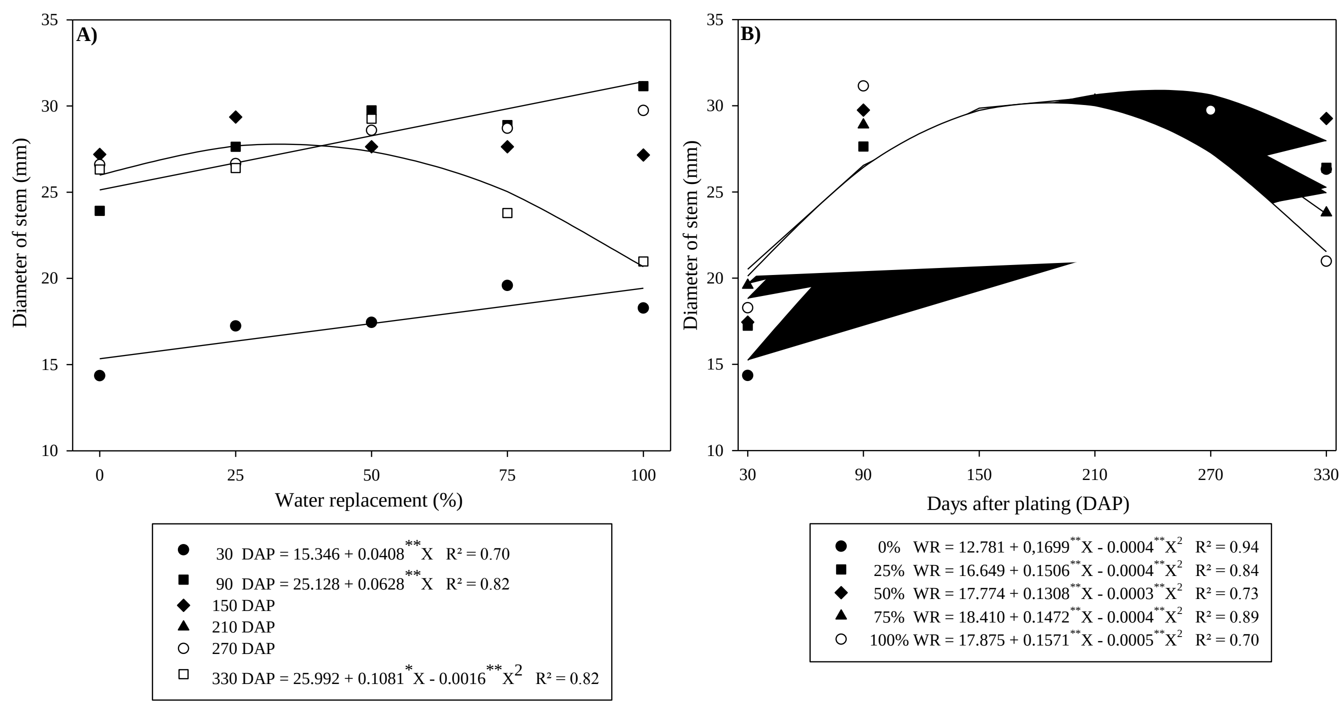


**Figure 2.** Diameter of sugarcane stem in function of (A) water replacement and (B) days after planting, Quirinópolis - GO, 2013/14.

WR, it was observed that there were linear increases at 30 and 90 DAP, and the increases were up to 4.08 and 6.08 mm, respectively, with 100% WR. Yet at 330 DAP, there was a quadratic behavior of maximum increase obtained with 33.78% WR, respectively corresponding to a value of 27.81 mm (Figure 2A). For the DS as a function of the DAP, it is observed that there was a quadratic behavior with 0, 25, 50, 75 and 100% WR, with

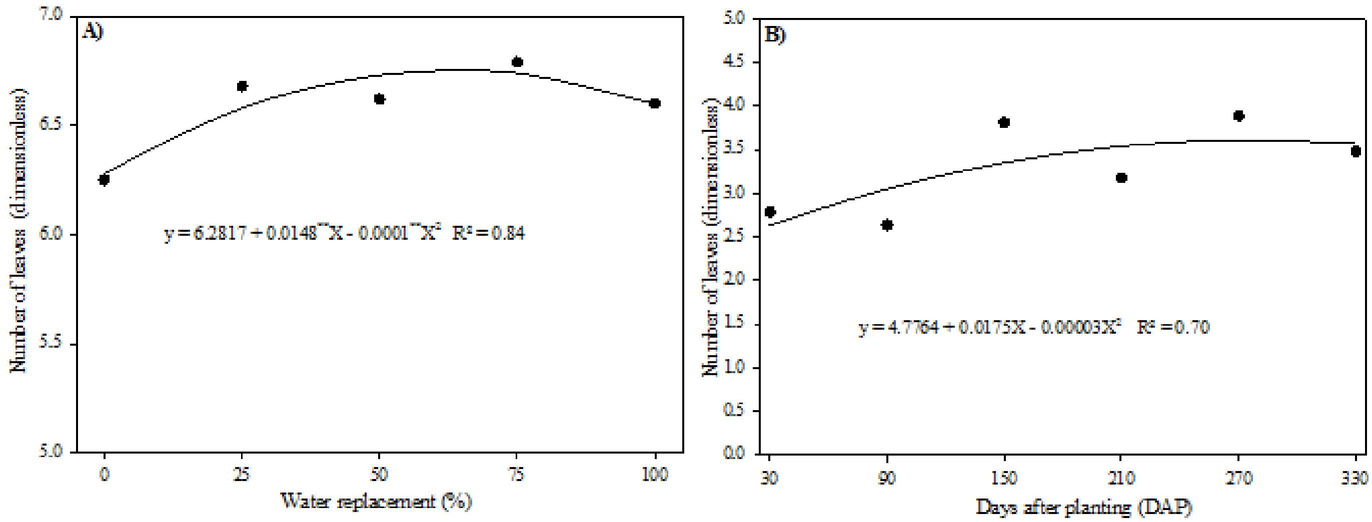


**Figure 3.** Number of sugarcane leaves in function of (A) water replacement and (B) days after planting, Quirinópolis - GO, 2013/14.

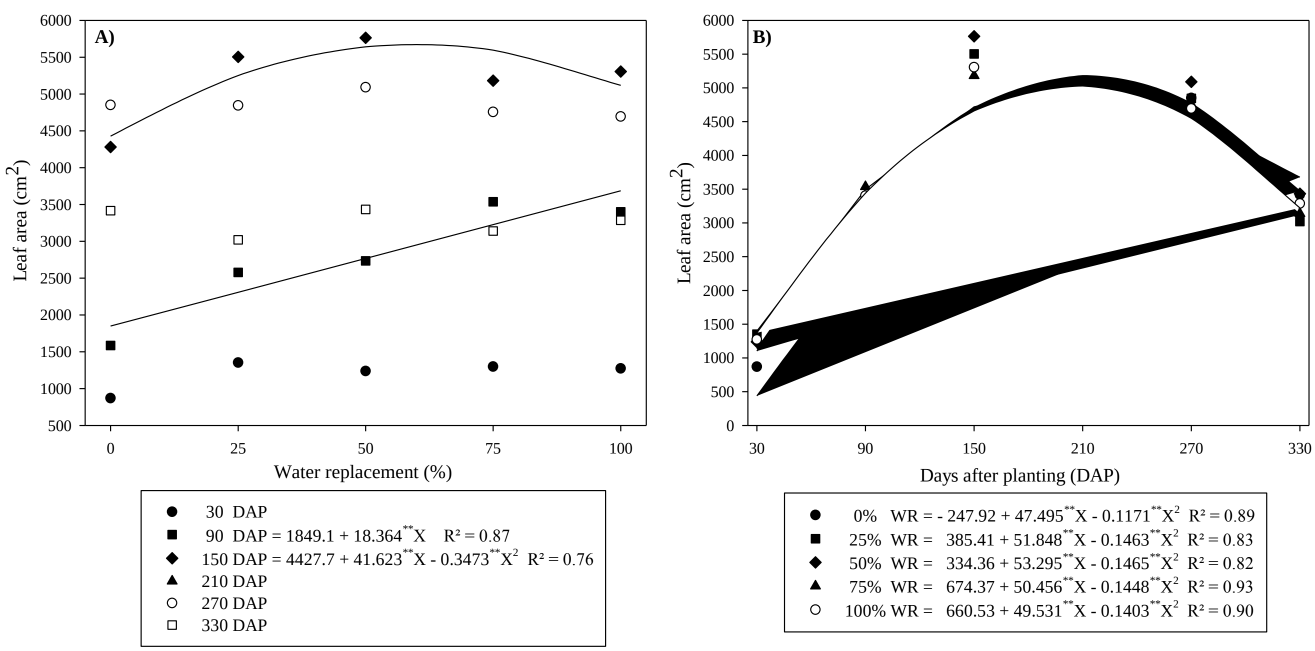


**Figure 4.** Leaf area in function of the water replacement (A) and days after planting (B) sugarcane, Quirinópolis - GO, 2013/14.

maximal increases obtained at 212, 188, 218, 184 and 157 DAP, respectively, corresponding to values of 30.82, 30.83, 32.03, 31.95 and 30.27 mm (Figure 2B). Thus, for the DS as a function of the WR, the largest increases and values were observed at 90 DAP, reaching 31.20 mm. For the DS as a function of DAP, the largest increases and values of DS were observed with 75% WR at 184 DAP, reaching up to 31.95 mm.

In the isolated analysis of NL as a function of WR, it was observed that there was a quadratic behavior with maximal increase at 74.5% WR, reaching the values of 6.82 leaves as in Figure 3A. For NL as a function of DAP, a quadratic behavior with maximum increasing at 291 DAP, with values of 7.32 leaves was noted (Figure 3B).

In the analysis of the interaction of LA as a function of WR, a linear increase was observed at 90 DAP, the increase was up to 50.17 with 100% WR, corresponding to a value of 1836.40 $cm^2$. Yet at 150 DAP, there was a quadratic behavior of maximum increase obtained at 59.92% WR, corresponding to a value of 5666.32 $cm^2$ (Figure 4A).

For the LA as a function of the DAP, there was a

**Table 5.** Summary of the analysis of variance for length of internodes (LI) and number of plants (NP), fluid replacement factors (WR) and days after planting (DAP) of sugarcane, Quirinópolis - GO, 2013/14.

| SV | DF | MS | |
|---|---|---|---|
| | | LI | NP |
| WR | 4 | 23.39** | 45.61* |
| Block | 3 | 5.80$^{ns}$ | 5.78$^{ns}$ |
| Residue$^{a}$ | 12 | 2.83 | 12.07 |
| DAP | 3 | 32.73** | 184.43** |
| WR x DAP | 12 | 2.37$^{ns}$ | 3.36$^{ns}$ |
| Residue$^{b}$ | 45 | 3.60 | 6.60 |
| CV a (%) | | 10.96 | 22.41 |
| CV b (%) | | 12.37 | 16.57 |

$^{ns}$ non-significant; **,* significant, respectively, at 1 and 5% probability by F test. SV, Sources of Variation; DF, Degree of Freedom; MS, Mean Square; CV, Coefficient of Variation.

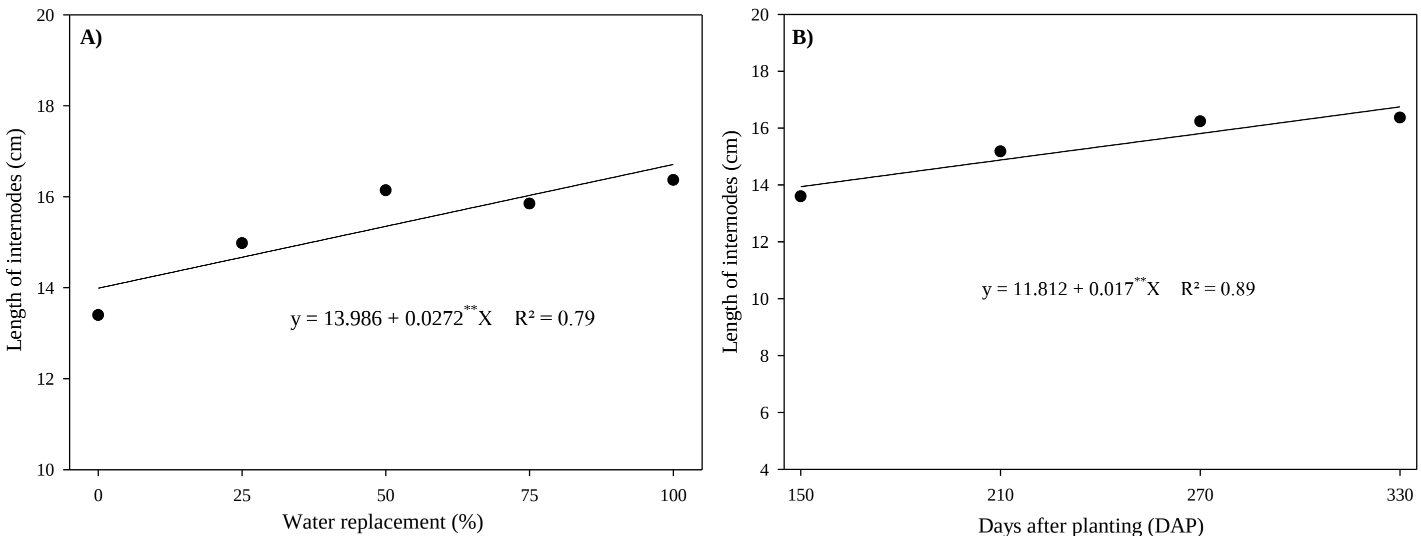


**Figure 5.** Lergth internodes of sugarcane in function of (A) water replacement and (B) days after planting, Quirinópolis - GO, 2013/14.

quadratic increase of 0, 25, 50, 75 and 100% WR, with increases of up to 202, 177, 181, 174 and 176 DAP, respectively, corresponding to values of 4567.92, 4979.07, 5181.27, 5069.75 and 5032.05 $cm^2$ (Figure 4B). Thus, for the LA as a function of the WR, the largest increases and values were observed at 150 DAP, reaching increases of about 3740.16 $cm^2$ with 59.92% WR. For the LA as a function of DAP, the largest increases and values of LA were observed with 50% WR at 181 DAP, reaching 5181.27 $cm^2$.

In the summary of the analysis of variance, there was no significant interaction between the factors WR and DAP for the variables length of internodes (LI) and number of plants (NP), though there was significant isolated effect of these variables both for WR as DAP (Table 5). In the isolated analysis of LI as a function of WR, a linear behavior was observed with increases of about 19.44% at 100% WR, corresponding to a value of 2.72 cm (Figure 5A). For the LI as a function of DAP, there was a linear behavior with increases of about 12.58% at 100% WR, corresponding to a value of 1.70 cm (Figure 5B).

In the isolated analysis of the NP as a function of the WR, it was observed that there was a linear behavior with increasing about 28.18% with 100% WR, corresponding to a value of 3.83 plants (Figure 6A). For the NP as a function of the DAP, a linear behavior with increasing up to 45.38% with 100% WR was noted. This corresponds to a value of 4.16 plants (Figure 6B).

In the summary of the analysis of variance, it was observed that there was a significant effect of the WR factor for the variables total recoverable sugars (TRS) and stem productivity (SP) (Table 6).

In the isolated analysis of TRS as a function of WR, a

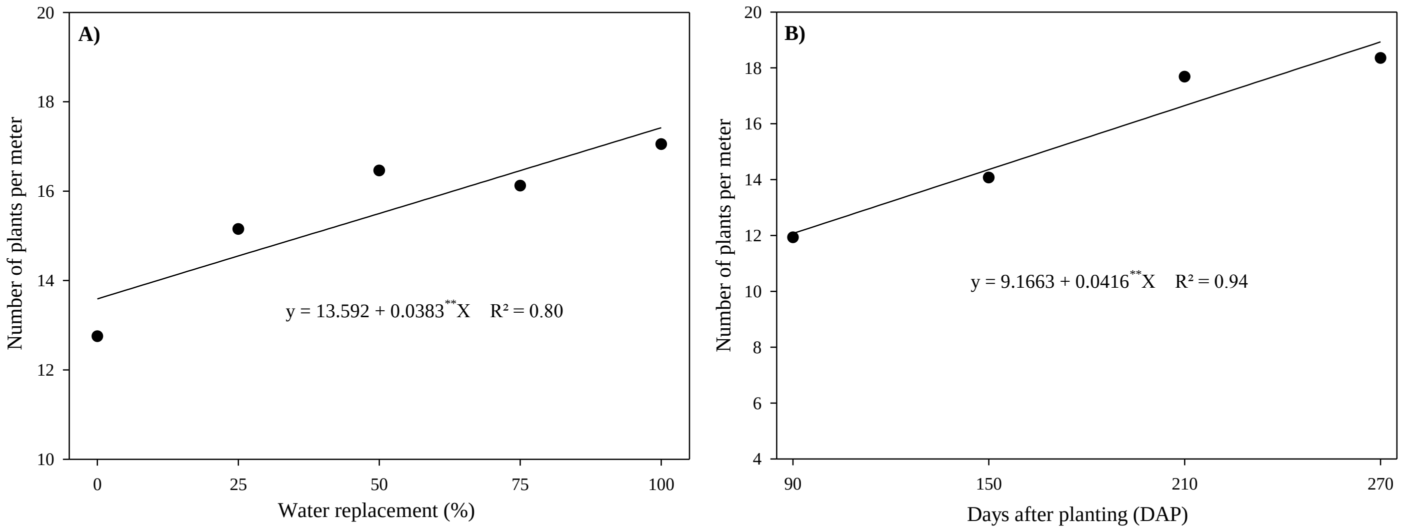


**Figure 6.** Number of plants per meter in function of the (A) water replacement and (B) days after planting of sugarcane, Quirinópolis - GO, 2013/14.

**Table 6.** Summary of the analysis of variance for the variable amount of total recoverable sugar (TRS) and stem productivity (PC) according to fluid replacement factors (HR), Quirinópolis - GO, 2013/14.

| SV | DF | MS | |
|---|---|---|---|
| | | TRS | SP |
| WR | 4 | 62.47** | 2357.66** |
| Block | 3 | 27.97$^{ns}$ | 2357.66$^{ns}$ |
| Residue | 12 | 12.68 | 396.88 |
| CV (%) | | 2.25 | 16.94 |

$^{ns}$ non-significant; **,* significant, respectively, at 1 and 5% probability by F test. SV, Sources of Variation; DF, Degree of Freedom; MS, Mean Square; CV, Coefficient of Variation.

linear behavior was observed with increasing about 6.28 to 100% WR, corresponding to a value of 9.64 kg $t^{-1}$ (Figure 7A).

In the isolated analysis of SP as a function of WR, it was observed that there was a quadratic profile with maximal increases obtained with 86.16% WR, corresponding to a value of 133.49 t $ha^{-1}$, which corresponds to 81.52 increment t $ha^{-1}$ (61.07%) (Figure 7B).

## DISCUSSION

In crop year 2013/14 precipitation in the experiment site was 1587.60 mm, as shown in Table 2, high enough value for the development of sugarcane, but the same does not occur with regularly throughout the season, as this precipitation occurred during the months of 11/2013 to 05/2014 thus months successors to planting 06/2013 to 10/2013 precipitation is insufficient, and the culture period depends on the volume total water added via the irrigation was 0, 115, 230, 378 and 504 mm. respectively for fluid resuscitation of 0, 25, 50, 75 and 100% of the required irrigation.

Studying the growth rates of sugarcane, variety SP 79-1011, under irrigation and rain fed regimes, Farias et al. (2008) found for irrigated sugarcane, a maximum height of 152.80 cm at 193 days, and growth rate in height, at 280.0 DAP, of 0.5457 cm $day^{-1}$. As for the culture subjected to the rainfed system, this maximum height was 148.19 cm at 236.20 days, the growth rate in height of the plants subjected to this management, at 280.0 DAP, was 0.5292 cm $day^{-1}$. Gonçalves (2008) and Pincelli (2010) also found different height response in four cultivars of sugarcane submitted to water stress. Silva et al. (2008) considered that plant height as one of the components to form the production potential of sugarcane, and state that the irrigation empowers the responsive varieties to best express their genetic potential.

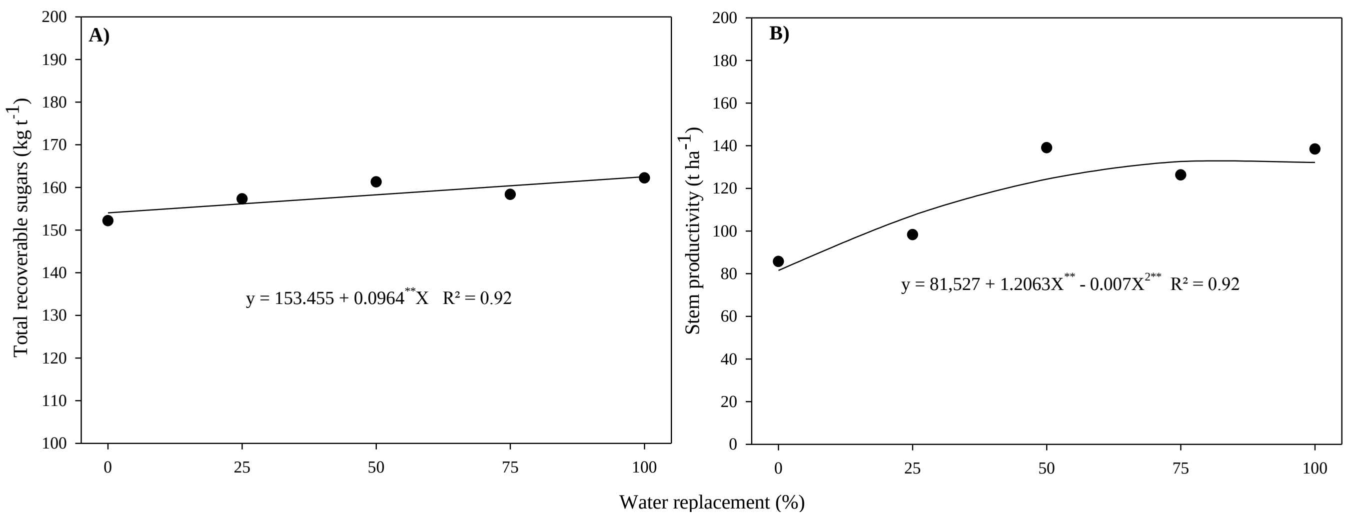


**Figure 7.** Total recoverable sugars in sugarcane in function of (A) water replacement and (B) stem productivity sugarcane, Quirinópolis - GO, 2013/14.

The increase in the diameter of stem in accordance with the evaluation periods was also observed by Oliveira et al. (2010) and Arantes (2012), they reported that not with standing, the following reduction of this morphological parameter from 291.0 days after cutting.

Machado et al. (2009) observed a significant reduction in the amount of leaves due to the water deficit. Smit and Singels (2006) reported that leaf senescence is responsive to water deficit and occurs after the reduction in leaf emergence. The reduction of leaves regarding plants with water deficit (Inman-Bamber, 2004; Pimentel, 2004) was attributed to the strategy by reducing the transpiring surface and the metabolic expenditure for the maintenance of tissues (Inman-Bamber and Smith, 2005; Smit and Singels, 2006; Inman-Bamber et al., 2008).

Results found by Chaves et al. (2008) and Pincelli (2010) demonstrated a reduction in the leaf area of those under water stress, because when subjected to water stress conditions, plants have a number of morphological and physiological changes such as leaf rolling, alteration of the leaf angle and reduction of the leaf area. Farias et al. (2007) observed an increase of approximately 46.0% in the leaf area index of sugarcane with full irrigation. The role of the crop canopy is an important factor in the yield of crops, as it intercepts the solar radiation that drives the processes of photosynthesis and evaporation, in addition to causing shading on weeds (Smit and Singels, 2006). Results showed that the photosynthetic capacity of sugarcane decreases drastically due to reduced leaf area (Inman-Bamber et al., 2009).

Machado et al. (2009) observed contradictory results, he observed that the internode length increased ($p<0.05$) in response to water deficit such that the greater the deficit, the greater the length of the internode. Inman-Bamber and Smith (2005) reported that the susceptibility of sugarcane to water stress is greater when plants are in the phase of elongation of the stems. In sugarcane, the growth is affected by water deficit by restrictions both in the cell division and in the cell elongation.

Oliveira et al. (2010) stated that the tillering in sugarcane grows up to six months after planting/cutting and from this period a reduction begins, resulting from competition for light, area, water and nutrients, reflecting thus in the reduction and stoppage of the process, in addition to the death of the younger tillers. According to Silva et al. (2014), tillering is a component for forming the production potential of sugarcane in conjunction with the length and diameter of stems, and the irrigation enables the responsive cultivars to better express their genetic potential.

Farias et al. (2008) analyzed the effect of irrigation water slides in the industrial quality of sugarcane, and found a strong correlation between the variables. There was a tendency of increase in TRS for higher water values applied. Oliveira et al. (2011) found no changes in the TRS to the total amount of water available to the culture. Inman-Bamber and Smith (2005) reported that the susceptibility of sugarcane to water stress is greater when plants are in the elongation phase of the stem, which causes serious damage in sucrose yield.

Study by Oliveira et al. (2011), with 11 varieties of cane sugar in two water regimes (rainfed and irrigated), found that there were productivity increase of up to 151% in irrigated regime. Gava et al. (2011) studied three genotypes (RB86-7515, RB85-5536 and SP80-3280) found average stem production of 132.2 t $ha^{-1}$ for irrigation management and 106.5 t $ha^{-1}$ for dryland management, in the first cycle. In studies by other authors, it was found that sugarcane genotypes respond differently to increased water availability (Inman-Bamber and Smith, 2005; Smit and Singels, 2006; Silva et al., 2007).

The use of irrigation promoted greater growth and productivity of sugarcane, reducing the effects of drought in the dry season in the planting area, indicating technical feasibility of this management as an alternative to increase productivity, as well as industrial quality sugarcane.

## Conclusion

The growth of sugarcane was influenced positively by water replacement, depending on the season and applied blade, for plant height variables, stem diameter, leaf number and leaf area. The response of the variable length of internode and plant number showed no dependence on irrigation during periods evaluated. The plant height, stem diameter, leaf number and leaf area linearly responded to fluid replacement to around 150 days after planting and from then on the influence of high rainfall committed differentiation of fluid replacement blades. The stem diameter, leaf area and leaf number had its maximum growth until 218 days after planting and plant height to 270 days after planting, with an average water replacement of 76%. The length of internode number and plant due to the fluid replacement had average linear increases of 20 to 100% water replacement. The number of plants depending on the time tended to increase up to 197 days after planting, with 26.42% increase. The total recoverable sugars obtained respective increases of 6.28% in the depth of 100% of fluid replacement. The sugarcane yield obtained maximum increases of 61.07% and 81.52 t $ha^{-1}$ on the blade 86.16% of water replacement with a productivity of 133.5 t $ha^{-1}$.

## Conflict of Interests

The authors have not declared any conflict of interests.

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# Effect of saline water, bovine biofertilizer and potassium on yellow passion fruit growth after planting and on soil salinity

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**The monitoring of plants growth constitutes an important activity during the crops formation, including the yellow passion fruit. In this direction, an experiment was carried out in Remigio, Paraiba State, Brazil, to evaluate the effects of saline water irrigation, bovine biofertilizer and potassium on yellow passion fruit growth plants and soil salinity. Treatments were arranged in randomized block with three replications and 12 plants per plot, using factorial design 2 x 2 x 2, relative electrical conductivity of irrigation water of 0.35 to 4.00 dS m$^{-1}$, in soil with and without biofertilizer and potassium chloride (KCl) conventional and coated with polymers. The variables studied were electrical conductivity of the soil at depths of 0-20 and 21-40 cm, plant height at 30 days after transplanting (DAT), period of the seedlings transplanting to pruning of the main haste and lateral branches, number of productive branches and stem diameter at 30, 90, 150, 210 and 270 DAT. The interaction between water salinity, biofertilizer and potassium increased the soil salinity. The biofertilizer and the slow release of KCl increased the plant growth in height, anticipating the main stem pruning and productive side branches, productive branches number and stem diameter of the plants.**

**Key words:** *Passiflora edulis*, electrical conductivity, organic input.

## INTRODUCTION

The use of saline water for irrigation of foodstuff crops, in general, for a long time is becoming a necessity in the whole world (Rhoades et al., 2000; Malash et al., 2005; Kang et al., 2010). As for the yellow passion fruit, while being sensitive to salinity (Ayers and Westcot, 1999), in semiarid areas of the Paraiba State and Rio Grande do Norte State, in Brazil, it has been irrigated with saline water above 3 dS m$^{-1}$ (Cavalcante et al., 2005; Soares et al., 2008; Bezerra et al., 2014). According to the questioners, irrigation with saline water of this level or higher affect the growth and production of most commercial value plants, but the culture has produced moderately sensitive plant and up to moderately tolerant to salts (Dias et al. 2011; Diniz et al., 2011).

The irrigation even with water without salt restriction, salt concentration below 0.5 g $L^{-1}$ or 0.75 dS $m^{-1}$, ensures the production of food, but increases by at least 50% soil salinity (Ayers and Westcot, 1999). In arid and semiarid areas, the problem is more serious because the waters, in general, have higher salt content and therefore more compromising to the soil and plants (Mesquita et al., 2012). This situation requires the adoption of techniques that leach the salts of the root environment of plants as the leaching fraction (Rhoades et al., 2000) and also of inputs exercising physical improvements expressed by the pore space (Benbouali et al., 2013), chemical by the availability of macro and micronutrients (Patil, 2010) and biological in the increase in population and diversification of soil fauna (Maiti, 2010).

The bovine biofertilizer produced by anaerobic fermentation of fresh cow manure and water, applied to the soil in liquid form, attenuates the aggressive effects of salts during the formation of seedlings of yellow passion fruit– *Passiflora edulis* (Nascimento et al., 2012) and growth of the plants after transplanting in the field (Dias et al., 2013). Regarding production of crops Silva et al. (2011) and Lima Neto et al. (2013) noted that bovine biofertilizer attenuated the effects of salinity irrigation water from moderate restriction to severe restrictions to the beans of String –*Vigna unguiculata* and peppers- *Capsicum annum*. It was also verified that the said organic input has mitigated the negative action of irrigation water salts in the production and quality of yellow passion fruit– *P. edulis* (Dias et al., 2011; Freire et al., 2014; Nascimento et al., 2015).

In addition to organic fertilizers in solid form (Silva, 2008; Ahmed and Moritani, 2010) or liquid, such as biofertilizers (Mahmoud and Mohamed, 2008) and humic substances (Turkmen et al., 2005; Khaled and Fawy, 2011) employed in reducing the risks of salts, the interaction between salinity and mineral fertilization with nitrogen and potassium should also be evaluated in mitigating the harsh effects of the salts to the plants (Lima et al., 2014; Prazeres et al., 2015). When considering that potassium stimulates the maintenance of ionic balance or osmoregulation of plants, turgidity cell, control the opening and closing of stomata, plant resistance to water stress and soil salinity (Gurgel et al., 2010), the application of a source of slow release of macronutrient should also attenuate the depressive effects of salts in the different phases of phenological plants. The coated or protected fertilizers with polymers release the partially nutrient, but continuously during the crop cycle, also, reduction in losses by leaching, volatilization and result in greater efficiency in soil water absorption, solubility and availability to the plants (Zahrani, 2000). These properties, according to Guareschi et al. (2011) reduce the nutritional imbalance due to nutrients polymerized inside the capsules gradually released into the root zone, meeting the needs of the plants as they age. Another advantage is that they maintain the water content in the cells and, in fact, exerts a diluting effect on the salts absorbed by plants under irrigation with saline water (Ayers and Westcot, 1999); once the concentration of salts decrease with increase in humidity environment (Choi et al., 2005).

For the above, this study aimed to evaluate the effects of irrigation with increasing salinity of water, cattle and potassium biofertilizers, from conventional source and slow release, on growth of yellow passion fruit after transplanting of seedlings and in the soil salinity.

## MATERIALS AND METHODS

The experiment was carried out during the period of July/2013 to May/2014, in Macaquinhos Farm Remigio country, Paraiba State Brazil, located by the geographical coordinates of 7° 00 '1.95' 'S, 35° 47' 55'' W and altitude of 562 m, set in Mesoregion Agreste Paraibano and Microregion Western Curimatau (INTERPA, 2008). The climate of the municipality, according to Köppen classification (Brazil, 1972), is the As' type that means hot, humid and rainy season from March to July with rainfall of 640 mm during the experimental period. The soil of the area, according to the criteria of the Brazilian System of Soil Classification- SiBCS (EMBRAPA, 2013), has been classified as Entisol Dystrophic, non-saline. Before installing the experiment, soil samples from depths of 0-20 and 21-40 cm were collected for physical and chemical characterization and fertility (Table 1), using the methodologies contained in Donagema et al. (2011). At the same depths, soil was characterized as the salinity of the saturation extract together with the irrigation water and bovine biofertilizer diluted with water in ratio 1:1 (50%), which, by being applied in liquid form, has been evaluated as water for irrigation (Table 2) using the methods of Richards (1954).

The treatments were arranged in a randomized block design with three replications and 12 plants per plot, using the factorial 2 x 2 x 2, referring to the electrical conductivity values of irrigation water of 0.35 and 4.00 dS $m^{-1}$, the soil without and with bovine biofertilizer at levels of 0 and 50% of the recommended dose of 15 L $m^2$ (Santos, 1992) and fertilization with two sources of potassium (60% $K_2O$), conventional potassium chloride and coated with an organic polymer to slow release potassium during the plant growth.

The holes were opened in dimensions of 40 x 40 x 40 cm and prepared with soil material in the first 20 cm; due to the low content of magnesium and sulfur (Table 1) along with a mixture of 100 g containing 75% calcitic limestone containing 48% CaO, 4.5% MgO

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**Table 1.** Chemical and physical characterization of soil in the layers, 0-20 and 21-40 cm and cattle manure.

| Chemical attributes | 0 - 20 cm | 21 - 40 cm | Cattle manure | Physical attributes | 0 - 20 cm | 21 - 40 cm |
|---|---|---|---|---|---|---|
| pH | 6.00 | 6.21 | 8.64 | SD (g $cm^{-3}$) | 1.61 | 1.59 |
| P (mg $dm^{-3}$) | 23.51 | 12.06 | 36.11 | PD (g $cm^{-3}$) | 2.66 | 2.65 |
| K (mg $dm^{-3}$) | 81.34 | 76.04 | 7892.3 | TP (%) | 0.39 | 0.40 |
| $Na^+$ ($cmol_c$ $dm^{-3}$) | 0.07 | 0.07 | 3.86 | Sand (g $kg^{-1}$) | 847 | 821 |
| $H^+$+$Al^{3+}$ ($cmol_c$ $dm^{-3}$) | 1.32 | 1.48 | 1.24 | Silt (g $kg^{-1}$) | 102 | 124 |
| $Al^{3+}$ ($cmol_c$ $dm^{-3}$) | 0.0 | 0.0 | 0.0 | Say (g $kg^{-1}$) | 51 | 55 |
| $Ca^{2+}$ ($cmol_c$ $dm^{-3}$) | 2.45 | 2.20 | 5.40 | Cdw (g $kg^{-1}$) | 13 | 13 |
| $Mg^{2+}$ ($cmol_c$ $dm^{-3}$) | 0.35 | 0.60 | 4.5 | FDS (%) | 74.5 | 76.4 |
| SB ($cmol_c$ $dm^{-3}$) | 3.08 | 3.05 | - | SDI (%) | 25.5 | 23.6 |
| CEC ($cmol_c$ $dm^{-3}$) | 4.40 | 4.54 | - | Smfc (g $kg^{-1}$) | 98.1 | 99.1 |
| V (%) | 70.00 | 67.18 | - | Smpwp (g $kg^{-1}$) | 43 | 45 |
| OM (g $kg^{-1}$) | 6.41 | 4.14 | 591.68 | Aw (g $kg^{-1}$) | 55.1 | 54.1 |
| | | | | Textural Classification | Sand Franca | |

SB = Sum of bases ($Ca^{2+}$ + $Mg^{2+}$ + $K^+$ + $Na^+$); CEC = Cation Exchange Capacity = [SB + ($H^+$+$Al^{3+}$); V = saturation by exchangeable bases (SB / CTC) 100; OM = organic matter; SD = soil density; PD = particle density; TP = total porosity; FDS = flocculation degree of soil; SDI = soil dispersion index = 100 - FDS; Cdw = clay dispersed in water; Aw = available water; Smfc = soil moisture at field capacity; Smpwp = Soil moisture at permanent wilting point.

**Table 2.** Characterization of soil, irrigation waters and bovine biofertilizer in the proportion of 50% in water, as to salinity.

| Variables | 0 – 20 cm | 21 – 40 cm | $A_1$ | $A_2$ | Bio |
|---|---|---|---|---|---|
| CE (dS $m^{-1}$) | 0.43 | 0.29 | 0.35 | 4.00 | 3.10 |
| pH | 6.93 | 6.67 | 6.12 | 6.25 | 6.37 |
| $Ca^{2+}$ ($mmol_c$ $L^{-1}$) | 0.87 | 0.72 | 1.19 | 2.51 | 6.97 |
| $Mg^{2+}$ ($mmol_c$ $L^{-1}$) | 0.78 | 0.55 | 0.59 | 7.92 | 8.85 |
| $Na^+$ ($mmol_c$ $L^{-1}$) | 2.11 | 1.32 | 1.48 | 29.31 | 4.18 |
| $K^+$ ($mmol_c$ $L^{-1}$) | 0.56 | 0.34 | 0.19 | 0.38 | 10.47 |
| $Cl^-$ ($mmol_c$ $L^{-1}$) | 2.66 | 1.93 | 2.51 | 35.56 | 21.97 |
| $CO_3^{2-}$ ($mmol_c$ $L^{-1}$) | 0.00 | 0.00 | Abs | 0.11 | Abs |
| $HCO^-_3$ ($mmol_c$ $L^{-1}$) | 0.89 | 0.61 | 0.54 | 2.85 | 4.65 |
| $SO^{2-}_4$ ($mmol_c$ $L^{-1}$) | 0.67 | 0.31 | 0.36 | 0.24 | 3.53 |
| SAR (mmol $L^{-1}$) | 2.32 | 1.66 | 1.57 | 12.83 | 1.49 |
| ESP (%) | 1.59 | 1.54 | --- | --- | --- |
| Classification | NS | NS | $C_1S_1$ | $C_4S_1$ | $C_4S_1$ |

SAR = sodium adsorption ratio = $Na^+$/ $[(Ca^{2+}+Mg^{2+})/2]^{1/2}$; ESP = exchangeable sodium percentage = 100 ($Na^+$/CTC); NS = Non saline; $A_1$ = surface dam water; $A_2$ = water rich in sodium chloride; $C_1$ and $C_4$ = respectively low and high risk of soil salinity; S1 = below sodification soil risk with irrigation, Bio = bovine biofertilizer; Abs = absence.

and 78% of PRNT mixed with 25% of agricultural gypsum ($CaSO_4.2H_2O$) with 24% CaO, 16% S, 0.81% $P_2O_5$ and 14% humidity, 10 L of cattle manure with C/N ratio of 1:18 discounted moisture of 6%. Seedlings were formed via seeds of yellow passion fruit genotypes BRS Yellow Giant in substrate containing two parts of the first 20 cm of the same material soil of the experimental area, a part of cattle manure incorporated into the holes and 1% by mass fosmag (18% $P_2O_5$, 14.0% Ca, 3.5% Mg, 10.0% S, 0.15% B, 0.18% Cu and 0.65% Zn).

Before the transplant, the second half of July, 2013, when the seedlings were an average height of 25 cm and four pairs of leaves, they were incorporated per hole 3 g of urea (45% N), 5 g of simple superphosphate (18% $P_2O_5$, 18,0% Ca and 10,0% S) and 3 g of each source of potassium chloride with 60% of $K_2O$. The plant support system was espalier with a flat wire no. 12, installed on top of the piles to 2.2 m above the ground level. The water of lower salinity irrigation (0.35 dS $m^{-1}$) was obtained from the surface dam and 4.00 dS $m^{-1}$ was obtained by diluting the non-iodized sodium

**Table 3.** Quantitative urea, simple superphosphate and potassium chloride.

| Fertilization date | Level of soil fertilization (g plant$^{-1}$) | | |
|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ |
| 16/07/2013 | 3 | 5 | 3 |
| 16/08/2013 | 3 | - | 3 |
| 16/09/2013 | 5 | 10 | 5 |
| 15/10/2013 | 10 | - | 10 |
| 30/10/2013 | 10 | - | 10 |
| 15/11/2013 | 10 | 20 | 10 |
| 19/12/2013 | 20 | - | 20 |
| 20/01/2014 | 10 | 10 | 10 |
| 18/02/2014 | 30 | - | 30 |
| 17/03/2014 | 30 | 40 | 30 |
| 15/04/2014 | 30 | - | 30 |
| Total nutrient | 161 g N plant$^{-1}$ | 85 g $P_2O_5$ plant$^{-1}$ | 161 g $K_2O$ plant$^{-1}$ |
| Total fertilizer/plant | 358 g urea | 188 g s. simple | 268 g potassium chloride |
| Totalfertilizer/ha | 596 kg urea | 313 kg ha$^{-1}$ s. simple | 446 kg ha$^{-1}$ potassium chloride |

chloride, with purity of 92%, with dam water (Rhoades et al., 2000). The biofertilizer was produced by anaerobic fermentation of fresh manure of cattle and water for 30 days (Santos, 1992) provided a blade 6 L m$^2$ after dilution in dam water, at a ratio of 1:1, one day before and every 90 days after transplanting the seedlings- DAT in the area of 0.8 m$^2$ of a circumference of 50 cm radius having the plant with the hole center. In each application of biofertilizer, the plants without the input were irrigated with the same amount of each type of water used for irrigation.

The irrigation of the plants was every 48 h, based on the maximum daily blade crop evapotranspiration of 14 L plant$^{-1}$ day$^{-1}$ obtained by the product of pan evaporation class 'A' (ETa x 0.75) installed at the experimental site (ETo = ETc x 0.75) and for each crop coefficient –Kc of 0.4; 0.8 and 1.2 (ETc = ETo x Kc), respectively referring the first 60 days after transplanting-DAT, from 60 to 90 DAT and from of the flowering stage until harvest. In the treatments with water 4.00 dS m$^{-1}$, despite the sandy texture of the soil, an irrigation blade was applied (10% higher) to reduce the risk of salinity in plants by leaching salts of the root environment (Ayers and Westcot, 1999).

The fertilizer was applied to plants in covering with nitrogen (urea - 45%) and each source of potassium (60% $K_2O$) was made monthly from the transplanting of seedlings and phosphorus (simple superphosphate 18% $P_2O_5$, 18.0% Ca and 10.0% S) every two months up to April 2014, as indicated in Table 3. The culture of yellow passion fruit was planted on the spatial arrangement of 3 x 2 m, relative to a 1667 plants density per hectare; the transplant was done in the second half of July, 2013, the support plants was made in simple espalier with a flat wire no. 12 installed to 2.2 m height at the top of the stakes.

The conduction of field seedlings was performed in a single stem to the support wire at the top of the stakes, pruning the apical bud being performed when the plant had 10 to 15 cm above the espalier, for emitting two lateral branches which have been oriented in opposite directions proceeding with pruning of the secondary branches to reach 1.5 m of length.

At 30 days after transplanting the height of the plants was measured with a millimeter tape measure. Growth of stem diameter of yellow passion fruit plants fitted to the logistic model, depending on the age of plants.

The model is represented in Equation 1:

$$Y = \frac{A}{1 + B\exp^{-kt}}$$

Where: Y- Expresses the stem diameter of the plants of passion fruit (mm); A- asymptotic parameter that corresponds to the stem diameter of the plant age; B- corresponds to the location parameter without biological interpretation; K- determines the expansion rate of growth; Exp- refers to the base of neperian logarithm; t- refers to the time of transplanting to reading (day).

Transplanting period of seedlings until plants reach the support wire was recorded for growth assessment up to 2.2 m height for the pruning of the main stem. Transplanting period to the pruning of the side branches and 100 DAT productive branches of the plants were counted and also recorded. When the plants were in full flowering, 115 DAT, simple soil samples were collected in each quadrant of the plants, in the depths of 0-20 and 21-40 cm and made into composite samples for repetition to evaluate the salinity in the root environment of plants (Richards, 1954). The results were submitted to analysis of variance by F test, mean interactions were compared by Tukey at 5% probability and the equation fit for growth assessment by the diameter of the plants was done using the Statistical Analysis System software (SAS / STAT 9.3 (2011).

## RESULTS AND DISCUSSION

As shown in Table 4, in 0-20 cm, the interaction water × potassium significantly influenced the electrical conductivity of the saturation extract, while from 21-40 cm, the interaction water × biofertilizer led to statistical difference. Regarding the growth of plants, it was observed that the interaction water × potassium exerted a significant difference on the period of transplanting to pruning of the main stem (PTPMS) and the number of productive branches at 100 days after transplanting (NBT), while the biofertilizer interfered significantly with the plant height at 30 days after transplanting (PH 30 days), absolute growth rate (AGR), and the period for

**Table 4.** Analyzes of variance, by mean square, regarding the electrical conductivity of the soil saturation extract (ECes) at the time of full bloom of plants at 0-20 and 21-40 cm, plant height at 30 days (PH 30 Days), absolute growth rate (AGR), period of transplanting to pruning of the main stem (PTPMS), pruning period of lateral branches (PPSB) and number of productive branches to 100 days after transplanting (NBT) of yellow passion fruit.

| Source of variation | ECse | | PH 30 DAYS | AGR | PTPMS | PPSB | NBT |
|---|---|---|---|---|---|---|---|
| | 0-20 cm | 21-40 cm | | | | | |
| Block | 0.14$^{ns}$ | 0.006$^{ns}$ | 89.0182$^{ns}$ | 1.3648$^{ns}$ | 102.1432$^{ns}$ | 1.6278$^{ns}$ | 1.7717$^{ns}$ |
| Water (W) | 31.77* | 26.88** | 20.6276$^{ns}$ | 0.0183$^{ns}$ | 2.1901$^{ns}$ | 3.8762$^{ns}$ | 19.41$^{ns}$ |
| Residue (a) | 0.06 | 0.02 | 402.0182$^{ns}$ | 0.1214$^{ns}$ | 30.7526$^{ns}$ | 34.0607$^{ns}$ | 11.6808$^{ns}$ |
| Potassium (K) | 1.00** | 0.03$^{ns}$ | 9.0651$^{ns}$ | 0.193$^{ns}$ | 20.6276$^{ns}$ | 3.9919$^{ns}$ | 0.4401$^{ns}$ |
| Biofertilizer (B) | 3.67** | 0.85** | 602.5026* | 0.0945$^{ns}$ | 57.8151$^{ns}$ | 72.8431* | 20.0141* |
| W x K | 0.56** | 0.01$^{ns}$ | 141.3776$^{ns}$ | 0.5607$^{ns}$ | 72.6276* | 19.3501$^{ns}$ | 26.2155** |
| W x B | 0.01$^{ns}$ | 0.74** | 39.3984$^{ns}$ | 0.5225$^{ns}$ | 42.0026$^{ns}$ | 1.8797$^{ns}$ | 9.0651$^{ns}$ |
| K x B | 0.38$^{ns}$ | 0.1$^{ns}$ | 0.0651$^{ns}$ | 0.0729$^{ns}$ | 0.7526$^{ns}$ | 1.9605$^{ns}$ | 4.5211$^{ns}$ |
| W x K x B | 0.1$^{ns}$ | 0.01$^{ns}$ | 194.0859$^{ns}$ | 0.0428$^{ns}$ | 16.2526$^{ns}$ | 0.4504$^{ns}$ | 0.0026$^{ns}$ |
| Residue (b) | 0.05 | 0.03 | 109.1501$^{ns}$ | 0.258$^{ns}$ | 12.9688$^{ns}$ | 10.116$^{ns}$ | 2.6811$^{ns}$ |
| CV a (%) | 5.79 | 3.98 | 395.53 | 3.12 | 50.36 | 36.42 | 80.72 |
| CV b (%) | 5.28 | 4.87 | 107.38 | 6.64 | 21.24 | 10.81 | 18.52 |
| Average | 4.23 | 3.55 | 101.64 | 3.88 | 61.07 | 93.5 | 14.47 |

$^{ns}$: Not significant, * significant at 5%, ** significant at 1%.

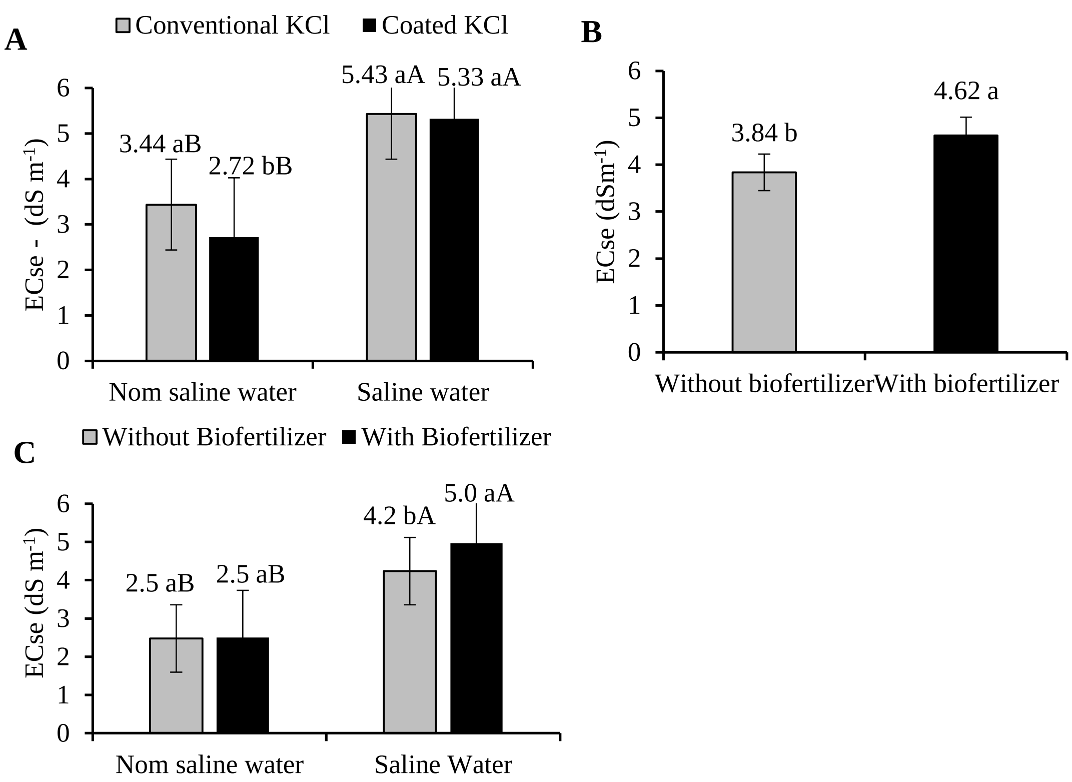


**Figure 1.** Electrical conductivity of saturation extract of the soil in layer 0 - 20 cm (A and B) and 21 - 40 cm (C) in the beginning of flowering of passion fruit, at 115 DAT, depending on the water salinity in soil with and without biofertilizer with conventional and coated KCl. Columns with the same letters, lowercase, the interactions water x potassium within biofertilizer upper case in the interactions water x biofertilizers in potassium and same Greek letters between the potassium x biofertilizers within the different waters, do not differ statistically by F test ( P> 0.05).

pruning the side branches (PPSB).

In Figure 1, is observed that the interaction between the salinity of the water, bovine biofertilizers and potassium types interfered significantly in the electrical conductivity of the soil saturation extract (ECse) in the first 20 cm and the interaction between salinity and bovine biofertilizers in the same variable in the layer 21 - 40 cm. At layer 0 - 20 cm, increasing water salinity, regardless of the addition of bovine biofertilizer and potassium type, raised the salt content of the soil, in general, superior in treatments with biofertilizer and conventional potassium chloride, regarding the soil without bovine biofertilizer and with potassium chloride coated with organic polymer (Figure 1A and B). With regards to the effects of the salt water, the results are in agreement with Gonçalves et al. (2011) and Mesquita et al. (2012) when registering the salinity increases with increasing salt content of waters. Larger values of ECse in the soil with conventional potassium chloride and biofertilizer can be due to the high salt content of 116% KCl (Murray and Clapp, 2004) and the high electrical conductivity of biofertilizer (3.1 dS $m^{-1}$) (Table 2), as also observed by Diniz et al. (2013) in seedlings of neem (*Azadirachta indica*) and Souto et al. (2015) in cultivated soil with noni (*Morinda citrifolia* L.), both irrigated with saline water in the soil with bovine biofertilizer. At the highest range (21-40 cm) values of electrical conductivity of the saturation extract, although lower than those of the superficial layer exhibit the same behavior of increased soil salinity, with and without organic inputs applied in liquid form.

By relating the data of Figure 1A with the initial soil ECse (0.43 dS $m^{-1}$) (Table 2) it can be seen that irrigation, even with non-saline water (0.35 dS $m^{-1}$) increased salinity at 115 DAT in the range of 0-20 cm in 667 and 737% in soil with and without biofertilizer fertilized with conventional potassium chloride. In the same situation in the soil with a slow release of potassium chloride, the increments were lower with increases of 412 and 667% as compared to the soil with conventional fertilizer. In the same treatments, irrigation with saline water (4.00 dS $m^{-1}$) significantly raised the salt content in 1086 and 1248% in soil with and without biofertilizer treated with traditional potassium chloride and in 1039 and 1248% in soil with chloride potassium polymer coated. From the results, it is observed that, despite the high percentage increase of electrical conductivity in the soil irrigated with water without salt restriction (0.35 dS $m^{-1}$), soil in the period studied did not reach the salt level (Richards, 1954) characterized by ECse soil equal to or higher than 4 dS $m^{-1}$. Moreover, the sandy texture of soil, sand average content in the range 0 - 40 cm higher than 84% (Table 1) and 10% leaching blade added to the blade irrigation with saline water for leaching of salts (Ayers and Westcot., 1999; Rhoades et al, 2000) were not enough to maintain the soil in the non-saline level with ECse below 4 dS $m^{-1}$.

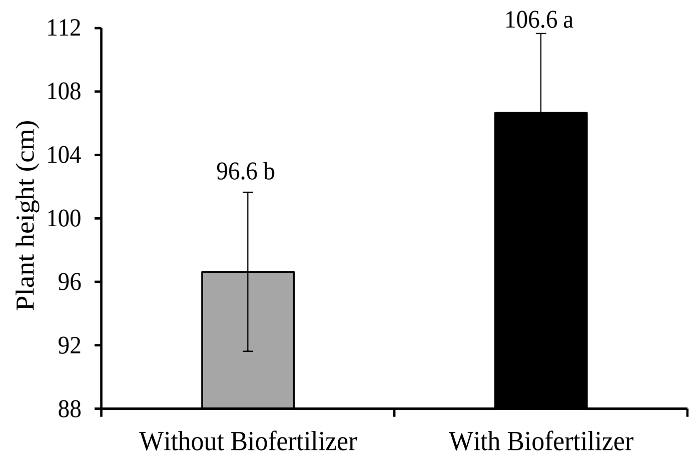


**Figure 2.** Passion flower plant height BRS Yellow Giant, at 30 DAT, in the soil without and with bovine biofertilizer. Means with the same letters do not differ by F test.

The electrical conductivity of saturation extract, unlike the surface layer, was not influenced by the kinds of potassium chloride and did not differ among treatments with and without the biofertilizer layer, 21 - 40 cm (Figure 1C). However, considering the low initial value of 0.29 dS $m^{-1}$ (Table 1) with no difference between the soil in the absence and presence of biofertilizer, the increase was in both cases of 762%, but without raising the value CEes to the saline soil category, that is, electric conductivity >4.00 dS $m^{-1}$ (Richards, 1954). In a similar form to that observed at the layer of 0-20 cm, irrigation with saline water in these treatments also increased the CEes soil in 1348 and 1624%, thus higher than that in 1086 and 1245%, 1039 and 1248% soil with KCl conventional and slow release, with and without biofertilizer to the saline level. When considering that the ECse soil before application of the treatments, at the layer 0 - 20 cm, was 48.3% higher than the layer 21- 40 cm, it is observed that the entrainment of salts to the deepest layer resulted in higher salt accumulation, was promoted respectively by appropriate physical conditions of the soil to the dynamics of water (Table 1), high electrical conductivity of biofertilizer (Table 2) in 10% leaching fraction added to the irrigation water blade of the saline water and the action of biofertilizer in the physical improvement of the soil (Benbouali et al., 2013).

The initial growth of the plant height at 30 DAT was influenced only by the addition of biofertilizer supplied to the soil (Figure 2). At this age, the plants reached 96.6 and 106.6 cm respectively in soil with and without organic inputs. When considering that the seedlings were transplanted with an average height of 25 cm, 71.6 and 81.6 cm values with superiority of 14% was afforded by the bovine biofertilizer. These results, although lower

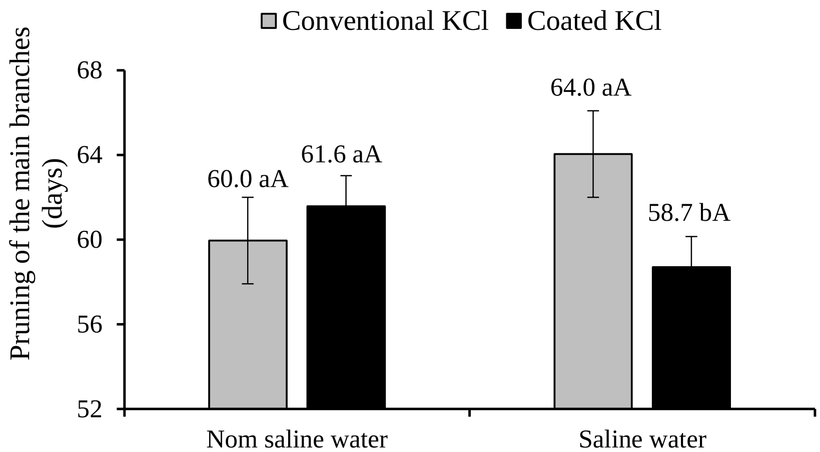


**Figure 3.** Period of transplanting seedlings to pruning the main stem of the passion fruit BRS Yellow Giant, according the water salinity and types of potassium. Columns with the same lowercase letters do not differ for potassium type in the same type of water and the same upper case letter do not differ in the type of water and same type of potassium by F, p <0.05.

than 92 cm recorded by Dias et al. (2013) in yellow passion fruit plants irrigated with water of lower salt concentration (2.5 dS $m^{-1}$) indicates that the high salt level of the irrigation water (4.00 dS $m^{-1}$) did not affect the initial growth of plants during the initial phase.

The plants of yellow passion fruit in the field grow tutors made by a string or thin stake, support wire installed on the stakes or fence posts at a certain height. Thus, the growth in height between the transplanting period of seedlings and pruning of the main stem can be assessed. In Figure 3, it is observed that the plants irrigated with non-saline water was brought from 60 to 61.6 days after transplanting to reach the wire, but showed no significant difference with the conventional potassium effect and slow release to growth at 230 cm (220 cm to the wire + 10 cm above) and at that weight, the main stem pruned to the lateral branches. The values are similar to the variation from 59 to 63 days recorded by Cavalcante et al. (2007) in yellow passion fruit in Nova Floresta, Paraíba, as Guinezinho under irrigation with non-saline water (0.5 dS m-1) in the soil without biofertilizer.

In the soil irrigated with saline water (4.0 dS m-1) the plants reached higher growth when fertilized with potassium chloride coated by vegetable polymers and achieved the support wire 5.3 days before those of the soil with conventional potassium chloride. When considering the same growth of the main stem of 230 cm, in both situations, and to relate the period of 58.7 to 64.0 it appears that the slow-release potassium chloride 8.3% attenuated degenerative action of irrigation water salinity on the growth in height of passion fruit BRS yellow Giant. The later pruning of plants treated with conventional KCl may be due to rapid release of chloride ion, which, despite being micronutrient in high level, exerts a toxic action of plants and increases the saline water phytoxicity. The behavior of the data in the treatments with KCl coated with vegetable polymers is similar to yellow passion fruit plants irrigated with saline water of 0.5 to 4.5 dS $m^{-1}$, the soil with bovine biofertilizer supplied a week before and every 90 DAT (Day et al., 2013), in mitigating the depressive effects of salts on plants.

The organic polymers used in the KCl coating, as well as biofertilizer contain humic substances that exert attenuation on water salinity and soil to plants as reported by Mahmoud and Mohamed (2010) on wheat seedlings (*Triticum aestivum*) under irrigation with saline water and biofertilizers. The respective mineral fertilizer with organic coated stimulated more plant growth in saline soil (CEes> 4.0 dS $m^{-1}$) caused by irrigation with saline water, as observed in Figure 1. This situation was similar to that of Guareschi et al. (2011) in non-saline soil, they found that application of KCl coated polymers 15 days before seeding, provided higher dry matter yield, number of pods and productivity soya beans, relative to plants soil with conventional KCl.

The period of transplanting of seedlings to pruning the lateral branches from where the productive branches arise was significantly reduced from 95.2 to 91.8 DAT, between the soil plants without and with biofertilizers and shows a growth 3.57% faster to plants promoted by organic input (Figure 4). Despite modest average reduction of 3.4 days in plants irrigated with saline and good quality water, the results are promising as compared to 100 and 91 DAT recorded for the growth of lateral branches of passion fruit irrigated with non-saline water in the soil without and with bovine biofertilizer (Cavalcante et al., 2007).

The issuance of productive branches at the 100 DAT

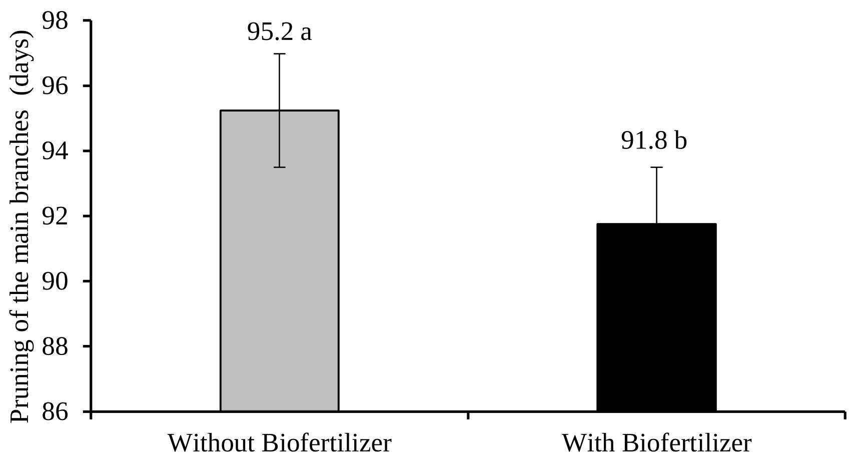


**Figure 4.** Period of transplanting to pruning the lateral branches in plants of passion fruit BRS Giant yellow, in soil without and with bovine biofertilizer.

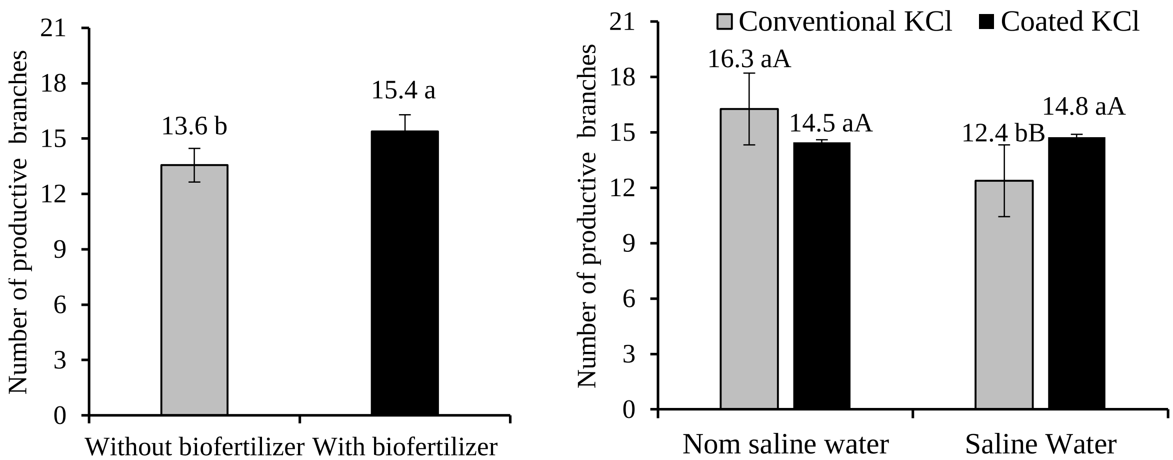


**Figure 5.** Number of productive branches at 100 DAT in passion fruit BRS Yellow Giant (A), in soil without and with bovine biofertilizer, (B), according on irrigation water salinity and types of potassium chloride. Columns with the same lowercase letters (B) do not differ in the type of potassium in the same type of water and with the uppercase letters do not differ as to type of water in the same type of potassium, by F test, p <0.05.

responded to biofertilizer effects, and the interaction between irrigation water and the types of potassium chloride (Figure 5). The addition of biofertilizer (Figure 5A) gave 13.2% more productive tertiary branches that plants in the soil without said organic input and the value of 15.4 branches at 100 DAT, is in the range of 8-23 branches plant $^{-1}$ registered by Dias et al. (2013), from 113 to 153 DAT in yellow passion fruit irrigated with saline water in the soil with biofertilizer, but lower than variation from 27 to 30 branches plant$^{-1}$ of the same culture in the soil with and without bovine biofertilizer irrigated with non-saline water (Choi et al., 2007).

The different types of potassium did not interfere with productive branches of plants irrigated with non-saline water (0.35 dS m$^{-1}$), but the type coated with polymers provided greater issue of productive branches by passion fruit BRS yellow Giant irrigated with saline water of electrical conductivity, 4.00 dS m$^{-1}$ (Figure 5B). The data express coherence with the growth in height of the main stem evaluated by transplanting the pruning period (Figure 3) in which the pruning was more delayed or more precocious and the number of productive branches is respectively lower or higher. The different types of potassium did not differ with regards to the issue of productive branches in plants irrigated with lower salinity water, but potassium chloride coated with vegetable polymers increased by 19.4%, the issue of productive branches of plants irrigated with higher saline water content. The slow release provides potassium for a longer time in the soil and absorption by plants resulting

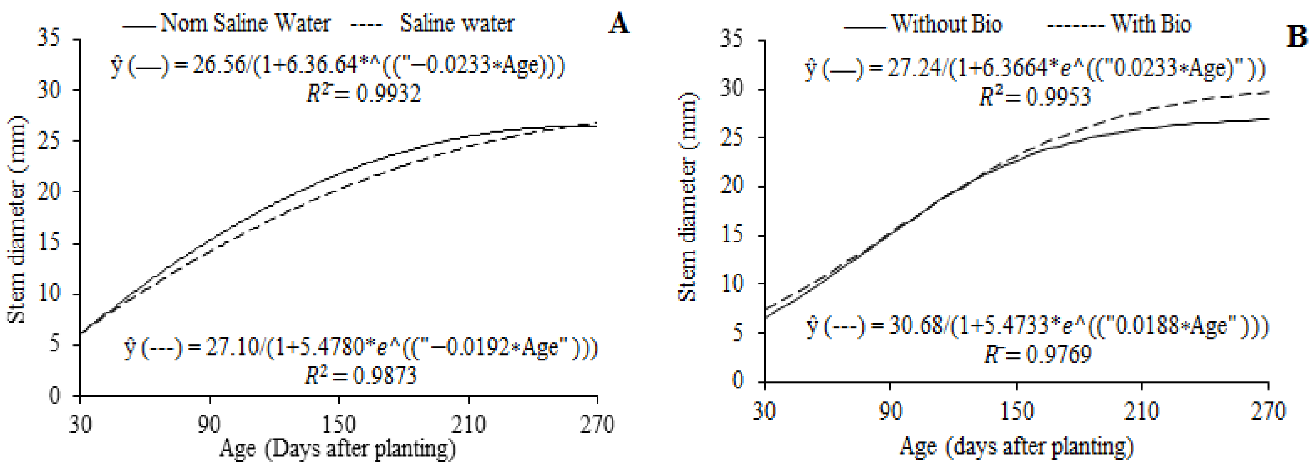


**Figure 6.** Average values of stem diameter of the plants, according to age after seedlings transplanting and irrigated with non-saline water (──) and saline (-----) (A), in soil without (──) and with (----) bovine biofertilizer (B).

in cell osmotic regulation, keeping turgor (Taiz and Zeiger, 2013), also, contributing to the nutritional balance (Guareshi et al., 2011) and, indeed, to the phyto growth and the issue of productive branches, including in saline environment.

In cultivation period of 30 at 270 DAT plant growth by diameter, there was significant response to the effects of interaction between saline water and plants age and bovine biofertilizer and plants age (Figure 6). The stem diameter of plants irrigated with non-saline water, obtained an increase of 1.6 mm in the range of 115 at 145 DAT (Figure 6A), exceeding the same period by 8%, the diameter of the plants irrigated with saline water. From that age, despite the increase in respective values, the data between the plants treated with the different waters were basically the same and the increments between the ages for each type of water, was nil or almost nil. The similarity between the results, especially from 210 at 270 DAT, may be due to sandy texture of the soil (Table 1) and blades of 10% more applied to the plants irrigated with water of greater salt concentration for the leaching of the salts root environment (Ayers and Westcot, 1999), stimulating the growth of plants.

The plants of with biofertilizers reached 270 DAT, the largest stem diameter of 29.7 mm, thus 10.4% higher than the 26.9 mm of plants grown in soil without organic inputs. The supremacy of the data from the 190 DAT is compatible with Dias et al. (2011), Nascimento et al. (2012), Bezerra et al. (2015) to conclude that the bovine biofertilizer reduces the intensity of the harmful effects of water salinity to yellow passion fruit during the growth of seedlings in the greenhouse and the plants in the field.

The passion fruit BRS yellow giant diameters at DAT 270 (Figure 6) exceeded the values of 12.31 mm from 30 to 210 DAT under irrigated crop with non-saline water obtained by Cavalcante al. (2007), and the average value of 17.8 mm at DAT 150 in irrigated crop with increasing salinity water from 0.5 to 4.5 dS $m^{-1}$ (Dias et al., 2013).

## Conclusion

Increased salinity of the water increases the soil condition of non-saline to saline. The biofertilizers, despite raising the salinity of the soil, stimulates the growth of passion fruit BRS Yellow Giant in soil irrigated with saline water. The high water salinity of 4.00 dS $m^{-1}$ did not affect the growth of plants in sandy soil. The slow-release potassium chloride stimulates the growth of plants irrigated with high salinity water in sandy soil.

## Conflict of Interests

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

# Nematicidal effect of *Crambe abyssinica* leaf extracts to *Meloidogyne javanica* on tomato

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**Root-knot nematodes (*Meloidogyne javanica*) interferes with the production of tomato. The indiscriminate use of chemical nematicides brings negative consequences to society. The aim of this study was to investigate the effect of crambe extract on the control of *M. javanica*, with different modes and application times, in tomato. Studies were conducted during the 2014 cropping season at the climatized greenhouse located at the Biological Cotrol Complex and Protected Cultivation. Prof. Dr. Mário César Lopes, belongs to State University of West Paraná- UNIOESTE, campus Marechal Cândido Rondon, Paraná, Brazil. The experiment was laid out in a factorial design. The roots of tomato seedlings were immersed in the extract, with different modes of application (roots + soil, roots + leaf, roots + soil + leaf), in four different times of application (before inoculation; during the inoculation; after inoculation; and weekly until 45 days after inoculation). Seven days after the transplant of tomato plants was performed, evaluations were made for the inoculation of 2.500 eggs of *M. javanica* (and 513 J2) per pot, and 45 days after inoculation. For egg mass, times after inoculation and weekly were efficient, with greater reduction by way of root + leaf and root + soil, respectively. The reduction of total root-knots was efficient for the weekly time by way of root + soil and root + soil + leaf, and lesser than 41 and 47.75% compared to the control. In the repetition of the experiment, for modes by root + soil + leaf in weekly applications, eggs mass and total root-knots were lesser than 60.95 and 27.95% compared to the control. Although, other methods and application times also present positive results in reducing J2 and eggs per gram of root and per 100 cm$^3$ of soil, the weekly time by way of root + soil + leaf confirmed their results in a repetition of the experiment with reduced population *M. javanica*.**

**Key words:** *Solanum lycopersicum* L., root-knots, egg mass, induced resistance, nematode.

## INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the most popular vegetable in Brazil (Belan et al., 2011) and its area under cultivation has increased within decade, from 60 thousands há in 2005 to 6 5 thousands in 2014 (IBGE, 2015). Nematodes pose a threat to tomato production. Root-knot nematodes (*Meloidogyne* species) causes annual estimated losses of $118 billion to crops in the world (Atkinson et al., 2012).

Root-knot nematodes are found in tropical and temperate regions and are among the most damaging pathogens worldwide (Trudgill and Blok, 2001). This genus makes drastic changes in root development, to induce and keep on the giant cells, which are power supply to the nematodes (Caillaud et al., 2008). Giant cells are the result of cellular hypertrophy and hyperplasia and symptoms are associated with root-knots and reduction in volume of the root system, and consequently, the plant soak up less water and nutrients, resulting in lesser crop yields (Ferraz and Monteiro, 2011). When the second stage juvenile (J2) infects a root and establishes its feeding site, a reprogramming of the cells correlated with gene activity in the metabolism, protein synthesis, cell division and transport, and signal transduction takes place (Gheysen and Fenoll, 2002).

The plant does not allow a passive penetration of the pathogen, but it activates defense system, including protein-RP, phytoalexins, phenolic compounds and other (Molinari, 1996; Stangarlin et al., 2011). For activation of plant defense mechanisms in nematode control, abiotic and biotic inducers can be used (Salgado and Silva, 2005).

Chemical nematicides are used to control nematodes, but its continued use can reduce its efficiency, making nematodes resistant, in addition to negative impacts on the environment and society (Javed et al., 2008; Zhang et al., 2012). Therefore, there is an increasing demand for development of new natural nematicides, aiming a partial or total replacement of chemical nematicides (Aissani et al., 2013). The tomato crop is too dependent on the use of pesticides, thus it is necessary to study alternative actions, and understand the applicability and plant extracts mode of action, so these can be used efficiently in the management of diseases (Schwan-Estrada, 2009). Studies on the use of secondary plant metabolites against root-knot nematodes have been reported by several workers (Dias-Arieira et al., 2003; Lopes et al., 2005; Oka et al., 2006).

Plant extracts have been used in countless modes and application times for the control of nematodes, with protective or healing effect, induction of resistance or direct effect (Chinnasri et al., 2003; Molinari and Loffredo, 2006; Javed et al., 2008). However, several studies have shown nematode control efficiency correlated with glucosinolates in plants, particularly, plants belonging to the family Brassica (Walker, 1996; Wu et al., 2011; Aissani et al., 2013). The crambe (*Crambe abyssinica* Hochst) belongs to the Brassicaceae family and it contains glucosinolates (Lazzeri et al., 1994). However, there are few studies involving crambe in control of nematodes, as well as studies involving activation of resistance mechanisms in *Brassica*. Therefore, considering the demand of consumers for safe food associated with beneficial effects caused by the compounds present in *Brassicas* and few crambe studies, the study aimed to evaluate the crambe extract effect on control of *Meloidogyne javanica*, with diferent modes and application times in tomato.

## MATERIALS AND METHODS

The experiment was conducted at the climatized greenhouse located at the Biological Cotrol Complex and Protected Cultivation of Prof. Dr. Mário César Lopes, belonging to State University of West Paraná- UNIOESTE, campus Marechal Cândido Rondon, Paraná, Brazil. The experiment was conducted between the periods of April and June, 2014 and it was repeated in October to December, 2014. The experiment was conducted in a greenhouse and the pots were arranged in a completely randomized design (CRD) on benches at a mean temperature of 22°C, with five replications.

The hydroalcoholic extract of 250 mg $L^{-1}$ (70% ethanol and 30% water) was used and stored at the ambient temperature, protected of light for 15 days (Loguercio et al., 2005), evapored and resuspended in water. The crambe leaves were collected at vegetative stage (35 days after emergence, DAE), were dried at 45°C for 48 h and gound. Tomato seedlings, Santa Cruz Kada, were used for 25 days after sowing (DAS), and transplanted in pots with 3 L capacity, filled with sterilized soil by autoclaving at 120°C/1 atm for 1 h, in the mixture 3:2:1 (soil: sand: organic matter). Later, a soil sample was sent for chemical analysis, for later correction.

The inoculum was obtained from infected tomato plants cultivated in greenhouse and identified based on perineal region setup (Hartman and Sasser, 1985). The variables were analyzed 45 days after inoculation, concomitantly with the end of the experiment.

Data were collected based on the number of eggs and J2 per 100 $cm^3$ of soil and grams root, number of root-knots and egg mass in the roots. After separation of the roots from the soil, they were washed and dried at room temperature to fresh root mass weighing, with subsequent storage of roots and soil in plastic bags, with temperature at 4°C.

The centrifugal flotation method in sucrose solution was used for the extraction of eggs and soil nematodes (Jenkins, 1964). Extraction of *M. javanica* eggs and J2 from infested tomato roots was based on the method described by Freitas et al. (2007). The eggs and J2 retained on the 400 mesh sieve were transferred to Peters blade and quantified by optical microscope.

To check for egg mass in the roots, these egg mass were stained with Phloxine B to 15 mg $L^{-1}$ for 20 min, then washed to remove excess dye (Taylor and Sasser, 1978), dried with paper towel and counted root-knots with egg mass and no mass eggs, with table magnifying aid. The total root-knots was obtained by the sum of root-knots egg mass and no mass eggs.

The experiment was laid out in a factorial design (3×4 + 1). The extract was first applied by way of the root system and later in three different modes in the plant: soil, leaf and soil + leaf in four

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**Table 1.** Mass eggs on the tomato plants roots inoculated with *Meloidogyne javanica*, in wich the roots of tomato plants were treated with *Crambe abyssinica* extract in different modes and application times.

| Modes of extract application | Application times | | | |
|---|---|---|---|---|
| | **Before inoculation** | **During the inoculation** | **After inoculation** | **Weekly** |
| Roots + Soil | $15.91^{Ab\alpha}$ | $17.25^{Aa\alpha}$ | $17.12^{Aa\alpha}$ | $14.78^{Ab}$ |
| Roots + Leaf | $22.21^{Aa\alpha}$ | $19.58^{Aa\alpha}$ | $15.36^{Bab}$ | $19.84^{Aa\alpha}$ |
| Roots + Soil + Leaf | $16.39^{ABb\alpha}$ | $17.70^{Aa\alpha}$ | $13.39^{BCb}$ | $11.64^{Cb}$ |
| Control | | $20.34^{\alpha}$ | | |
| CV (%) | 15.44 | 6.07 | 12.82 | 7.62 |

Means followed by the same uppercase letters horizontally and by the same lessercase letters vertically, do not differ statistically by Tukey test at 5% probability. Values transformed into $\sqrt{x + 0.5}$; $^{\alpha}$Means do not differ from additional treatment by Dunnett test at 5% probability.

application times: (1) previously inoculation (three days after transplanting); (2) during inoculation (seven days after transplanting); (3) after inoculation (one week after inoculation); and (4) weekly until 45 days after inoculation (including all application times mentioned earlier) and an additional treatment: inoculated and untreated control.

The plants were treated with fungicide (Trifloxystrobin + Tebuconazole (75 + 150 g, i.a. $ha^{-1}$) due to the presence of Stemphylium leaf, caused by the fungi *Stemphyllium* species, 15 days after transplanting, in a interval of 3 days between the application of the extract treatment, and the second fungicide application was made 15 days after the first application.

The extract was first applied by way of the root system in all plants except for the control, at transplanting time and seedlings roots were immersed for a period of 3 seconds and transplanted in the pots; later, the plants with treatment by way of the leaves had their powdered leaves in the adaxial face until point of dripping. Not to come into contact with the ground, the pots were covered with aluminium foil and journal. Order for the spray does not come into contact with other plants; the pots were removed and isolated. Treated plants received 30 ml of extract by way of soil per pot, corresponding to 1% v/v. All treatments were performed in the morning. Seven days after the transplant, the inoculation of 2.500 eggs of *M. javanica*. (and 513 J2) per pot was performed.

Data analysis was performed Lilliefors normality test at 5% probability. In the absence of normality, test Q was used; therefore, all the data were with four replications. Even in the absence of normality, data from egg mass and J2 and eggs per 100 $cm^3$ of soil were transformed to $\sqrt{x + 0.5}$. Eggs and J2 per g of root data were transformed into log (x+1). Thereafter, the analysis of variance were carried out and means related to treatment were compared to Tukey test médium. When the additional treatment was significant in the analysis of variance, an additional test was used, Dunnett. Statistical software genes (Cruz, 2006) was used. The experiment was repeated once to confirm the best application times. It was conducted using a factorial design (3x2+1). Being the extract applied by way of the root system and in three different parts of the plant, the application times were: after inoculation (14 DAT) and weekly until 45 days after inoculation. After inoculation and weekly showed greater reduction in the population of *M. javanica* and it was repeated for confirmation.

## RESULTS AND DISCUSSION

In the application times after inoculation and weekly, the *M. javanica* egg mass was lesser than in the control (Table 1). After inoculation, the root+leaf and root+ soil+ leaf were lesser than the control in 24.50 and 34.17%, respectively. Already, for the weekly time, the way with less egg mass were root+soil with 27.33% and root+soil+leaf with 42.77% compared to the control. Although these do not differ from each other, the latter presented 15.44% less egg mass than by way of root+soil and 8.60% below the root+soil+leaf after inoculation time. Thus, successive applications and from the beginning of cultivation until the end, increase the tomato protection, for induction of resistance mechanisms and/or direct effect.

Leaf applications of plant extracts can induce systemic nematicide action, with fast and cheap control, and have lesser toxicity, such substances that act systemically can be released via root exudates, changing its composition and giving greater protection to plants (Lopes et al., 2005). In this study, extract applications after inoculation by way of root+leaf, may have presented systemic action, however, the control was better when associated with the application ways. Already, successive applications of the extract by way of root+leaf, may have released exudates that stimulated the hatching and penetration, favoring the development of nematode within the root. According to Dias-Arieira et al. (2003), roots exudates may inhibit or stimulate the emergence of juvenile nematodes.

Oka and Cohen (2001), found that foliar applications of BABA (DL-α-Amino-*n*-butyric acid) against *Meloidogyne* in wheat and barley (*Hordeum vulgare* L.), reduced the number of mass eggs, but higher concentrations of BABA was needed to induce resistance in plants, not showing symptoms of phytotoxicity.

As shown in Table 2, only by way of root+soil and root+soil+leaf in weekly applications differed from the control to reduce root-knots on tomato roots by 41 and 47.75%, respectively, and these did not differ between itself. Foliar applications did not differ from the control in all tested times. These results corroborate the ones found by Lopes et al. (2005), in which leaf applications leaves

**Table 2.** Total root-knots on the tomato plants roots inoculated with *Meloidogyne javanica*, in wich the roots of tomato plants were treated with *Crambe abyssinica* extract in different modes and application times.

| Modes of extract application | Application times | | | |
|---|---|---|---|---|
| | **Before inoculation** | **During the inoculation** | **After inoculation** | **Weekly** |
| Roots + Soil | $542.75^{Ab\alpha}$ | $474.00^{Aa\alpha}$ | $502.25^{Aa\alpha}$ | $350.25^{Ab}$ |
| Roots + Leaf | $751.50^{Aa\alpha}$ | $553.75^{ABa\alpha}$ | $549.00^{Ba\alpha}$ | $588.25^{ABa\alpha}$ |
| Roots + Soil + Leaf | $530.75^{Ab\alpha}$ | $561.50^{Aa\alpha}$ | $437.50^{ABa\alpha}$ | $310.25^{Bb}$ |
| Control | | $593.75^{\alpha}$ | | |
| CV (%) | 22.63 | 8.39 | 10.91 | 25.43 |

Means followed by the same uppercase letters horizontally and by the same lessercase letters vertically, do not differ statistically by Tukey test at 5% probability. $^{\alpha}$Means do not differ from additional treatment by Dunnett test at 5% probability.

and seeds extracts of *Mucuna pruriens* (L.) or *Ocimum basilicum* L. leaves extracts did not affect the height and fresh weight of the shoots of tomato, as well as the number of eggs per root system and the number of root-knots induced by *M. javanica*, but the application of the extracts in soil only reduced the number of nematode eggs. It is believed that the degradation by soil microflora may have affected the efficiency of extracts applied to the soil; in addition, the amount of used extract may have been low. This may ocurr in this study for the application by way of soil, leading to the need for repeated applications.

According to Almeida et al. (2012), extracts of different plant species such as neem (*Azadirachta indica*), nettle (*Fleurva aestuans*), and castor bean (*Ricinus communis*) prepared by different methods were applied in the soil and promote the number of root-knots reduction on inoculated tomato plants with *M. Javanica* eggs/juveniles, making it less attractive to nematodes and reducing parasitism, in a nematicide way, reinforcing the hypothesis that plant metabolites may exhibit biocidal activity. At the time after inoculation, there was no difference between modes of application and the control. However, at this same time, there was a reduction in the mass number of eggs by way of root+leaf and root+soil+leaf, so it can be concluded that the extract has acted in reproduction, once feeding sites were induced. According to Campos et al. (2011), *M. javanica* can penetrate at the roots and form feeding sites, however, it has not been ensured that it will reproduce, because the nutritional status influence the reproduction. Continuous stimulation of the nematode for induction and maintenance of giant cells is necessary, otherwise the cells be atrophied (Reddigari et al., 1985).

The times before inoculation and during the inoculation did not reduce total egg mass and root-knots (Tables 1 and 2). This may be due to the tomato seedlings being in adaptation period and/or there was no recognition of elicitor and signaling in the plant. Another hypothesis may be due to the inoculum *M. javanica*, in which different stages of embryogenesis enables the hatching of juveniles along the experiment conduction time.

According to Salgado et al. (2007), regardless of the time, the Acibenzolar-S-Methyl (ASM) application did not differ from control for number of root-knots, reproduction factor and population of *Meloidogyne exigua* in coffee. The authors attributed this to the inoculum, wich present different stages of embryogenesis, recommending the use of juveniles (J2) rather than eggs, once the penetration phase and early formation of roots feeding site could coincide with the phase of maximum effect ASM. However, Silva et al. (2002) developed a work with ASM applications each 7 days in tomato plants inoculated only with eggs and observed reduction of egg mass and root-knots of *Meloidogyne* spp.

Times that show effect on egg mass (Table 1) was after inoculation and weekly and on total root-knots (Table 2) weekly. Therefore, these times were repeated (Table 3) for confirmation of the effect on *M. javanica* in tomato.

The lowest mass number of eggs was observed only in root+soil+leaf when applied weekly, with reduction of 60.95% compared to the control (Table 3). Thus, can be concluded that there was resistance induction associated with the direct effect on nematodes. Applications of plant extracts of *Tagetes patula* by way of leaves and soil, activate defense mechanisms in tomato roots against *Meloidogyne incognita* (Franzener et al., 2007).

In Table 3, the total number of root-knots by way of root+soil+leaf when applications were weekly, was lesser than 27.95% when compared with the control. Thereby confirming that the crambe extract should be applied from the start of cultivation until the end, and all modes of application, thus, join the possible effects which generated resistance induction and/or direct effect. According to Williamson and Kumar (2006), resistance mechanisms can occur in plants against nematodes, such as cell death near the front end of nematodes, affecting the development of feeding sites, as can occur after the beginning of power, promoting or atrophying an abnormal development of the feeding site.

**Table 3.** Egg mass (ME) and root galls (GR) on the tomato plants roots inoculated with *Meloidogyne javanica*, in wich the roots of tomato plants were treated modes *Crambe abyssinica* extract in different ways and application times(repetition of experiment).

| Modes of extract application | ME | | GR[a] | |
|---|---|---|---|---|
| | Application times | | | |
| | After inoculation | Weekly | After inoculation | Weekly |
| Roots + Soil | 407.25$^{Aa\alpha}$ | 340.50$^{Aa\alpha}$ | 23.54$^{Aa\alpha}$ | 20.57$^{Aa\alpha}$ |
| Roots + Leaf | 261.75$^{Aa\alpha}$ | 378.50$^{Aa\alpha}$ | 22.15$^{Aa\alpha}$ | 19.70$^{Aa\alpha}$ |
| Roots + Soil + Leaf | 415.50$^{Aa\alpha}$ | 197.00$^{Ba}$ | 22.23$^{Aa\alpha}$ | 16.73$^{Ba}$ |
| Control | 504.50$^{\alpha}$ | | 23.22$^{\alpha}$ | |
| CV (%) | 36.15 | 40.42 | 11.98 | 17.23 |

Means followed by the same uppercase letters horizontally and by the same lessercase letters vertically, do not differ statistically by Tukey test at 5% probability. $^{\alpha}$Means do not differ from additional treatment by Dunnett test at 5% probability. [a]Values transformed into $\sqrt{x+0.5}$.

**Table 4.** Eggs and second stage juvenile (J2) of *Meloidogyne javanica* per gram root, in wich the roots of tomato plants were treated with *Crambe abyssinica* extract in different modes and application times.

| Modes of extract application | Application times | | | |
|---|---|---|---|---|
| | Before inoculation | During the inoculation | After inoculation | Weekly |
| Roots + Soil | 1.54$^{Aa\alpha}$ | 1.14$^{Bb}$ | 1.22$^{ABb}$ | 1.41$^{ABab\alpha}$ |
| Roots + Leaf | 1.65$^{Aa\alpha}$ | 1.60$^{Aa\alpha}$ | 1.56$^{Aa\alpha}$ | 1.65$^{Aa\alpha}$ |
| Roots + Soil + Leaf | 1.84$^{Aa\alpha}$ | 1.59$^{ABa\alpha}$ | 1.53A$^{Bab\alpha}$ | 1.30$^{Bb}$ |
| Control | | 1.64 α | | |
| CV (%) | 9.11 | 16.48 | 8.54 | 11.49 |

Means followed by the same uppercase letters horizontally and by the same lessercase letters vertically, do not differ statistically by Tukey test at 5% probability. $^{\alpha}$Means do not differ from additional treatment by Dunnett test at 5% probability. Values transformed into log (x+1).

Allyl isothiocyanate and allyl nitrile derivatives of glucosinolates present in *Brassicas* and the important in the control of soil pathogens were evaluated for their persistence, that is, expression of biological activity in the soil (Borek et al., 1995). These were influenced by several factors, resulting in irreversible chemical conversion or absorption to soil constituents. The allyl isothiocyanate and allyl nitrile presented an average of 97.1 and 80% of transformation in the first 10 days, respectively. Allyl isothiocyanate was negatively affected by organic carbon and total nitrogen, an increase in temperature of 10 to 25°C adversely affected the useful life. In temperature of 20°C, the useful life was about 4 days, but was positively affected by increased humidity. Since the disappearance of allyl nitrile in soil occurred more quickly in moist soil, there was higher concentrations in organic carbon and low temperatures. Thus, the quick dissipation of both compounds in the soil has important implications for the control of pathogens in soil and must provide multiple spraying or soil application, therefore, isothiocyanates have various reactions with nucleophilic groups, alcohols, phenols, esters, thiols, thiophenols, ammonia, amines, hydroxyamines, and hydrazines (Borek et al., 1995). Perhaps, for that reason, applications in soil must be repeated in this study.

According to Table 4, root+soil had presented less J2 and eggs of *M. javanica* per g of the root at the time of inoculation, and lesser than 30.49% compared to control. However, the time after inoculation by way of root+soil did not differ statistically with a reduction of 25.61% compared to the control. Despite the fact that the weekly time did not differ statistically from the time of inoculation, it did not differ from the control. These results may be due to the action of the extract on hatching eggs and accordingly J2 is least in the roots. The mechanisms involved in the control of *M. javanica* by way of root+soil in weekly applications must be related to nutrition, because they had less egg mass and root-knots, not affecting the penetration of J2 as well as root+leaf and root+soil+leaf ground sheet after inoculation, which reduced the reproduction, but did not reduce the penetration.

Acording to Rocha and Campos (2004), exudates cell can act as inhibitors or stimulants to the hatching, as well as nematostáticos or nematicides, since the effect on the enzyme acetylcholinesterase leads the J2 to reduce their

**Table 5.** Eggs and second stage juvenile (J2) of *Meloidogyne javanica* per 100 $cm^3$ of soil, in wich the roots of tomato plants were treated with *Crambe abyssinica* extract in different modes and application times.

| Modes of extract application | Application times | | | |
|---|---|---|---|---|
| | Before inoculation | During the inoculation | After inoculation | Weekly |
| Roots + Soil | $56.61^{Aa\alpha}$ | $40.99^{Ba}$ | $37.24^{Ba}$ | $40.14^{Bb}$ |
| Roots + Leaf | $48.60^{Aab\alpha}$ | $44.48^{Aa}$ | $34.63^{Ba}$ | $49.14^{Aa\alpha}$ |
| Roots + Soil + Leaf | $46.86^{Ab\alpha}$ | $38.96^{ABa}$ | $28.92^{Ca}$ | $35.78^{BCb}$ |
| Control | | $54.19^{\alpha}$ | | |
| CV (%) | 9.34 | 11.28 | 11.69 | 11.93 |

Means followed by the same uppercase letters horizontally and by the same lessercase letters vertically, do not differ statistically by Tukey test at 5% probability. $^{\alpha}$Means do not differ from additional treatment by Dunnett test at 5% probability. Values transformed into $\sqrt{x+0.5}$.

movements. So, maybe nematostatic effect for some period occurred in times of inoculation and after inoculation by way of root+soil, but when there was penetration, the nutritional status of the root were enough to develop feeding and reproduction sites.

Corroborating with work for the time after inoculation with application by way of root+soil, Mateus et al. (2014) concluded that *Verbena officinalis* L. and *Erythrina mulungu* M. extracts were applied to the soil once after tomato inoculation with *M. incognita* eggs, and the number of eggs per root system was reduced, interfering in the multiplication of the nematode.

According Rahman et al. (2011), growing population of *M. javanica* in grapevine roots treated with *Brassica* seeds flour for 2 to 3 consecutive years, has increased the susceptibility, which was, probably, due to allelochemicals absorption by roots, leading to a higher population of J2 in the roots.

The applictions by way of root+leaf does not differ from the control in any of the studied appliction times to J2 and *M. javanica* eggs per gram root (Table 4). Already, by way of root+soil+leaf differ from the control only for the weekly application, below 20.73%, this treatment can have an effect on hatching eggs and/or inhibitory effect of penetration. The reduction of J2 within the root, reduces forming of feeding site and lesser reproduction. The penetration of J2 of sedentary endoparasitic nematodes may occur, but the plant does not host the nematode, for other events must occur for parasitism success (Faria et al., 2003).

Aqueous extract of *Cajanus cajan* L., *Origanum vulgare* L., *Mucuna aterrima* P. and *Momordica charantia* L. promoted a reduction in the number of eggs per root system; the extract was applied in the soil on the day of *Rotylenchus reniformis* infestation eggs and consecutively to every 15 days up to 60 days (Gardiano et al., 2011). Corroborating with this study, in which applications extracts by way of soil and foliar, consecutively, presented nematode control.

In Table 5, application times during the inoculation and after inoculation did not differ each other, and they presented less J2 and eggs per 100 $cm^3$ of soil compared to the control. The weekly application time showed differences for modes of application, and by way of root+soil and root+soil+leaf with smaller population in the soil, lesser than 25.93 and 34% compared with the control, respectively. Perhaps, a repellent effect and/or nematostatic is the mechanism involved, by direct effect of the extract or by means of induction exudates roots. Biochemical changes occurring in plants after being induced resistance may result in changes in the nature of exudates and can attract or repel nematodes (Salgado and Silva, 2005).

The applications by way of root+soil showed no difference between the tested times, except prior to inoculation with the highest population in the soil. Already, for modes root+leaves, the only time that differed with less population in the soil was after inoculation and 36.09% lesser than that compared to the control. By modes of root+soil+leaf, times have reduced the number of J2 and eggs per 100 $cm^3$ of soil were in inoculation lesser than 28.10% after inoculation lesser 46.63 and 33.97% compared to the control, but did not differ statistically from the time after inoculation. 33.97% lesser than the compared to the control, but did not differ statistically from weekly time after inoculation.

Based on the smaller population in the soil, the application times wich had a greater effect were: after inoculation and weekly, despite the time of inoculation also have been shown to be effective, modes with further reduction was not in this. In the repetition of the experiment (Table 6), the modes that differ from the control J2 and to eggs per gram of ground were root+soil and soil+root+leaf applied weekly, whereas root+soil was intermediate and 14.57% lesser compared with the control, while by way of root+soil+leaf presented less J2 and eggs per gram of root and 20.65% lesser compared to the control. The population of J2 and eggs per 100 $cm^3$ of soil was lesser than the control only by way of root+soil+leaf when applied weekly, with reduction of

**Table 6.** Eggs and second stage juvenile (J2) *Meloidogyne javanica* per gram of root and per 100 cm$^3$ of soil, in wich the roots of tomato plants were treated with *Crambe abyssinica* extract in different modes and application times(repetition of experiment).

| Modes of extract application | Eggs and J2 per gram root | | Eggs and J2 per 100 cm$^3$ of soil | |
|---|---|---|---|---|
| | Application times | | | |
| | Afterinoculation | Weekly | After inoculation | Weekly |
| Roots + Soil | 2.38$^{Aa\alpha}$ | 2.11$^{Bab}$ | 3.03$^{Aa\alpha}$ | 3.14$^{Aa\alpha}$ |
| Roots + Leaf | 2.50$^{Aa\alpha}$ | 2.43$^{Aa\alpha}$ | 3.04$^{Aa\alpha}$ | 3.03$^{Aa\alpha}$ |
| Roots + Soil + Leaf | 2.26$^{Aa\alpha}$ | 1.96$^{Bb}$ | 3.01$^{Aa\alpha}$ | 2.61$^{Bb}$ |
| Control | | 2.47$^{\alpha}$ | | 2.96$^{\alpha}$ |
| CV (%) | 9.54 | 5.36 | 4.62 | 5.85 |

Means followed by the same uppercase letters horizontally and by the same lessercase letters vertically, do not differ statistically by Tukey test at 5% probability. $^{\alpha}$Means do not differ from additional treatment by Dunnett test at 5% probability. Values transformed log (x+1).

11.82%.

Differences were observed between the periods of April to June and in repetition of the experiment in October to December. To J2 and eggs per gram root, the applications by way of roots+soil in both times tested, there were diferences. The penetration reduced by way of root+soil+leaf in weekly applications was confirmed in the repeat experiment. For J2 and eggs per 100 cm$^3$ of soil, the efficiency by modes of root+soil+leaf and absence of control for root+leaf weekly applications, was confirmed in the repeat experiment. The differences observed between the periods of April and June and repeat experiment in October and December may be due to difference in temperature between them. In the periods of October to December, temperatures were higher, with an average of 24.8°C favoring the reproduction; already in the the periods of April to Jun, the average temperature was 19.3°C. These temperature data are from Automatic Surface Observing Weather Station.

In a complementary way, the incorporation of mustard (*Brassica juncea*) biomass and seeds flous in soil reduced the density of *M. javanica* of the grapevines, but a lesser increase in the population after the suppession by the treatments was found, requiring annual treatment for several consecutive years to reduce the population of *M. javanica* and improve the grape production, once that the population increase is associated with the eggs hatching, and the longevity of compounds present in *Brassicas*, as isothiocyanates, which depend on a number of factors such as soil moisture (Rahman and Somers, 2005).

## Conclusion

Times after inoculation and weekly were effective for most of the variables studied. However, the weekly time stood out by modes of soil+root+leaf, because it showed low mass number of eggs, total root-knots, J2 and eggs per gram root and 100 cm$^3$ of soil. Although, other treatments also demonstrate efficiency, some were not confirmed in a repetition of the experiment. In this sense, there is a combined effect of mechanisms related to the induction of resistance and a direct effect about the nematode, with applications of crambe extract from the beginning of tomato cultivation until the end to reduce the population of *M. javanica*.

## Conflict of Interests

The authors have not declared any conflict of interests.

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# Profit loss per hectare according to profit efficiency level among smallholder rice farmers in Central Liberia

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**Self-sufficiency in rice production has been an essential issue in the Liberian agriculture sector. With the increasing demand and low national productivity of rice (1.2 t/ha), Liberia remains a net importer of rice unless domestic production improves significantly. This study was conducted to analyze smallholder rice farmers' level of efficiency and profit-loss due to allocative and technical inefficiencies. A two stage random sampling with stratification was adopted to collect data from 400 rice farmers in Central Liberia. The results show that high level of inefficiency exist with 33% of profit-loss among smallholders rice farmers due to a combination of technical and allocative inefficiencies. The average profit-loss is about 19,900 LRD/ha. Factors that are related to profit-loss and inefficiency are lack of credit and extension services and the non-usage of yield improving technologies such as high yielding improved seeds, fertilizer and herbicide. Lastly, inefficiency and profit-loss were high in upland rice production than lowland rice production.**

**Key words:** Liberia, profit-loss, inefficiency, smallholder rice farmers.

## INTRODUCTION

Rice is the primary staple food crop for Liberia's 3.5 million people representing over 33% of their food consumption and accounting for approximately 50% of adult caloric intake; with an annual per capita consumption estimated at 133 kg (USAID-BEST, 2014). There is an increasing demand of rice due the increased in population, especially in the highly populated urban centers. Moreover, rice is largely a price-inelastic commodity in the household, reinforcing the colloquial expression that "one has not eaten that day if one has not eaten rice" (USAID, 2009). In Liberia, rice and its price are considered politically sensitive. Tsimpo and Wodon (2008) estimated that a 20% rise in the price of rice would increase the poverty headcount by 3 to 4% points. Furthermore, the significance of rice in the Liberian diet can be elucidated by its demand and consumption pattern over the years. Average annual production from 2009-2012 was about 290,600 metric tons whereas the total average annual consumption was over 400,000 metric tons (NRDS, 2012; FAO, 2013). With the increasing

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demand, the country will continue to be a net importer of rice unless domestic production improves significantly. This is possible since the country offers ideal conditions for rice production (NRDS, 2012; USAID-BEST, 2014).

For the past decade, there have been many interventions in the agriculture sector by the government and its partners to enhance the productive capacity of farmers to boost rice production in Liberia through research and development. There are programs created to link farmers to inputs such as improved seed, fertilizer, herbicide, insecticide, etc. Other programs have rehabilitated existing rice production facilities, constructed agro-processing facilities and farm to market roads (MOA, 2010). The crop ranks first in terms of research priorities among all crops within the Central Agriculture Research Institute (CARI). CARI conducts research and variety development for the creation of improved rice seed varieties.

Despite the high production potential and various programs, yield in Liberia is just about 1.2 t/ha (NRDS, 2012; FAO, 2013; USAID-BEST, 2014). This is low as compared to other West African countries with 2.7 t/ha in Ghana, 3.0 t/ha in Côte d'Ivoire, 3.4 t/ha in Mali and 4 t/ha in Benin (Donkoh and Awuni, 2011; Oladele et al., 2011; Donkor and Uwusu, 2014). The yield gap is approximately triple as compared to the national rice development strategy potential yield of 4 t/ha (NRDS, 2012). The above figures depict a big potential for increased output. However, the biggest challenge is limited knowledge on the causes of this gap. This study, therefore, aimed at analyzing smallholder farmers' level of efficiency and profit loss per hectare due to allocative and technical inefficiency in rice production so as to fill the identified gap.

## Theoretical framework

In microeconomic theory of the firm, production (economic) efficiency is decomposed into technical and allocative efficiency. Farrell provided a framework for the computation of a production frontier. However, it was not until the work of Aigner and Chu (1968) that the frontier function was first explicitly specified in a parametric form. Afriat (1972) used a one-sided error term in which observed variations were said to be endogenous, while weather, wars and droughts were treated as random factors. Aigner et al. (1977) and Meeusen and van den Broeck (1977) employed the concept of a stochastic frontier in which a two sided random error term was introduced explicitly in a production function.

Farrell (1957), defined efficiency in his pioneering study as the ability to produce a given level of output at lowest cost. He distinguished three types of efficiency: (1) technical efficiency, (2) price or allocative efficiency and (3) economic efficiency which are the combination of the first two. Technical efficiency is an engineering concept referring to the input-output relationship. A firm is said to be efficient if it is operating on the production frontier. On the other hand, a firm is said to be technically inefficient when it fails to achieve the maximum output from the given inputs, or fails to operate on the production frontier. Technical efficiency represents a farm's ability to produce a maximum level of output from a given level of inputs. Allocative efficiency is the ability of a farm to use inputs in optimal proportions, given their respective prices and available technology (Rahman, 2003). The combination of technical and allocative efficiency provides the level of economic efficiency. That is to say, if the farm uses resources allocatively and technically efficiently, it is said to have achieved total economic or profit efficiency.

According to Ali and Flinn (1989), profit efficiency, within a profit function context, is defined as the ability of a farm to achieve the highest possible profit, given the prices and levels of fixed factors of that farm and profit inefficiency is defined as profit loss from not operating on the profit frontier given farm specific prices and resource base. Ali et al. (1994) stated that profit function approach combines the concepts of technical and allocative efficiency in the profit relationship and any error in the production decision is assumed to be translated into lower profits or revenue for the producer.

Battesse and Coelli (1995) extended the stochastic production frontier model by suggesting that the inefficiency effects can be expressed as a linear function of explanatory variables, reflecting farm-specific characteristics. The advantage of Battesse and Coelli (1995) model is that it allows estimation of the farm specific efficiency scores and the factors explaining efficiency differentials among farmers in a single stage estimation procedure. The present paper utilizes this Battesse and Coelli (1995) model by postulating a profit function, which is assumed to behave in a manner consistent with the stochastic frontier concept. The stochastic profit function is defined as:

$$\pi_i = f\left(P_{ij}, Z_{ik}\right).\exp(\varepsilon_i) \quad (1)$$

Where $\pi_i$ is the normalized profit of the $i^{th}$ farm defined as revenue less variable cost, divided by farm specific output price; $P_{ij}$ is the price of $j^{th}$ variable input faced by the $i^{th}$ farm divided by output price; $Z_{ik}$ is level of the $k^{th}$ fixed factor on the $i^{th}$ farm; $\varepsilon_i$ is an error term and $i$ =1,…,n, is the number of farms in the sample.

The error term ($\varepsilon_i$) is assumed to behave in a manner consistent with frontier concept (Rahman 2003; Tsue et al. 2012):

$$\varepsilon_i = V_i - U_i \quad (2)$$

Where $V_i$s is assumed to be independently and identically distributed $N(0, \sigma_v^2)$ two sided random errors, independent of the $U_i$s; and the $U_i$s is non-negative random variables, associated with inefficiency in production, which are assumed to be independently distributed as truncations at zero of the normal distribution with mean, $\mu = \delta_0 + \sum_d \delta_d W_{di}$ and variance $\sigma_u^2(|N(\mu, \sigma_u^2|)$, where $W_{di}$ is the $d^{th}$ explanatory variables associated with inefficiencies on farm $i$ and $\delta_0$ and $\delta_d$ are the unknown parameters.

## MATERIALS AND METHODS

### Study location and sampling procedure

This study was conducted in Liberia, in 2015 in two Counties, namely, Nimba and Bong. These two Counties are located in the Central Region of Liberia. Nimba and Bong are generally suitable for rice production; hence it was appropriate for this study. The two Counties ranked the highest in the 2011 rice production with about 61,600 (21.2%) and 60,900 (21.0%) metric tons, respectively. The combined estimates of these two counties accounted for 42.2% of the total production and 41.2% of area of rice harvested in Liberia (NRDS, 2012).

The study adopted a two stage random sampling with stratification. At the first stage, villages from each district were stratified into two (that is, upland and lowland rain-fed villages). In the second stage, a simple random sampling method was used to select farmers from village list of rice producers on probability proportional to size basis. Thus, in all, 400 rice producers (200 from Nimba and 200 from Bong) were selected from the villages. A structured questionnaire was then used to collect primary quantitative data from the sampled population. The data included information on rice farming operations such as: quantities of seeds, planting and topdressing fertilizer, herbicides, pesticides, land area, labour man-days and output data for rice such as quantity sold, consumed and retained for seed. In addition, information on average input prices was also collected from the respondents. Additional data focused on household socio-economic and institutional characteristics such as the farmer's age, sex, years of schooling, farming experience, main occupation, household size, income and asset profiles, distance to the market, marketing information, extension contacts, group membership, pre and post-harvest loses and credit.

### Method of analysis

The stochastic profit frontier function (Equation 3), and the inefficiency function (Equation 4) were estimated using the FRONTIER 4.1 computer software (Coelli, 1996). The program combines the two-stage procedure into one and produces maximum likelihood estimates of the parameters of a stochastic profit frontier function. This procedure is superior to two-stage procedures because it does not violate the assumption that the inefficiency effects are independently and identically distributed (Battesse and Coelli, 1995; Coelli, 1996; Kumbhakar et al., 2015). After the translog stochastic frontier estimate, individual farmers efficiency score and actual profit were used to calculate profit loss (Equation 5) using Microsoft Excel and finally, profit efficiency scores and profit loss for the farmers were categorized into tercile (low, medium and high) and analyzed using IBM SPSS vision 21.

### Empirical model

This study estimates a flexible translog profit function and inefficiency models for rice production in Central Liberia. More details on the selection of the functional form are according to Saysay et al., 2016. The models were derived as follows:

$$ln\pi' = \alpha_0 + \sum_{i=1}^{4} \alpha_1 lnP_i + \frac{1}{2}\sum_{i=1}^{4}\sum_{k=1}^{4} \tau_{ik} lnP_i \, lnp_k + \sum_{i=1}^{4}\sum_{l=1}^{1} \emptyset_{il} lnP_i \, lnZ_l + \sum_{l=1}^{1} \beta_l lnZ_l + \frac{1}{2}\sum_{l=1}^{1}\sum_{q=1}^{1} \varphi_{lq} lnZ_l \, lnZ_q + v - u \quad (3)$$

And

$$u = \delta_0 + \sum_{d=1}^{11} \delta_d W_d + \omega \quad (4)$$

Where, $\pi'$ = restricted profit (total revenue less total cost of variable inputs) normalized by price of output (Py); $P_i$ = price of the i[th] input (Pi) normalized by the output price (Py), where (i = 1, 2, 3, and 4): $P_1 =$ Seed cost normalized by output price of rice (Py); $P_2 =$ fertilizer cost normalized by output price of rice (Py); $P_3$ = herbicide cost normalized by output price of rice (Py); $P_4 =$ labour cost normalized by output price of rice (Py); $Z_l =$ the quantity of fixed input (l =1); $Z_1 =$ Area planted with rice (hectare under rice); $v =$ two sided random error; $u =$ One sided half-normal error; $ln =$ Natural logarithm; $W_d =$ variables explaining inefficiency effects; $d_1 =$ education; $d_2 =$ farming experience; $d_3 =$ off-farm income; $d_4$ = household size; $d_5$ = occupation; $d_6$ = lack of credit; $d_7$ = lack of extension services; $d_8 =$ group membership; $d_9 =$ market information access; $d_{10}$ = variety; $d_{11}$ = agroecology

After rice farmer profit efficiency level was known, the profit loss was calculated using the following formula:

$$PL = Maximum\, profit\, (1 - PE) \quad (5)$$

Where, PL is the profit loss and PE is the profit efficiency. The maximum profit per hectare could be calculated by dividing the actual profit per hectare with the efficiency level.

## RESULTS AND DISCUSSION

### Profit loss according to profit efficiency level per hectare among rice farmers

The indication of profit loss is also a chance of enhancing profit efficiency by identifying the source of profit loss. The results in Table 1 show that profit loss is higher at a lower efficiency level and profit loss is also negatively related to farmer's actual profit. The average profit loss among rice farmers is relatively high approximately more than 19,900 Liberian dollars (LRD) per hectare. This is an indication that there is still a relatively high profit potential to be obtained by farmers if rice production is conducted technically and resources allocated efficiently in the study area.

The average profit efficiency level among rice farmers in the study area was about 67%, indicating the existence of a relatively large level (33%) of profit-loss due to a combination of technical and allocative inefficiencies. In order to determine the characteristics that distinguish profit efficiency level among rice farmers in the study area, profit efficiency scores by farmers were categorized into three, that is, low, medium and high. The low profit

**Table 1.** Profit loss according to profit efficiency level for rice farmers.

| Efficiency range | Frequency | Percentage | Actual profit (LRD/ha) | Profit loss (LRD/ha) |
|---|---|---|---|---|
| 0.10 - 0.20 | 9 | 2.3 | 6,362.86 | 34,143.19 |
| 0.21 – 0.30 | 14 | 3.5 | 11,078.41 | 32,170.07 |
| 0.31 – 0.40 | 28 | 7.0 | 21,411.18 | 37,185.32 |
| 0.41 – 0.50 | 28 | 7.0 | 20,941.74 | 25,211.30 |
| 0.51 – 0.60 | 38 | 9.5 | 29,939.67 | 23,011.56 |
| 0.61 – 0.70 | 62 | 15.5 | 37,254.61 | 18,915.47 |
| 0.71 – 0.80 | 107 | 26.8 | 52,161.24 | 16,304.69 |
| 0.81 – 0.90 | 110 | 27.5 | 83,458.64 | 14,601.50 |
| 0.91 – 0.99 | 4 | 1.0 | 175,047.14 | 15,900.81 |
| Total | 400 | 100 | | |
| Mean | | | 50,769.07 | 19,915.86 |
| Min | | | 1.05 | 0.33 |
| Max | | | 245,362.53 | 90,819.79 |
| Std. Dev | | | 35868.20 | 10547.71 |
| Median | | | 43,114.94 | 17,580.16 |

NB: LRD = Liberian dollar: 85 LRD = 1 USD (March, 2014 Central Bank of Liberia exchange rate).

**Table 2.** Descriptive statistics of profit efficiency tercile in Nimba and Bong Counties.

| Category | N | Mean | St. Dev | Min | Max |
|---|---|---|---|---|---|
| Low | 139 | 0.46 | 0.14 | 0.13 | 0.64 |
| Medium | 133 | 0.73 | 0.04 | 0.65 | 0.79 |
| High | 128 | 0.86 | 0.03 | 0.80 | 0.93 |
| Total | 400 | 0.67 | 0.19 | 0.13 | 0.93 |

efficiency farmers represented 35% of the sample population with the mean efficiency score of 0.46, the medium profit efficiency farmers accounted for 33% with the mean efficiency score of 0.73 and the high profit efficiency farmers represented 32% of the sample population with the mean efficiency score of 0.86 (Table 2).

**Profit efficiency and profit loss terciles in rice production among farmers**

The results in Tables 3 and 4 discuss profit efficiency and profit loss terciles among rice farmers in the study area. The results show that the proportion of upland rice farmers in the low profit efficiency category is more than twice of farmers in the lowland ecology. On the other hand, the proportion of rice farmers in the high profit efficiency category is approximately two times as larger than farmers in the upland ecology (Table 3). In terms of profit-loss, the proportion of farmers in the upland ecology in the high profit loss category is more than twice larger than the lowland farmers (Table 4). The Chi square test results show a strongly statistically significant difference (P = 0.000). This implies that farmers who are in the lowland ecology as compared to upland farmers tend to be more profit efficient and incur less profit loss.

Furthermore, farmers who cultivated improved (high yielding) varieties as compared to local varieties tend to be more profit efficient and experience less profit-loss (Tables 3 and 4). There is a strongly statistically significant difference between rice varieties cultivated by farmers among the profit efficiency and profit loss categories (P = 0.000). This implies that farmers who cultivated improved variety get high actual profit per hectare due to high output per hectare. The evidence with respect to the effect of improved variety indicates profits higher for those farmers paying higher prices for seeds. However, this may partially reflect farmers' profit made due to use of improved (high yielding) varieties; as it has been noted that the improved varieties seed prices are usually much higher as compared to the local varieties. This result is consistent with finding of Wadud and Rashid (2011) and Galawat and Yabe (2012). Therefore, adopting improved (high yield) varieties in rice production will improve profit efficiency. In addition, farmers who use fertilizer and herbicide in rice production were more in the high profit efficiency category than

**Table 3.** Profit efficiency tercile in rice production among farmers in Nimba and Bong Counties.

| Variable | | No. | Profit efficiency tercile LRD/ha | | | Chi square | P value |
|---|---|---|---|---|---|---|---|
| | | | Low (%) | Medium (%) | High (%) | | |
| Agroecology | Upland | 225 | 45 | 30 | 25 | | |
| | Lowland | 175 | 21 | 38 | 41 | 26.092 | 0.000*** |
| Variety | Improved | 186 | 23 | 30 | 47 | | |
| | Local | 214 | 45 | 36 | 19 | 39.240 | 0.000*** |
| Use of fertilizer | Used fertilizer | 50 | 28 | 32 | 40 | | |
| | Did not use fertilizer | 350 | 36 | 33 | 31 | 1.919 | 0.383 |
| Use of herbicide | Used herbicide | 37 | 38 | 22 | 40 | | |
| | Did not use herbicide | 363 | 35 | 34 | 31 | 2.699 | 0.259 |
| Sex | Male | 348 | 35 | 33 | 32 | | |
| | Female | 52 | 33 | 35 | 33 | 0.115 | 0.944 |
| Experience | Low level experience | 116 | 56 | 26 | 18 | | |
| | Experienced | 105 | 43 | 31 | 26 | | |
| | High level experience | 179 | 16 | 39 | 45 | 55.995 | 0.000*** |
| Off-farm income | Yes | 185 | 35 | 35 | 30 | | |
| | No | 215 | 34 | 32 | 34 | 0.524 | 0.770 |
| Occupation | Farming | 327 | 31 | 31 | 38 | | |
| | Formal employment | 73 | 52 | 41 | 7 | 27.000 | 0.000*** |
| Access to credit | Had access to credit | 245 | 27 | 31 | 42 | | |
| | Did not have credit access | 155 | 48 | 36 | 16 | 32.842 | 0.000*** |
| Extension services | Received extension services | 67 | 25 | 25 | 50 | | |
| | Did not Receive extension services | 333 | 37 | 35 | 28 | 11.025 | 0.004*** |

***Significant at 1% level.

farmers who did not use fertilizer and herbicide but Chi square result shows no statistically significant difference.

Moreover, the Chi square test result confirms that there is no statistically significant difference between sex of rice farmers and profit efficiency (P = 0.944). This result implies that sex is not essential for rice farmer's profit efficiency. Farmers who have high experience in rice farming under the high profit efficiency category were approximately two times larger than the experienced farmers and the low experienced farmers. It is important to note that more low experienced farmers (56%) were found in the low profit efficiency category as compared to the experienced and high experienced farmers. On the other hand, the proportion of farmers with low rice farming experience were more (53%) in the high profit loss category than experienced (32%) and high experienced rice farmers (21%). The Chi-square test confirms a strongly statistically significant difference in level of rice farming experience and profit efficiency (P = 0.000). This implies that farmers who have more experience in rice farming as compared to those who have less experience tend to incur less profit loss and high profit efficiency. This result conformed to the findings of Rahman (2003). Farming experience helps farmers to effectively and efficiently allocate resources, thereby allowing them to operate at higher level of efficiency.

The proportion of the respondents whose main occupation is farming under the high profit efficiency category was more than three times larger than those who were formally employed and doing rice farming as secondary occupation. On the other hand, about half of the respondents who are formally employed (50%) were under the low profit category, which is higher than those that are fully involved into rice farming (31%). The result shows a strongly statistically significant difference. The result implies that respondents who are fully involved in rice cultivation as compared to those who are partly involved in rice production tend to be more profit efficient, achieve high actual profit and incur less profit loss. Engaging in non-farm employment could deprive the farm

**Table 4.** Profit loss tercile in rice production among farmers in Nimba and Bong Counties.

| Variable | | No. | Profit loss tercile in LRD/ha | | | Chi square | P-value |
|---|---|---|---|---|---|---|---|
| | | | Low (%) | Medium (%) | High (%) | | |
| Agroecology | Upland | 225 | 21 | 35 | 44 | | |
| | Lowland | 175 | 49 | 31 | 20 | 38.790 | 0.000*** |
| Variety cultivated | Improved | 186 | 48 | 32 | 20 | | |
| | Local | 214 | 21 | 35 | 44 | 39.800 | 0.000*** |
| Use of fertilizer | Used fertilizer | 50 | 90 | 10 | 0 | | |
| | Did not use fertilizer | 350 | 25 | 37 | 38 | 83.768 | 0.000*** |
| Use of herbicide | Used herbicide | 37 | 87 | 14 | 0 | | |
| | Did not use herbicide | 363 | 28 | 35 | 37 | 53.170 | 0.000*** |
| Gender | Male | 348 | 33 | 33 | 34 | | |
| | Female | 52 | 39 | 36 | 25 | 1.876 | 0.391 |
| Rice farming experience | Low level | 116 | 23 | 24 | 53 | | |
| | Experienced | 105 | 32 | 36 | 32 | | |
| | High level | 179 | 41 | 38 | 21 | 31.815 | 0.000*** |
| Off-farm | Yes | 185 | 35 | 30 | 35 | | |
| | No | 215 | 32 | 36 | 32 | 1.627 | 0.443 |
| Occupation | Farming | 327 | 35 | 35 | 30 | | |
| | Formal employment | 73 | 27 | 25 | 48 | 8.804 | 0.012** |
| Access to credit | Had access to credit | 245 | 35 | 40 | 25 | | |
| | Did not have credit access | 155 | 30 | 24 | 46 | 21.240 | 0.000*** |
| Extension service | Received extension services | 67 | 42 | 39 | 19 | | |
| | Did not receive extension services | 333 | 32 | 32 | 36 | 7.083 | 0.029** |

***Significant at 1% level; **Significant at 5% level.

of valuable time to perform farming operations in a timely manner. This result is consistent with the findings of Rahman (2003) and Islam et al. (2011) who found that non-farm employment can lead to an increase in inefficiency and profit loss. This is contrary to Hyuha et al. (2007) who found that access to off-farm income increases profit efficiency. Off-farm income can be used to purchase agricultural input and other services which can improve productivity and enhance efficiency.

The results show a strongly statistically significant difference between credit access and profit efficiency (P = 0.000). Farmers with access to credit under the high profit efficiency category are three times more than those without access to credit. On the other hand, approximately half of the farmers without access to credit (48%) were in the low profit efficiency category, which is larger than farmers with access to credit (27%) in the low profit efficiency category. Furthermore, farmers without access to credit were about twice more in the high profit loss category than farmers with access to credit. This implies that access to farm credit can increase rice farming profit efficiency and reduce profit loss. This result collaborates with the findings of Dwi et al. (2014) and Yasin et al. (2014). The importance of credit support to the efficiency and success of smallholder farmers has also recently been reported by other researchers (Rahman and Smolak, 2014; Sinyolo et al., 2016). Access to credit reduces the liquidity problem that usually affects farmers during the production period, and it enhances the use of agricultural inputs in production by ensuring that farmers secure the inputs in time. This leads to improved, farm level efficiency and agricultural productivity, resulting in increased farming revenues, which subsequently act as incentives that reduce poverty among farmers. As such, the provision of credit should be at the conduit of any effort to improve smallholder production.

The results show that the proportion of farmers with access to extension services under the high profit efficiency category was about twice larger than the farmers without access to extension services. The reverse is true for farmers without access to extension services under the low profit efficiency category, whereby the proportion of farmers without access to extension services (37%) was more than farmers with access to extension services (25%). Also, farmers without access to extension services were more (36%) in the high profit loss category than farmers with access to extension services (19%). The Chi square test confirms that there is a statistically significant difference. This implies that farmers who have access to extension services as compared to those who do not have access to extension services tend to be more profit efficient and incur less profit loss. The result shows that access to extension services can reduce profit loss, increase actual profit and profit efficiency. The result is supported by other findings of Rahman (2003) and Hyuha et al. (2007).

## CONCLUSION AND RECOMMENDATION

The study shows that high level of inefficiency exists with 33% of profit-loss among smallholder rice farmers due to a combination of technical and allocative inefficiencies. Smallholder rice farmers in the study area average profit-loss was about 19,900 LRD/ha which could be minimized by improving technical and allocative efficiencies. It is indicated that farmers with more rice farming experience are more efficient and may incur low-profit loss than farmers with less experience. Furthermore, farmers who had access to credit and extension services operate at higher level of efficiency and incur less profit loss than farmers who do not. Also, farmers who were fully involved in rice cultivation were more profit efficient, achieve high actual profit and incur less profit loss than farmers who were partly involved in rice production. The study also shows that farmers in the lowland ecology are more efficient and experience less profit loss than farmers in the upland ecology. The significance of yield improving inputs such as high yielding improved rice varieties, fertilizer and herbicide in improving efficiency is also evident in this study. The use of high yielding improved rice varieties, fertilizer and herbicide enhances efficiency, increases actual profit and reduces profit loss.

The study recommends that policies and interventions in the rice sub sector should focus on the development and rehabilitation of more lowland with good source of irrigation and application of appropriate rice production technologies such as the use of improved high yielding varieties, fertilizer and herbicide. Hence, this underscores the significance of institutional support that would provide for increased participation of farmers and farmers' group in intervention programs that promote the adoption of rice yield enhancing technologies. Programs of such should include farmer field school with focus on demonstration and on-farm trails and promotional events, while rigorous efforts and attention should be given towards ensuring a wider and effective coverage for extension services.

Also, improvement in efficiency would require focused policies and programs increasing and improving access to credit to rice farmers; thereby creating incentives for farmers to get fully involved in rice production. There is need to focus on bringing micro-finance institutions closer and accessible to smallholder farmers, to enhance their ability in purchasing the much needed inputs. Alternatively, inputs credit guarantee scheme can help farmers to timely acquire inputs which will increase productivity and hence reduce inefficiency.

## Conflict of Interests

The authors have not declared any conflict of interests.

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# Evaluation of morphological aspects of common bean (*Phaseolus vulgaris* L.) genotypes for post-flowering drought resistance in Rift Valley of Ethiopia

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**The development of bean varieties adapted to drought situations is a key strategy to minimize crop failure and improve food security. In this study, 25 genotypes of common beans (*Phaseolus vulgaris* L.) were grown under post flowering drought stress and non-stress conditions to evaluate their performance at Melkassa Agricultural Research Center during the off-season months (from December to May) in 2011/2012. The treatments were laid out on a triple lattice design with three replications. A number of plant attributes were measured at mid-pod fill and harvesting stages. Under drought stress, the highest seed yield (125.3 gm$^{-2}$) was recorded for a Dimtu variety, while the lowest (72.5 gm$^{-2}$) for SB-15945-17. Therefore, Dimtu was the most drought tolerant genotype under drought stress. On the contrary, SB-15945-17 had the lowest seed yield under drought stress and drought-induced seed yield reduction of 50.8%. Seed yield showed significant and positive correlation with number of pods per plant (r =0. 39), number of seeds per pod (r =0. 32) and hundred seed weight (r =0. 41) under drought stress. The study demonstrated the existence of genetic variability among the common bean genotypes when subjected to post-flowering drought stress and such variability could be utilized in the development of common bean genotypes suitable for drought prone-areas.**

**Key words:** Common beans, correlation, drought stress, genotype, *Phaseolus vulgaris*.

## INTRODUCTION

Drought is the most important limiting factor for crop production and it is becoming an increasingly severe problem in many regions of the world. In addition to the complexity of drought itself (Passioura, 2007), plant responses to drought are complex and different mechanisms are adopted by plants when they encounter drought (Hinkossa et al., 2013). Drought can be defined as a state where a dry soil (due to lack of rain or delayed irrigation) causes a substantial reduction in crop performance in terms of plant survival, economic yield or crop quality (Muñoz-Perea et al., 2007). Common bean (*Phaseolus vulgaris* L.) performance is severely constrained by periodic water deficits in most production areas (Beebe et al., 2013; Hinkossa et al., 2013; Yaqoob et al., 2013). Frequency of occurrence of water deficits, severity of stress, timing of stress relative to plant age,

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and sensitivity of the plant at different stages of growth interact to determine yield loss associated with water deficits (Beebe et al., 2013; Hinkossa et al., 2013).

Post-flowering drought responses have been identified in common bean (Hinkossa et al., 2013). Post-flowering response is observed when water limitation occurs during the grain-filling stage (Subbarao et al., 1995). The most sensitive stages to grain filling in common bean were at flowering and ten days prior to flowering (Hinkossa et al., 2013; Yaqoob et al., 2013). It was noted that post-flowering heat stress caused yield losses up to 50% due to reduced seed filling duration (Bernier et al., 2007).

Common bean is probably native to the tropical parts of South America (Onwueme and Sinha, 1991), from where it was perhaps introduced to Africa and other continents (Baudoin et al., 2001; Beebe et al., 2013). After its dissemination, it is grown extensively in five major continental areas: Africa, North and Central America, South America, Eastern Asia and Western and Southeastern Europe (Adams et al., 1985; Beebe et al., 2013). Moreover, common bean is a non-centric crop, with multiple domestication sites throughout the distribution range. Even though the exact time of its introduction is controversial, it is generally believed that common bean was probably brought to Ethiopia in the 16$^{th}$ century (Gepts, 1990).

In common bean, four different drought scenarios have been identified in the growing region (Subbarao et al., 1995; Tilahun et al., 2004). The first scenario represents terminal drought where there could be enough moisture for early establishment and growth, but later phonological stages are exposed to moisture deficit (Beebe et al., 2013). The second scenario represents intermittent drought where dry spells happen any time during the growing period and, the third scenario represents predictable drought where common bean plants could be exposed to stress at an early stage of growth but could receive enough water at later stages. The last scenario represents dry, semi-arid climate where the amount of rainfall is relatively low to cover the physiological demand of the crop at any stage of growth (Bernier et al., 2007; Beebe et al., 2013).

Even though the previous research efforts made by the national program in Ethiopia and by other international research institutions have resulted in a release of a number of improved common bean varieties with resistance to drought, the evaluation of the morpho-physiological attributes to drought tolerance in these varieties still remain the subject of investigation. Information on genetic progress achieved over time from breeding efforts for drought tolerance attributes since the early inception of common bean breeding and the morpho-physiological factors of genetic improvement achieved so far from the same efforts have also not been systematically studied. The study was to evaluate genotypic differences in growth, physiological response and yield of the bean genotypes when subjected to post-flowering drought stress.

## MATERIALS AND METHODS

### Description of the study area

The study was carried out at Melkassa Agricultural Research Center located in Central Rift Valley of Ethiopia. The elevation of the center is 1550 m above sea level at 8” '24’ "N latitude and of 39” '21’ "E longitude. Loam and clay loam soil textures are the dominant soil types in the area.

### Experimental materials, procedure and design

The genotypes used for the study were obtained from National Bean Research Project of Melkassa Agricultural Research Center, which consisted of 21 released varieties and 4 inbred lines. The study was conducted from December to May in 2011/2012 at the Research Station. Twenty-five genotypes were laid out in triple lattice design under drought stress and non-stress conditions in three replications. The crop was planted on 10$^{th}$ February, 2012. Each genotypes was grown in two rows of 3 m length kept at 0.6 m apart. The distance between plants within a row was 0.1 m. Plants of both stressed and non-stressed treatments received full irrigation from planting to flowering stage. Drought stress was initiated at late flowering stage (up to 10 days after flowering). The drought stressed plots received irrigation at an interval of 12 to 14 days. The non-stressed plots received irrigations every 6 days until physiological maturity. Other cultural practices used were similar for both growth conditions.

### Parameters measured

Five plants were randomly sampled from the useful area of each split plot, and the following parameters were assessed:

(1) Above ground biomass weight: was determined by adding up various plant part
(2) Leaf area ($cm^2$): was estimated by measuring the maximum length (ML) and width (MW) of leaves and multiplying these by a correction factor of 0.6 derived from the actual leaf area determined by leaf area meter (Setegn, 2006).
(3) Days to 50% flowering (DFF): number of days was taken by each genotype from the day of planting for the day on which 50% of the plants in a plot opened at least one flower per plant.
(4) Days to 90% maturity (DM): Determined as the number of days from date of planting to the date when 90% of the plants in each plot attained physiological maturity.
(5) Pod Harvest Index (PHI %) = [pod weight] / [leaf weight + stem weight +pod weight] x 100
(6) NPPP: Number of pods per plant
(7) NSPP: Number of seeds per pod
(8) 100-seed weight (HSW) (g): weight of hundred randomly sampled seeds from all plants harvested per plot.
(10) Seed yield ($gm^{-2}$): Seed yield was determined as: Seed yield ($gm^{-2}$) = (Seed weight/plot area)
(11) Harvest Index (%): the ratio of seed yield to the above ground dry weight (stem + leaves + pods + seed) at harvest.
(12) Drought susceptibility index (DSI) for seed yield: DSI = (1-Yds/Yns)/DII, where Yds and Yns mean yields of a given genotype in drought stress and non-stress, respectively (Fisher and Maurer, 1978).
(13) Geometric mean (GM): the GM was determined for seed yield

as GM = (ns x ds)$^{1/2}$ where ns and ds are mean of a given genotype in drought stress and non-stress, respectively.

#### Statistical analysis

The analysis of variance was computed for all parameters considered using SAS (v 9.1.3) GLM procedure (SAS Institute, 2004) software to demonstrate the existence of differences among the genotypes under the two growth conditions. Means of the parameters that exhibited significant differences were separated using Duncan's Multiple Range Test (DMRT). The nature and magnitude of associations among the quantitative traits were analyzed using simple correlation test at 5 and 1% probability.

## RESULTS AND DISCUSSION

### Effect of drought stress on biomass production

The effect of drought stress was highly significant for above ground fresh and dry biomass weights at mid pod-fill and harvesting stages (Table 1). The water regime x genotypes interactions term was also significant for both fresh and dry weights at both mid-pod fill and harvesting stages. Relative to non-stress, drought stress caused significant reductions in above ground biomass weight in the range of 12.0 (Gofta) to 41.4% (IBADO) for fresh weight, 7.3 (SB-15945-19) to 58.6% (IBADO) for dry weight at mid pod- fill stage. Higher biomass accumulation in legumes is positively correlated with higher seed yield, while negatively with drought tolerance since genotypes that are water saving are commonly low-yielding. This implies that above ground biomass determines sink establishment and economic yield. These results are in agreement with those obtained by Setegn (2006); Subbarao et al. (1995); Tilahun et al. (2004) and Hinkossa et al. (2013). In addition, common bean genotypes under drought stress responded to drought by leaf movement, leaf shedding, reducing leaf area and inhibition of the expansion of younger leaves (Acosta-Gallegos and Adams, 1991).

### Effect of drought stress on growth

Effect of drought stress on leaf area and days to 90% maturity were highly significant, whereas differences among genotypes were significant for all the four traits (Table 2). Drought induced reduction in leaf area and days to 90% maturity ranged from 7.9% (IBADO) to 54.7% (Atndaba), and 3.5% (Mexican-142) to 9.4% (Dinknesh), respectively. The highest leaf area (790.3 $cm^2$) was recorded for Cranscope, while the lowest (350.0 $cm^2$) for SB-15945-17 under drought stress. The highest number of days to maturity was recorded by Zebra and the lowest by Argene under both growth conditions. Adams et al. (1985) and Hinkossa et al. (2013) similarly reported that under drought stress common bean genotypes respond to drought by leaf movement, leaf shedding, reducing leaf area and inhibition of the expansion of younger leave.

### Effect of drought stress on seed yield and yield components

Although genotypic differences were significant only for harvest index, effect of drought stress was significant on seed yield, as well as harvest index (Table 3). Seed yield of all twenty five genotypes under drought stress were significantly lower than their corresponding non-stress growth conditions. Drought stress caused a significant reduction in seed yield that ranged from 22.6 (Dimtu) to 56.3% (Gofta) (Table 4). Under drought stress, the highest seed yield(125.3 g $m^{-2}$) was recorded for Dimtu, while the lowest (72.5 g $m^{-2}$) for SB-15945-17. Drought events during the seed filling stage can cause major reduction in yield by reducing starch accumulation as a result of limited assimilate partitioning to the developing grain (Hinkossa et al., 2013). Gofta had the highest (1.13) DSI for seed yield, whereas Dimtu had smallest (0.45) DSI for seed yield. Geometric mean (GM) was the highest for Dinknesh (147.5) followed by Dimtu (142.4) and the least was for SB-15945-17 (103.4) (Table 4). These results were similar with those reported by Setegn (2006), Tilahun et al. (2004), Hinkossa et al. (2013) and Yaqoob et al. (2013).

Differences between the watering regimes, among the genotypes and the water regime x genotypes interactions were significant for all seed yield components (Table 5). Drought stress induced reduction in number of pods per plant ranged from 2.4% (Cranscope) to 41.8% (Beshbesh) and number of seeds per pod within a range of 6.0 (Melka dima) to 40.6% (Mexican-142) (Table 6). Drought stress also caused a reduction in hundred seed weight that ranged from 3.3 % (Nazareth-2) to 36.5% (Argene) (Table 6). The amount of yield reduction depends not only on the timing of stress, but also on the severity of the stress (Passioura, 2007). Number of pods per plant is the most variable trait to affect yield in common beans. The studies shown that terminal drought could reduce pod formation, seed setting and seed filling by affecting the source-sink relationships. Tilahun et al. (2004) observed that pods per plant, seeds per pod and hundred seed weight are crucial for producing economic yield, and vary in time scale. Similar results were reported by Hinkossa et al. (2013) and Yaqoob et al. (2013).

### Correlation coefficient analysis

The correlation coefficient among most of the quantitative characters was highly significant under both growth conditions (Table 7). Seed yield was significantly and positively correlated number of pods per plant (r = 0.39), number of seeds per pod (r = 0.32) and hundred seed

**Table 1.** Analysis of variance of above ground dry and fresh weights of common bean genotypes grown under two water regimes and harvested at two developmental stages.

| Source of variation | df | Mid pod-fill stage | | Harvesting stage | |
|---|---|---|---|---|---|
| | | Fresh weight | Dry weight | Fresh weight | Dry weight |
| Replication | 2 | 47302.85 * | 2747.84* * | 430.64 * | 22.66 |
| Block | 4 | 1943.03 | 32.10 | 97.04 | 45.38* |
| Water regime (WR) | 1 | 188009.40** | 15708.17** | 22448.17 ** | 1854.34 ** |
| Genotype (G) | 24 | 6997.74 | 276.18 | 302.92** | 44.45** |
| WR x G | 24 | 1235.99* | 100.34 * | 225.01* | 12.29* |
| Error | 98 | 5600.48 | 200.17 | 127.43 | 13.42 |

*, ** Significant at P ≤ 0.05 and P ≤ 0.01, respectively.

**Table 2.** Analysis of variance for growth and phenological parameters of 25 common bean genotypes grown under two watering regimes.

| Source of variation | df | Leaf area | Days to 50% flowering | Days to 90% maturity |
|---|---|---|---|---|
| Replication | 2 | 35321.58* | 0.83 | 2.67** |
| Block | 4 | 145965.09** | 6.09** | 1.09** |
| Water regime (WR) | 1 | 1123375.74** | 0.81 | 826.03** |
| Genotype (G) | 24 | 78059.28** | 15.47** | 17.38** |
| WR x G | 24 | 20724.28** | 0.35 | 2.46** |
| Error | 98 | 10337.65 | 1.06 | 0.44 |

*, ** Significant at P ≤ 0.05 and P ≤ 0.01, respectively.

**Table 3.** Mean square of yield and harvest index of 25 common bean genotypes grown under two water regimes harvested at maturity stage.

| Source Of variation | Df | Seed yield | Harvest index |
|---|---|---|---|
| Replication | 2 | 229.81 | 308.24 ** |
| Block | 4 | 532.64 | 24.82 |
| Water regime (WR) | 1 | 229790.94** | 4895.18** |
| Genotype (G) | 24 | 395.81 | 111.54** |
| WR × G | 24 | 607.26** | 71.77** |
| Error | 98 | 638.05 | 36.68 |

**significant at P ≤ 0.01.

weight (r = 0.41) under stressed condition, while seed yield was positively correlated with days to 90% maturity (r = 0.19), under non-stressed condition (Table 7). Similarly, Szilagyi (2003) reported that correlation coefficients between the non-stress and drought stress were positive and highly significant for seed yield, number of pods per plant, 100-seed weight, and days to maturity. This indicated that number of pods per plant, number of seeds per pod, hundred seed weight and days to maturity have positive effect on seed yield.

## Conclusion

Accurate identification and detection of drought tolerance common beans genotype is the cornerstone for drought-prone areas. The study demonstrated that Dimtu was the most drought resistant genotype, produced the highest seed yield under drought stress. In contrast, SB-15945-17 had the lowest seed yield under drought stress, and this genotype can be considered the most drought-susceptible of all the genotypes. Although evaluation of drought resistance in common bean using the qualitative and quantitative traits remains an effective method, morphological comparisons have some limitations, including the influence of environment, subjectivity in the character evaluation and management practice. Therefore, complementary evaluation using appropriate molecular markers such as Amplified Fragment Length Polymorphism (AFLP) and Simple Sequence Repeat

**Table 4.** Effect of drought stress on seed yield and harvest index and seed yield based DSI and GM in 25 common bean genotypes grown at Melkassa.

| Genotype | Seed yield (g $m^{-2}$) | | | | | Harvest Index (%) | | |
|---|---|---|---|---|---|---|---|---|
| | Non-stress | Drought stress | % reduction | DSI | GM | Non-stress | Drought stress | % Reduction |
| Argene | 165.7$^{c-e}$ | 101.6$^{a-d}$ | 38.7 | 0.78 | 129.6 | 51.1$^{cd}$ | 42.9$^{c-f}$ | 16.0 |
| Atndaba | 171.7$^{d}$ | 79.1$^{d}$ | 53.9 | 1.08 | 116.5 | 74.1$^{a}$ | 46.9$^{b-e}$ | 36.7 |
| Awash melka | 183.0$^{bc}$ | 110.5$^{a-d}$ | 39.6 | 0.80 | 142.2 | 49.0$^{d}$ | 43.6$^{b-f}$ | 11.0 |
| Awash-1 | 170.1$^{cd}$ | 96.9$^{a-d}$ | 43.0 | 0.88 | 128.4 | 51.9$^{cd}$ | 42.3$^{c-f}$ | 18.5 |
| Beshbesh | 191.1$^{b}$ | 85.7$^{cd}$ | 55.2 | 1.10 | 127.9 | 55.1$^{b-d}$ | 46.0$^{b-e}$ | 16.5 |
| Chercher | 166.8$^{c-e}$ | 117.8$^{a-c}$ | 29.4 | 0.58 | 140.2 | 65.9$^{b}$ | 46.3$^{b-e}$ | 29.7 |
| Chore | 193.8$^{a}$ | 88.2$^{b-d}$ | 54.5 | 1.08 | 130.7 | 49.8$^{d}$ | 39.1$^{c-f}$ | 21.5 |
| Cranscope | 190.2$^{ab}$ | 85.9$^{cd}$ | 54.8 | 1.10 | 127.8 | 54.1$^{b-d}$ | 47.6$^{b-e}$ | 12.0 |
| Dimtu | 161.9$^{de}$ | 125.3$^{a}$ | 22.6 | 0.45 | 142.4 | 62.0$^{a-d}$ | 47.7$^{b-e}$ | 23.1 |
| Dinknesh | 194.7$^{a}$ | 111.8$^{a-d}$ | 42.6 | 0.86 | 147.5 | 58.6$^{b-d}$ | 45.4$^{b-f}$ | 22.5 |
| Gofta | 188.8$^{a-c}$ | 82.5$^{cd}$ | 56.3 | 1.13 | 124.8 | 50.2$^{d}$ | 45.4$^{b-f}$ | 9.6 |
| IBADO | 164.9$^{c-e}$ | 88.5$^{b-d}$ | 46.3 | 0.92 | 120.8 | 49.8$^{d}$ | 44.4$^{b-f}$ | 10.8 |
| Melka dima | 181.7$^{bc}$ | 79.7$^{d}$ | 56.2 | 1.12 | 120.3 | 66.2$^{b}$ | 37.2$^{ef}$ | 43.8 |
| Melkie | 167.9$^{c-e}$ | 99.2$^{a-d}$ | 40.9 | 0.82 | 129.1 | 60.8$^{a-d}$ | 47.0$^{b-e}$ | 22.7 |
| Mexican-142 | 187.3$^{a-c}$ | 93.3$^{a-d}$ | 50.2 | 1.02 | 132.2 | 56.5$^{b-d}$ | 35.6$^{f}$ | 36.9 |
| Nasir | 170.3$^{cd}$ | 99.6$^{a-d}$ | 41.5 | 0.84 | 130.2 | 61.3$^{a-d}$ | 57.9$^{a}$ | 5.5 |
| Nazareth-2 | 175.8$^{b-d}$ | 100.7$^{a-d}$ | 42.7 | 0.86 | 133.1 | 57.2$^{b-d}$ | 43.6$^{b-f}$ | 23.8 |
| Red wolayita | 160.5$^{de}$ | 124.1$^{ab}$ | 22.7 | 0.46 | 141.1 | 60.1$^{a-d}$ | 49.1$^{a-c}$ | 18.3 |
| Roba-1 | 166.6$^{c-e}$ | 75.3$^{d}$ | 54.8 | 1.10 | 112.0 | 53.6$^{b-d}$ | 44.4$^{b-f}$ | 17.2 |
| Tabor | 167.7$^{c-e}$ | 94.6$^{a-d}$ | 43.6 | 0.88 | 125.9 | 54.4$^{b-d}$ | 46.6$^{b-e}$ | 14.3 |
| Zebra | 175.3$^{b-d}$ | 100.9$^{a-d}$ | 42.4 | 0.84 | 132.9 | 52.3$^{b-d}$ | 45.9$^{b-f}$ | 12.2 |
| SB-15945-14 | 190.7$^{ab}$ | 98.6$^{a-d}$ | 48.3 | 0.96 | 137.1 | 56.9$^{b-d}$ | 38.3$^{d-f}$ | 32.7 |
| SB-15945-15 | 172.3$^{d}$ | 91.3$^{a-d}$ | 47.0 | 0.94 | 125.4 | 50.4$^{d}$ | 44.4$^{b-f}$ | 11.9 |
| SB-15945-17 | 147.5$^{e}$ | 72.5$^{e}$ | 50.8 | 1.02 | 103.4 | 52.6$^{b-d}$ | 38.0$^{b-d}$ | 27.8 |
| SB-15945-19 | 165.9$^{c-e}$ | 91.2$^{a-d}$ | 45.0 | 0.90 | 123.0 | 61.2$^{a-d}$ | 54.0$^{ab}$ | 11.8 |
| Means | 174.9 | 96.6 | 44.8 | 0.90 | 129.9 | 56.6 | 45.2 | 20.1 |
| LSD ($P \le 0.05$) | 2.2 | 1.2 | | | | 2.1 | 0.4 | |
| CV (%) | 7.8 | 6.4 | | | | 4.35 | 9.41 | |

Means within the same column followed by similar letters are not significantly different according to DMRT at 5% level of probability, DSI = drought susceptibility index, GM =geometric mean.

**Table 5.** Mean squares of seed yield components of 25 common bean genotypes grown under two water regimes at Melkassa.

| Source of variation | df | Number of pods per plant | Number of seeds per pod | 100-seed weight |
|---|---|---|---|---|
| Replication | 2 | 25.89 | 1.28 * | 0.18 |
| Block | 4 | 84.28 * | 0.61 | 422.89** |
| Water regime (WR) | 1 | 2884.67** | 100.21** | 424.37** |
| Genotype (G) | 24 | 87.81 ** | 0.87** | 265.71 ** |
| WR x G | 24 | 16.48 * | 0.63 * | 13.63** |
| Error | 98 | 28.21 | 0.36 | 4.69 |

*, ** Significant at $P \le 0.05$ and $P \le 0.01$, respectively.

(SSR) markers is needed to identify better varieties suitable for drought-prone areas. Understanding the genetics of drought tolerance, and having DNA markers linked to drought tolerance genes will help plant breeders to combine drought tolerance with other traits desired by farmers.

**Table 6.** Effect of drought stress on seed yield components of common bean genotypes grown at Melkassa.

| Genotype | Number of pods per plant | | | Number of seeds per pod | | | 100-seed weight (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Non-stress | Drought stress | % reduction | Non-stress | Drought stress | % reduction | Non-stress | Drought stress | % reduction |
| GX-1175-3 | $27.7^{cd}$ | $18.9^{d}$ | 31.8 | $5.4^{c-f}$ | $4.7^{a-c}$ | 12.9 | $27.3^{e}$ | $24.1^{e-g}$ | 11.7 |
| STTT-165-92 | $31.5^{a-d}$ | $23.0^{a-d}$ | 26.9 | $6.1^{a-e}$ | $4.7^{a-c}$ | 22.9 | $19.9^{i-k}$ | $18.1^{j-m}$ | 9.0 |
| AR04GY | $39.6^{ab}$ | $30.9^{a}$ | 21.9 | $6.1^{a-e}$ | $4.2^{a-c}$ | 31.1 | $23.0^{f-i}$ | $14.6^{m}$ | 36.5 |
| TA04JI | $37.6^{a-c}$ | $30.3^{ab}$ | 19.4 | $6.2^{a-d}$ | $4.4^{a-c}$ | 29.0 | $19.0^{jk}$ | $18.4^{j-m}$ | 3.2 |
| AFR-722 | $26.7^{cd}$ | $23.1^{a-d}$ | 13.5 | $5.2^{d-f}$ | $4.3^{a-c}$ | 17.3 | $47.2^{a}$ | $44.4^{a}$ | 5.9 |
| DOR-554 | $25.3^{d}$ | $22.3^{a-d}$ | 11.9 | $5.6^{b-f}$ | $4.1^{a-c}$ | 26.8 | $23.3^{f-i}$ | $22.2^{f-j}$ | 4.7 |
| Red wolayita | $30.9^{a-d}$ | $23.1^{a-d}$ | 25.2 | $6.4^{a-d}$ | $3.9^{c}$ | 39.1 | $22.2^{f-j}$ | $20.3^{g-l}$ | 8.6 |
| G-11239 | $33.9^{a-d}$ | $26.0^{a-d}$ | 23.3 | $6.4^{a-d}$ | $3.8^{c}$ | 40.6 | $17.7^{k}$ | $16.3^{lm}$ | 7.9 |
| SB-15945-15 | $28.9^{b-d}$ | $18.4^{d}$ | 36.3 | $6.9^{ab}$ | $4.1^{a-c}$ | 40.6 | $21.8^{f-j}$ | $21.2^{f-k}$ | 2.8 |
| SB-15945-17 | $32.7^{a-d}$ | $20.2^{b-d}$ | 38.2 | $6.5^{a-d}$ | $4.3^{a-c}$ | 33.8 | $18.9^{jk}$ | $17.6^{k-m}$ | 6.9 |
| SB-15945-19 | $28.1^{cd}$ | $18.1^{d}$ | 35.6 | $6.7^{a-c}$ | $5.1^{a}$ | 23.9 | $19.4^{i-k}$ | $17.8^{j-m}$ | 8.2 |
| Cross 5 | $37.6^{a-c}$ | $21.9^{a-d}$ | 41.8 | $5.9^{a.f}$ | $4.8^{a-c}$ | 18.6 | $20.9^{h-k}$ | $19.3^{i-l}$ | 7.7 |
| Mean | 30.8 | 22.1 | 28.2 | 5.9 | 4.3 | 27.1 | 26.1 | 22.7 | 13.0 |
| LSD (P ≤ 0.05) | 1.9 | 1.5 | | 2.4 | 1.4 | | 4.9 | 2.7 | |
| CV (%) | 6.17 | 9.16 | | 3.50 | 4.03 | | 2.6 | 5.08 | |

Means within the same column followed by similar letters are not significantly different according to DMRT at 5% level of probability.

**Table 7.** Correlation coefficient among eight quantitative traits of common bean genotypes grown under non-stress (above the diagonal) and drought stress (below the diagonal) conditions at Melkassa Agricultural Research Center.

| Variables | DFF | DM | PHI | NPPP | NSPP | HSW | SY | HI |
|---|---|---|---|---|---|---|---|---|
| DFF | 0.00 | 0.45** | -0.00 | 0.05 | 0.17 | -0.31 | 0.09 | -0.04 |
| DM | 0.43** | 0.00 | -0.05 | -0.06 | 0.06 | -0.05 | 0.19* | -0.11 |
| PHI | -0.02 | -0.10 | 0.00 | -0.01 | -0.06 | 0.08 | -0.22* | 0.55** |
| NPPP | 0.11 | -0.07 | -0.08 | 0.00 | 0.19* | 0.33** | 0.06 | 0.05 |
| NSPP | 0.29* | 0.25* | -0.12 | -0.05 | 0.00 | -0.47 | -0.11 | -0.05 |
| HSW | -0.23* | 0.05 | 0.03 | -0.15 | -0.22** | 0.00 | 0.08 | 0.07 |
| SY | 0.04 | -0.08 | -0.13 | 0.39* | 0.32* | 0.41* | 0.00 | -0.18 |
| HI | -0.08 | -0.04 | 0.18 | 0.54 | 0.29* | 0.20* | 0.15 | 0.00 |

* Significant at P ≤ 0.05, ** Significant at P ≤ 0.01. DFF = Days to 50% flowering, DM = Days to 90% maturity, PHI = Pod harvest index, NPPP = Number of pods per plant, NSPP = Number of seeds per pod, HSW =100-seed weight, SY =Seed yield, HI = Harvest index.

## Conflict of interests

The authors have not declared any conflict of interests.


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# Effect of hydro and osmo priming on yield and yield components of Chickpea (*Cicer arietinum* L.)

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**A field study was conducted at Debre Zeit Agricultural Research center station under rain fed condition with the objectives to determine the effect of seed priming for improving chickpea variety productivity and to determine the effectiveness of seed priming treatment and variety on stand establishment. The experimental factors were laid out in RCBD with three replications. The study indicated that all the phenological and growth traits significantly differed as a result of priming treatment and variety. With respect to yield and yield related traits, only seed yield kgha$^{-1}$, harvest index (%), seeds plant$^{-1}$ and seeds pod$^{-1}$ were significantly affected by the main effect. While, the rest of yield related traits responded differently due to variety alone. However, all variables studied in the field were not significantly affected by the interactions of the main effects. Improvement made due to main effect hydro and osmopriming was statistically similar for all phenological traits; seeds plant$^{-1}$ and seeds pod$^{-1}$ was considerably improved as a result of osmopriming than hydropriming. However, plant height, stand count at emergence and at harvest, seed yield kg ha$^{-1}$ were substantially increased by 7, 10, 12 and 15%, respectively as a result of water priming over the control. Therefore, from present study, it can be concluded that hydropriming can step-up economical benefit of chickpea growing farmers.**

**Key words:** Chickpea, hydropriming, osmopriming, productivity, seed priming.

## INTRODUCTION

Chickpea (*Cicer arietinum* L.) is 98 to 99% self-pollinated (Singh, 1987); diploid species having basic chromosome number of 16 and belongs to family Leguminasae (Poehlman and Sleper, 1995). It is one of the cool season food legume crops of Ethiopia which is mainly grown in the central, Northern and Eastern high land area of the country where the mean annual rainfall and altitude, respectively range from 700-2000 and 1400-2300 m. a. s. l. (Geletu, 1994).

Ethiopia shares 2% among the most chickpea producing countries following India (64%), Turkey (8%) and Pakistan (7%) (ICRISAT, 2004). Within 2002 and 2004, the global chickpea production was 8.0 million tons from an area of 10.1 million hectares giving an average productivity of 0.79 ton ha$^{-1}$ (ICRISAT, 2006).

Two types of chickpea are cultivated in the world viz.

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**Table 1.** Description of chickpea varieties used for the study.

| S/N | Chickpea varieties | Year of release | Seed color | Type/category |
|---|---|---|---|---|
| 1 | DZ-10-4 (local) | 1974 | White | Kabuli |
| 2 | Arerti | 1999 | White | Kabuli |
| 3 | Habru | 2004 | White | Kabuli |
| 4 | DZ-10-11(Local) | 1974 | Light Brown | Desi |
| 5 | Akaki | 1995 | Golden | Desi |
| 6 | Natoli | 2007 | Light Golden | Desi |

Source: MoAD (2008), and Menale et al. (2009).

the Desi and the Kabuli types. Both types of chickpea are grown in Ethiopia whilst unimproved local Desi variety being the most widely is grown in all places (Muehlbauer and Abebe, 1997).

In Ethiopia, most of the production is used for domestic consumption. Chickpea seed can be eaten as green vegetable (eshet), roasted (kollo), boiled (nifro) and dry vegetable. The flour of chickpea is also used to make 'shimbra asa', popular dish during fasting time. Flour of roasted chickpea seeds (shiro) are used to make shiro wot (sauce) and taken with injera (bread). Chickpea can also improve the soil fertility through biological nitrogen fixation and intercropped with cereals. Despite this fact, however, the yield of chickpea in Ethiopia is still low which can be attributed to biotic and abiotic factors (Geletu and Yadeta, 2002).

The major abiotic stresses contributing to the greatest source of variation of seed yield in chickpea are cold, heat and drought. Out of these, drought is the major and usual limiting factor as chickpea is essentially grown after the rainy season on residual soil water, which often exposes the crop to terminal drought (Geletu and Yadeta, 2002). This synonym has been described as in the semi-arid tropics, crops often fail to establish quickly and uniformly, leading to decreased yield because of low plant populations (Clark et al., 2001)

Despite chickpea plant can produce extra vegetative growth (in a favorable moisture regime) to cover available space, poor plant stands and stunted growth are often a major cause of low seed yields in semiarid environments (Saxena, 1987).

Resource-poor farmers often lack the means to optimize seed bed conditions before sowing and they are particularly at risk from adverse weather after sowing. Moreover, for farmers who grow annual crops from seed, good stand establishment is of paramount importance because patchy stands due to uneven germination result in low yields and often crop failure (Khan et al., 2008 Therefore, one way of improving productivity of chickpea in drought prone area is seed priming. Priming is a procedure that partially hydrates seed, followed by drying of seed, so that germination processes begin, but radical emergence does not occur. It includes soaking seed in water or osmotic solution, and intermixture with porous matrix material (Ghana and William, 2003).

Improvement of seed quality by physiological treatments is a simple, easy and impressive approach to enhance seed performance and agricultural productivity (Basu, 1994). For most crops mean yield increases due to priming range from zero to more than 200%, with an overall average increase of 30% (Harris, 2004).

On-farm priming of seeds of a range of tropical and sub-tropical crops have been tested as a means to promote rapid germination and emergence and to increase seedling vigor and hence yield (Harris, 2004).

It has been reported that seed priming trials in western India increased chickpea yield and those of other rain fed crops (Harris et al., 1999). Therefore, the present study was initiated with the objectives to determine the effect of seed priming for improving chickpea varieties productivity and to determine the effectiveness of seed priming treatment and variety on stand establishment.

## MATERIALS AND METHODS

### Description of the experimental site

The experiment was carried out at Debre Zeit Agricultural Research Center on station. The center is located at 47 km South East of Addis Ababa at 8° 44´N Latitude and 38° 58´ E Longitude at an elevation of 1980 m.a.s.l. The mean annual rain fall recorded at the station is 851 mm and the average annual minimum and maximum temperatures are 8.9 and 28.3°C respectively (Wikipedia, 2012).

### Experimental material, treatments and design

The experiment was conducted on six chickpea varieties released at different year (Table 1). The seed of six chickpea varieties produced in the same production year were obtained from National Chickpea Improvement Program, Debre Zeit Agricultural Research Center. The two priming treatments viz. water and 0.5% $KH_2PO_4$ were applied for 8 h. In addition, in one sample no treatment was applied. The primed treatments were prepared in distilled water. After 8 h soaking, primed seed of each variety was dried slowly at ventilated room.

### Experiment

Experimental design was two factors factorial in RCBD (chickpea varieties and priming media) with three replications. Seeds were sown in about 5 to 7 cm depth with a density of 33 seeds $m^{-2}$. Each plot consisted of four rows with 4 m length and, spaced 30 cm apart between rows and 10 cm space between each plant within the rows. And data were taken from two central rows of net area of 2.4 $m^2$.

#### Phenological data

**Days to 50% emergence:** It was recorded as the number of days taken from sowing up to 50% of seedling emergence from each plot.

**Days to 50% flowering:** The date on which 50% of the total plants flowered in the plot was recorded. The number of days taken to 50% flowering was computed from the date of sowing till 50% of the plants attained flowering.

**Days to 90% physiological maturity:** It was recorded as the number of days from the day of planting to the date when 90% of the plants attained physiological maturity in each plot.

#### Growth parameters

**Plant height (cm):** Plant height was measured in centimeters from ground level to the plant tip at physiological maturity using ten plants taken randomly from each plot.

**Stand count at emergence and at harvest:** Total numbers of plants in the two central rows were counted at emergence and at physiological maturity from the entire net area of each plot.

#### Yield and yield associated characters

Ten plants in the two central rows were taken randomly from each plot in all cases for yield and yield associated character data collection.

**Number of primary branches per plant:** Branches that grow from the main stem are primary branches. Number of primary branches per plant was obtained by dividing total number of primary branches from ten plants by ten.

**Number of secondary branches per plant:** Branches which grow from Primary branches are secondary branches. Numbers of secondary branches per plant were obtained by dividing total number of secondary branches from ten plants by ten.

**Number of pods per plant:** Number of pods per plant was computed by dividing total number of pods obtained from ten plants by ten.

**Number of seeds per plant:** Number of seeds per plant was calculated by dividing total number of seeds from ten plants by ten.

**Number of seeds per pod:** Number of seed(s) per pod was recorded by dividing total number of seeds from ten plants by total number of pods from ten plants.

**100 seed weight (g):** It was taken by weighing 100 seeds drawn randomly from the grain yield obtained from each experimental plot.

**Above ground biomass (yield kg $ha^{-1}$):** The weight in grams was recorded by weighing the total above ground biomass harvested from the two central middle rows from each experimental plot after air dried and was converted to get biomass yield per hectare.

**Seed yield (kg $ha^{-1}$):** Seed yield obtained in grams from each experimental plot's central two rows (2.4 $m^{2)}$ and was converted to get seed yield per hectare.

**Harvest index (%):** It was calculated as a ratio of total seed yield to total above ground biomass yield harvested from the two middle rows.

#### Data analysis

The collected data were subjected to statistical analysis as per the design using Statistical Analysis System (SAS, 2001) computer software. Where significant differences were detected, the mean separations were carried out using the least significant differences (LSD) at 0.05 level of probability. Linear correlations between yield and yield associated traits were calculated using SAS computer software.

## RESULTS AND DISCUSSION

### Phenological parameters

The results on phenological data as influenced by pre-sowing invigoration chickpea seed treatments as presented in Table 2.

### Days to 50% emergence

The difference between primed and non-primed seed for days to 50% emergence was significant (Table 2). Osmopriming found to decrease days to 50% emergence by17% as compared untreated while, hydro priming reduced days to 50% flowering by 16%. However, seed treated with water and 0.5% $KH_2PO_4$ recorded almost the same number of days for days to 50% of emergence. This is because primed seed will require little further imbibitions before the germination process starts, thus less time is required for the seed to germinate (Murungu and Madanzi, 2010). In such a way that it might have reduced the number of days required for seedling emergence.

Emergence enhancement in osmoprimed seed may be attributed to metabolic repair processes, a buildup of germination metabolites or osmotic adjustments during priming treatment (Bray et al., 1989). This finding agreed with Arif et al. (2008) who reported that seed priming hastened and improved days to 50% emergence of soybean seed with deionized water and PEG-8000 (300 g/L) by priming for 6 h. In agreement with this finding, several other reports showed improved and early seedling emergence in common bean as a result of water priming (Harris, 1996; Harris et al., 1999).

Variety also responded differently to the priming media at $p<0.05$. Among all varieties, least days were taken to emerge for DZ-10-4 variety but it was not significantly

**Table 2.** Effect of varieties and Priming treatments on days to 50% emergence, days to 50% flowering, days to 90% physiological maturity, plant height, stand count at emergence and harvest.

| Treatments | Phenological, growth and growth related traits | | | | | |
|---|---|---|---|---|---|---|
| | Days to 50% emergence | Days to 50% flowering | Days to 90% physiological maturity | plant height | Stand count at emergence | stand count at harvest |
| **Varieties** | | | | | | |
| DZ-10-4 | 7.11$^{b}$ | 44.56$^{c}$ | 115.00$^{b}$ | 42.24$^{b}$ | 49.33$^{b}$ | 44.56$^{b}$ |
| Arerti | 7.56$^{ba}$ | 54.67$^{a}$ | 120.33$^{a}$ | 41.11$^{bc}$ | 59.44$^{a}$ | 56.00$^{a}$ |
| Habru | 7.56$^{ba}$ | 37.78$^{e}$ | 110.56$^{d}$ | 44.29$^{a}$ | 57.11$^{a}$ | 55.11$^{a}$ |
| DZ-10-11 | 7.78$^{a}$ | 40.67$^{d}$ | 112.22$^{c}$ | 39.76$^{c}$ | 57.56$^{a}$ | 54.00$^{a}$ |
| Akaki | 8.00$^{a}$ | 48.89$^{b}$ | 112.11$^{c}$ | 36.02$^{e}$ | 55.22$^{ba}$ | 51.00$^{ab}$ |
| Natoli | 7.89$^{a}$ | 48.33$^{b}$ | 108.78$^{e}$ | 38.10$^{d}$ | 60.33$^{a}$ | 57.22$^{a}$ |
| **LSD** | 0.53 | 2.57 | 1.53 | 1.61 | 6.234 | 6.476 |
| **F-test** | * | ** | ** | ** | * | ** |
| **Priming media** | | | | | | |
| Control | 8.61$^{a}$ | 46.89$^{a}$ | 114.89$^{a}$ | 39.16$^{b}$ | 55.06$^{b}$ | 50.83$^{b}$ |
| Water | 7.25$^{b}$ | 44.44$^{b}$ | 112.83$^{b}$ | 41.96$^{a}$ | 60.72$^{a}$ | 57.11$^{a}$ |
| $KH_2PO_4$ (0.5%) | 7.11$^{b}$ | 46.11$^{a}$ | 111.78$^{b}$ | 39.65$^{b}$ | 53.72$^{b}$ | 50.50$^{b}$ |
| **LSD** | 0.3748 | 1.619 | 1.084 | 1.139 | 4.408 | 4.579 |
| **F-test** | ** | * | ** | ** | ** | ** |
| **CV(%)** | 7.234 | 5.216 | 1.414 | 4.176 | 11.52 | 12.758 |

*, **, significant at p≤0.05 and p≤0.01, respectively. Figure sharing the same letter in each column are not different statistically and those having different letter in the same column are significantly different from each other.

different from Arerti and Habru. In addition, DZ-10-11, Akaki and Natoli varieties had similar effect for days to 50% emergence and these were (Desi type) delayed for days to 50% emergence as compared to the Kabuli type of chickpea varieties used for this study. The interaction between the two factors (variety × priming medium) for days to 50% emergence was not significant. It was in conformity with the finding of Finch-savage et al. (2004) who reported that the variable response in maize seed to priming may be explained by the different varieties used, during seed soaking which may be amplified by wet conditions in poorly draining soils and high temperature during sowing. However, in the present study poor drainage during sowing was not limiting factor.

## Days to 50% flowering

The days to 50% flowering differed significantly due to invigoration seed treatments. Water treatments took significantly lesser days for 50% flowering by 2.5 days compared to unprimed seed which may be due to better early and faster emergence. While, the seeds treated with 0.5% $KH_2PO_4$ and untreated recorded almost equal number of days for 50% flowering (Table 2). This findings is as per with Musa et al. (1999) who found that seed priming resulted in earlier crop flowering on chickpea. Narayanareddy (2008) also found that seed water hydration decreased days to 50% flowering by two days over untreated control. The advantages of increased rate of emergence could be correlated with early flowering and early harvest observed in the present study. A similar observation in advancement of flowering was also reported by Basu (1999) in maize and rice. There were also significant differences among the varieties response for days to 50% flowering (Table 2). The least days taken for Habru 50% flowering whereas the highest days taken for Arerti 50% flowering. Next to Arerti, DZ-10-4 and DZ-10-11 respectively showed delay in 50% flowering. But the variety Akaki and Natoli had similar days for 50% flowering (Table 2). The interaction of variety x priming was not significantly different for days to 50% flowering.

## Days to 90% physiological maturity

The results on days to 90% physiological maturity as influenced by pre-sowing invigoration seed treatments are presented in Table 2. With respect to days to 90% physiological maturity, priming treatment and variety significantly ($P < 0.01$) affected time to 90% physiological maturity but there were no significant interactions observed. Both hydro and osmo invigoration seed treatments took significantly lesser days to physiological maturity compared to untreated control. The seeds treated with 0.5% $KH_2PO_4$ recorded lesser number of days to physiological maturity and it was harvested three days earlier than unprimed one. However, hydro and osmopriming failed to show significant differences between themselves for days to 90% physiological maturity. Primed chickpea seed had lesser days for days to 90% physiological maturity than non-primed seed, agreeing with the findings of Musa et al. (2001) who found earlier maturity in chickpea by soaking seeds for 8 h in water in which the primed one harvested 3 to 7 days earlier than unprimed one. Harris et al. (1999) also found that seed priming resulted in earlier crop maturity on chickpea. In general, the enhanced phenology in the chickpea due to priming is associated with faster emergence and reduction of imbibition periods (Harris et al., 1999).

Regarding the responses of varieties to days to 90% physiological maturity, Natoli attained physiological maturity earlier than any other variety and followed by Habru while, Arerti had the longest days for days to 90% physiological maturity. However, DZ-10-11 and Akaki attained physiological maturity equally where as an intermediate result was recorded for DZ-10-4 variety for physiological maturity (Table 2). This finding is in conformity with the findings of Murungu and Madanzi (2010) who found difference in response among wheat variety as a result of seed treatments.

## Growth and growth related parameters

### *Plant height (cm)*

The data on plant height (cm) at harvest as influenced by pre-sowing invigoration seed treatments are presented in Table 2. Significant differences were observed ($p<0.01$) due to invigoration seed treatments and varieties for plant height at harvest but there was no interaction effect for seed priming x variety. Water treated seeds were significantly higher by 2.8 cm or 7% for plant height at harvest over untreated control. However, the seeds treated with 0.5% $KH_2PO_4$ and unprimed recorded statistically similar plant height at harvest.

The enhanced plant height as a result of seed priming might be due to cell enlargement and increase in normal cell division (Karivaratharaju and Ramakrishnan, 1985). The better crop growth due to seeds treatment may also be attributed to the fact that treatments activate the synthesis of proteins, RNA, free amino acids and soluble sugars in the first phase of germination which could be advantages for subsequent phases of growth (Jyotsna and Srivastava, 1998). The enhancement of plant height may also be due to the improvement and faster plant emergence in invigorated seeds which might have created cooperative competition among the plants for light and resulted in taller plants. The result is in agreement with the result of Harris et al. (1999), who observed taller plants with seed invigoration. Similar findings were also observed by Musa et al. (2001) in chickpea upon hydro seed priming.

Effects of variety on the plant height was highly significant ($p<0.01$) in which Habru and Akaki produced the tallest and the shortest plant height, respectively among the varieties used for the study (Table 2). The two Kabuli type, namely DZ-10-4 and Arerti had similar plant height at harvest but both of these recorded higher plant height at harvest than all the varieties except Habru. In general Kabuli type of chickpea varieties attained higher plant height at harvest than the Desi type of chickpea varieties tested currently.

## Stand count at emergence and at harvest

The results of both stand count at emergence ($p<0.05$) and at harvest ($p<0.01$) were observed significantly different as affected by seed treatment, variety though their interactions were not significant at $p<0.05$. Water primed seeds recorded an increase of 10 and 12% over the control for stand count at emergence and stands count at harvest respectively. However, there was no significant difference between osmopriming and unprimed for both stand count at emergence and at harvest (Table 2).

This outcome is in agreement with other authors' findings. For example, Musa et al. (2001) reported that numbers of plants at harvest were increased by 10% due to water seed priming in chickpea. Similar result was also reported by Manigopa et al. (2007) in which seed priming increased the number of plants at harvest by 12.8% in chickpea (*Cicer arietinum* L.).

With respect to effect of variety for stand count at emergence and harvest, the Variety DZ-10-4 differed significantly from all other varieties tested for the study except Akaki variety. Stand count at emergence and at harvest for the varieties Arerti, Habru, DZ-10-11, Akaki and Natoli were all at par (Table 2).

## Yield and yield associated parameters

### *Seed yield and biomass yield*

The difference between primed and non-primed seed plots for seed yield kg $ha^{-1}$ was significant at $p<0.05$ and varieties were also responded differently with respect to seed yield and biomass yield kg $ha^{-1}$ at $p<0.01$. The interaction between the two factors namely seed priming x variety for improvement of chickpea seed yield was not significant (Table 3). Seed yield obtained from the primed seed plots were significantly higher than non-primed seed plots. Seed yield was enhanced with water and 0.5% $KH_2PO_4$ priming treatments by 15 and 3% respectively as compared to unprimed. In addition, seed priming by water showed an increase of 11% seed yield improvement over

**Table 3.** Effect of varieties and priming treatments on seed yield, biomass yield, harvest index, 100 seed weight, number of pods per plant, number of seeds per plant, number of seed(s) per pod, number of primary branches and secondary branches.

| Treatments | yield and yield associated traits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Seed yield (kg/ha)** | **Biomass yield (kg/ha)** | **Harvest Index (%)** | **100 seed weight** | **Number of pods per plant** | **Number of seeds per plant** | **Number seeds per pod** | **Number of primary branches** | **Number of secondary branches** |
| **Varieties** | | | | | | | | | |
| DZ-10-4 | 1873.9[d] | 3918.6[b] | 48.33[d] | 11.59f | 57.02[a] | 90.6[a] | 1.57[a] | 3.53[a] | 10.87[ab] |
| Arerti | 2596.9[b] | 3864.3[b] | 66.85[a] | 25.56[c] | 51.03[ba] | 57.6[b] | 1.13[d] | 2.78[bc] | 12.11[a] |
| Habru | 2257.2[bc] | 4042.9[b] | 56.05[c] | 33.39[a] | 36.41[c] | 42.6[c] | 1.17[d] | 3.64[a] | 6.93[c] |
| DZ-10-11 | 2083.4[dc] | 3715.0[b] | 55.91[c] | 12.66[e] | 59.8[a] | 84.7[a] | 1.41[b] | 3.83[a] | 12.36[a] |
| Akaki | 2203.2[dc] | 3953.6[b] | 55.83[c] | 20.9[d] | 43.88[bc] | 57.5[b] | 1.33[bc] | 2.76[c] | 10.32[ab] |
| Natoli | 3064.1[a] | 5135.2[a] | 59.83[b] | 29.03[b] | 46.02[c] | 56.6[b] | 1.25[cd] | 3.39[ab] | 8.93[bc] |
| **LSD** | 343.26 | 601.56 | 3.74 | 0.7084 | 9.7824 | 13.245 | 0.1509 | 0.615 | 2.650 |
| **F-test** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| **Priming media** | | | | | | | | | |
| Control | 2212.6[b] | 4042.2 | 54.89[b] | 22.08 | 47.51 | 58.87[b] | 1.22[b] | 3.18 | 9.88 |
| water | 2541.8[a] | 4107.6 | 61.60[a] | 22.21 | 48.28 | 60.58[b] | 1.25[b] | 3.36 | 10.26 |
| $KH_2PO_4$ (0.5%) | 2285.0[b] | 4164.9 | 54.90[b] | 22.27 | 51.29 | 75.38[a] | 1.46[a] | 3.42 | 10.63 |
| **LSD** | 242.72 | 425.37 | 3.74 | 0.501 | 6.917 | 9.53 | 0.047 | 0.435 | 1.87 |
| **F-test** | * | Ns | ** | Ns | Ns | ** | ** | Ns | Ns |
| **CV(%)** | 15.27 | 15.30 | 6.84 | 3.33 | 20.83 | 22.43 | 5.46 | 19.33 | 26.98 |

ns,*, **, non-significant at p<0.05, significant at p<0.05 and p<0.01 respectively. Figures sharing the same letters in each column are not different statistically and those having different letters in the column are significantly different from each other.

that of 0.5% $KH_2PO_4$ seed priming. However, seed yield obtained with osmopriming as well as that of the control were not different statistically (p>0.05) (Table 3).

The improvement in yield of primed seed plots may be due to early and improved emergence and early floral initiation in the priming treatments that ultimately resulted in the higher yield. It had been also hypothesized that faster emergence from seed priming would result in better resource utilization and allow more time for optimal growth and grain filling resulting in higher yield (Murungu and Madanzi, 2010). In addition to these, the effect of seed priming on the chickpea seed yield and its components is evidenced first in better and faster seedling establishment, earlier flowering and earlier maturity that allow some escape from terminal drought and heat stress (Musa et al., 2001). The significant increase in the number of plant at harvest and number of seeds per plant and as a result of seed treatments may be contributor of an increment of seed yield. Similar findings were observed by Sharma et al. (1993) who indicated higher yield due to early floral initiation, more flowers, and seeds plant$^{-1}$ in salicylic acid primed soybean seed. The improvement in the stand establishment due to priming can increase drought tolerance, reduce pest damage and increase seed yield of chickpea (Harris et al., 1999; Musa et al., 1999; Harris et al., 2000). The increase in yield of primed seed plots may be due to the fact that primed seed emerge faster and more uniformly and seedlings grow more vigorously, leading to a wide range of phenological and yield related benefits (Harris et al., 2000). These results are also in conformity with Arif et al. (2007) who reported that seed priming increase seed yield of chickpea. Arif et al. (2008) findings also confirmed that seed priming with water and osmoticum for 6 h improved seed yield of soybean.

Main effect due to variety on Seed yield kg $ha^{-1}$ is presented in Table 3. There were significant differences among the varieties with respect to seed yield in which highest seed yield was obtained for variety Natoli followed by Arerti. However, seed yield of varieties Arerti and Habru was at par. On the contrary, variety DZ-10-4 which produced the lowest seed yield was at par with DZ-10-11 and Akaki.

Main effect due to seed priming treatment was not significantly different for biomass yield kg $ha^{-1}$. In other ways, enhancement in any of the above traits as a result of seed treatments did not translate into biomass yield kg $ha^{-1}$. This result is in contrary with the finding of the Ghassemi-Golezani et al. (2010) who obtained satisfactory result for plant biomass as a result of hydropriming of pinto bean (*Phaseolus vulgaris* L.). Arif et al. (2007) who reported that seed priming increase biological yield of chickpea. Interaction effects between two factors were not effective with respect to plant biomass yield. However, variety showed significant difference for biomass yield kg $ha^{-1}$at $p<0.01$ (Table 4). Out of all the varieties, Natoli variety accumulated the highest above ground biomass yield. Even though the lowest biomass yield was obtained from DZ-10-11, it had similar biomass yield with all the varieties except Natoli ($P<0.05$) (Table 3).

## Harvest index and hundred seed weight

Harvest index (%) was affected by seed priming ($p<0.01$) but hundred seed weight (g) was not affected by priming treatments ($p>0.05$). Interaction of priming treatment × variety for these traits were not significant ($p>0.05$). Harvest index for water priming was significantly higher by 12% than that of osmopriming and control, but osmopriming was not significantly different from the control (Table 3).This result disagreed with the findings of Ghassemi-Golezani et al. (2010) who could not obtain satisfactory results for harvest index up on hydropriming of pinto bean (*Phaseolus vulgaris* L.) but he had found similar results with the present findings with respect to hundred seed weight. Earlier findings which are against the current findings were also reported by Musa et al. (1999) and Arif et al. (2007) who reported that thousand seed weight was increased in chickpea. The main effect due to variety was significantly affected both traits. Mean harvest index for Arerti was significantly higher than any other varieties followed by Natoli. In contrast, DZ-10-4 produced the lowest harvest index among all the varieties .Habru, DZ-10- 11 and Akaki almost produced similar mean harvest index among themselves (Table 3). Mean number of 100 seed weight for the varieties could be arranged in order of increasing from the lowest to the highest harvest index as followed as: DZ-10-4, DZ-10-11, Akaki, Arerti, Natoli and Habru. From this we concluded that 100 seed weight was found to be affected by seed size in which smaller seeded varieties produced lower 100 seed weight and larger seeded varieties produced higher 100 seed weight (Table 3).

## Pods per plant, seeds per plant and seeds per pod

These three traits were affected by both seed priming ($p<0.01$) and variety ($p<0.01$). Interaction of seed priming x variety for all the three traits were not significant ($p>0.05$). Osmo seed priming produced higher seeds per plant as well as seeds per pod by 28 and 20%, respectively as compared to unprimed. But there was no significant difference between water priming and control for both seeds per plant and seeds per pod (Table 3).These results endorsed the findings of Pongkao and Yothasiri (1995) that correlated increase in yield with increase in number of seeds per pod by soaking in water. Manigopa et al. (2007) findings revealed that seed priming increased number of seeds per plant in chickpea. Furthermore, these findings are also similar with Ros et al. (2000) who reported that soaking the seeds in $KH_2PO_4$ and $NaH_2PO_4$ improved the yield attributes namely seeds per plant and/or seeds per pod. But these results were not as per with the findings of Ghassemi-Golezani et al. (2010) who could not obtained satisfactory results for seeds per plant as well as seeds per pod up on hydropriming of pinto bean (*P. vulgaris* L). Number of pods per plant was not affected by seed treatments ($p>0.05$). However, seed primed in 0.5% $KH_2PO_4$ solution produced maximum pods $plant^{-1}$ followed by seed primed in distilled water. Minimum pods $plant^{-1}$ were produce from untreated seed. Similar results were reported by Arif et al. (2007) who mentioned that chickpea seed priming with 0.05 or 0.075% $ZnSO_4$ and water priming did not affect pods $plant^{-1}$ of chickpea. These results are also similar with earlier studies where chickpea seeds treated overnight with 0.5% $KH_2PO_4$ and water could not be effective for improvement of pods per plant over the unprimed. Sarwar et al. (2006) and Ghassemi-Golezani et al. (2010) also did not obtain significant results for pods per plant due to hydropriming of pinto bean (*P. vulgaris* L.). It was also endorsed with the findings of Arjunan and Srinivasan (1989) who reported that seed treatment with 0.5% $CaCl_2$ did not influence significantly matured pods per plant as compared to control in TMV-7 groundnut variety. However, he reported that number of pods per plant could be appreciably increased through pre-sowing groundnut seed treated with 2% $KH_2PO_4$. Narayanaswamy (2003) also recorded higher number of graded pods per plant when groundnut seed was treated with 1% $KH_2PO_4$. Likewise, number of seeds per plant and number of pods per plant also affected significantly by the variety ($p<0.01$). Mean number of pods per plant and seeds per plant of DZ-10-4 and DZ-10-11 were significantly higher than any other variety though these

**Table 4.** Linear correlation comparisons of phenological, growth, yield and yield associated traits at 5% and 1% level of significance.

| | DF | DM | PH | SCE | SCM | BY | HI | NSPP | NSPPo | NPoPP | HSW | NPB | NSP | SY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DE | 0.22 | 0.13 | -0.29* | -0.08 | -0.15 | -0.02- | -0.01 | -0.28* | -0.32* | 0.16 | 0.10 | -0.13 | -0.13 | -0.03 |
| DF | 1.00 | 0.57** | -0.37** | -0.05 | -0-09 | 0.04 | 0.35** | 0.05 | -0.09 | 0.06 | 0.05 | -0.46** | 0.25 | 0.22 |
| DM | | 1.00 | 0.17 | -0.14 | -0.20 | -0.30* | 0.24 | 0.14 | -0.21 | 0.28* | -0.21 | -0.29* | 0.25 | -0.11 |
| PH | | | 1.00 | -0.05 | -0.01 | -0.09 | 0.09 | -0.01 | -0.07 | -0.02 | 0.14 | 0.23 | -0.11 | -0.03 |
| SCE | | | | 1.00 | 0.86** | 0.35** | 0.37** | -0.36** | -0.31 | -0.24 | 0.29* | -0.12 | -0.01 | **0.49**** |
| SCH | | | | | 1.00 | 0.35** | 0.42** | -0.43** | -0.35** | -0.31* | 0.37** | 0.01 | -0.05 | **0.52**** |
| BY | | | | | | 1.00 | 0.02 | -0.10 | -0.08 | -0.03 | 0.32* | -0.08 | -0.01 | **0.83**** |
| HI | | | | | | | 1.00 | -0.31* | -0.52** | 0.01 | 0.41** | -0.11 | 0.07 | **0.57**** |
| NSPP | | | | | | | | 1.00 | 0.65** | 0.87** | -0.73** | 0.20 | 0.33* | -0.23 |
| NSPPo | | | | | | | | | 1.00 | 0.22 | -0.57** | 0.31* | 0.10 | -**0.35**** |
| NPoPP | | | | | | | | | | 1.00 | -0.57** | 0.03 | 0.38** | -0.001 |
| HSW | | | | | | | | | | | 1.00 | -0.14 | -0.45** | **0.48**** |
| NPB | | | | | | | | | | | | 1.00 | -0.11 | -0.12 |
| NSB | | | | | | | | | | | | | 1.00 | -0.03 |

*, ** = correlation is significant at 5 and 1% levels of probability respectively. DE = days to emergence, DF = days to flowering, DM = days to maturity, PH = plant height at maturity, SCE = stand count at emergence, SCH = stand count at harvest, BY= biomass yield $kgha^{-1}$, HI = harvest index, NSPP = number of seeds $Plant^{-1}$, NSPPo = number of seeds $pod^{-1}$, NPoPP = number of pods $plant^{-1}$, HSW = 100 seeds weight (g), NPB = number of primary branches $plant^{-1}$, NSP = number of secondary braches $plant^{-1}$ SY = seed yield $kgha^{-1}$.

were at par for both traits. Habru, Akaki and Natoli for pods per plant and Arerti, Akaki, and Natoli for seeds per plant had showed similar effect. Among all varieties, Habru produced the least number of seeds per plant (Table 3). In contrast, DZ-10-4 produced the largest number of seeds per pod among the varieties followed by statistically similar DZ-10-11 and Akaki. Arerti, Habru and Natoli also produced the same number of seed(s) per pod. In addition, Natoli had the same number of seed(s) per pod with Akaki (Table 3).

### Primary and secondary branches per plant

Analysis of variance revealed that number of primary and secondary branches per plant were only affected by variety (p<0.01). Significant interactions were not observed for seed priming × variety on these traits (p>0.05). Mean number of primary branches per plant for DZ-10-4, Habru, DZ-10-11 and Natoli varieties as well as mean number of secondary branches per plant for DZ-10-4, Arerti, DZ-10-11 and Akaki were not different significantly. Arerti and Akaki furnished lesser number of primary branches per plant. Arerti variety had also the same number of primary branches per plant with that of Natoli variety. In contrary, lesser and similar numbers of secondary branches per plant were recorded for Habru and Natoli varieties. In addition, number of secondary branches per plant for DZ-10-4, Akaki and Natoli varieties were not differed significantly (Table 3). Different responses among different varieties for the considered traits may be due to genetical differences in varieties which agreed with the findings of Armin et al. (2010) who found different responses among the watermelon varieties due to priming treatments

Numbers of primary and secondary branches per plant were not significantly affected by seed priming. This finding is in agreeable with the findings of Paula et al. (1996) who recorded that mustard seed treated with 1% of $KH_2PO_4$ did not show significant difference for number of branches per plant. However, Manigopa et al. (2007) reported that seed priming brought considerable increase in lateral branches (primary and /or secondary) per plant in chickpea.

### Correlations between yield and yield associated parameters

Correlation analysis between growth parameters, yield and yield related traits, were given in Table 4. Correlation analysis between yield and yield components revealed that stand count at emergence (r=0.49, p=0.01), stand count at harvest (r=0.52, p=0.01), biomass yield (r=0.83, p=0.01), harvest index (r=0.57, p=0.01) and hundred seeds weight (r=0.48, p=0.01) were positively and significantly associated with seed yield (Table 4). Moreover, negative and significant association of number of seeds per pod (r = -0.35) with seed yield was obtained (Table 4).

From these correlation results, it could be concluded that stand count at emergence and stand count at harvest were found to be important yield components that may improve the yield potential of chickpea due to good stand establishment as a result of hydro priming.

## Conclusion

Farmers and researchers have recognized that poor crop establishment is one of the major bottlenecks for crop production. This is particularly a problem for post rainy crops like chickpea mainly grown in such a sub-optimal environment. Therefore, seed priming (pre-sowing soaking) has been offered as a solution to this problem that will maximize the probability of obtaining a good stand of healthy and vigorous plants. From the present investigation, hydro priming had substantially increased seed yield by 15% over the control. Therefore, hydropriming is viable and sound technology that could increase economic benefit of chickpea especially for resource poor farmers in the marginal areas and small holder chickpea producers in Ethiopia.

## Conflict of Interests

The author have not declared any conflict of interests.

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# Rainfall trend and variability analysis in Setema-Gatira area of Jimma, Southwestern Ethiopia

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**In this study, the trend and variability of rainfall were analyzed for Setema and Gatira meteorological stations. Daily rainfall data for two stations was obtained from National Meteorological Agency of Ethiopia. Mann-Kendall's test was employed for a rainfall trend analysis. Standardized rainfall anomaly index, rainfall concentration index and coefficient of variation were used as descriptors of rainfall variability. The trend analysis revealed decreasing rainfall trend in Setema and increasing trend in Gatira. However, rainfall trends were not statistically significant (p < 0.05). The coefficient variation of the study area for Setema was (CV = 23%), while for Gatira it was (CV = 8%) which showed lower inter-annual variability. The rainfall concentration index revealed that 35% of years with values of PCI >16 in setema indicate poor monthly distribution. Monthly rainfall concentration range from moderate to high and total rainfall of the study area concentrated in ½ of the period. The standardized anomalies of annual rainfall revealed negative anomalies 42% at Setema and 50% of years at Gatira. All most in all stations annual rainfall has shown negative anomalies for much of the 1983/4 and 1994. Present study only showed local level rainfall trend and variability analysis, so future study should include watershed or regional levels.**

**Key words:** Climate, rainfall trend, standard anomaly index, precipitation concentration index.

## INTRODUCTION

Climate variability and change are among the major environmental challenges of the 21st century (Parry et al., 2007). Today, there is strong evidence and understanding that climate change is happening and it is recognized as being one of the greatest challenges of our century. Climate change affect with increased average annual temperatures, reduced and increased variability in rainfall reduces crop yield and threatens food security in low-income and agriculture-based economies (Meybeck et al., 2012). IPCC (2007) report confirmed a change to precipitation due to climate change. However, Change in rainfall and temperature are not globally uniform (Parry et al., 2007). Regional variations can be much larger, and considerable spatial and temporal variations may exist between climatically different stations.

Agriculture is the most dominant sector of Ethiopia

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**Table 1.** Representative meteorology station site histories.

| Stations | Region | Zone | Woreda | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|---|---|
| **Setema** | Oromia | Jimma | Setema | 08°02.443' | 036°19.956' | 2116 |
| **Gatira** | Oromia | Jimma | Gatira | 07°59.114' | 036°12.945' | 2361 |

economy contributing 42 to 45% of GDP and 80% of employments (Gebregziabher et al., 2011). Despite its significant contribution to national economy the sector is challenged mainly by climate related disaster. According to World Bank (2010) report, drought and flood are very common climate change-related hazards in Ethiopia, with significant drought events occurring every 3 to 5 years. The main source of water for the sector is natural rainfall, so any change in rainfall amount and distribution lead to serious production deficit (Hagos et al*.,* 2009). In this regard, knowing the variations in the general rainfall pattern is vital to understand the climate change variations and its consequence on ecosystem (Krishan, 2013).

Precipitation trend analysis on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change by the scientific community. Assessing rainfall trends and variability is paramount to understanding the variations in space and time. The IPCC (2007) suggested that detail analysis is of local precipitation variability. In Ethiopia, several studies have been carried out on rainfall and temperature trend and variability analysis based on historical data of some selected weather stations (Baley, 2014, Ayelow et al., 2012, and Hadgu et al., 2013) and over whole the country (NMA, 2007; McSweeney et al*.,* 2008; Koricha et al*.*, 2012; wing et al., 2008). Among the studies NMA (2007) reported that annual rainfall remained more or less constant when averaged over the whole country (NMA, 2007). However, mean annual temperature in Ethiopia has increased by 1.3°C between 1960 and 2006, at an average rate of 0.28°C per decade increased (McSweeney et al*.,* 2008). On other hand, Wing et al. (2008) report shows a significant decline in main season (June to September) rainfall was recorded in the southwestern and central parts of Ethiopia. Similarly, Baley (2014) findings revealed declined rainfall in central rift valley of Ethiopia. It is very difficult to detect long-term rainfall trends in Ethiopia, due to the high inter-annual and inter-decadal rainfall variability. Assessing trends and variability in rainfall based on past records helps with better understanding of problem associated with drought, floods and various water uses (Jain et al., 2012). Moreover, it also essential to develop adaptation strategies and for planning agricultural activity (Aghajani, 2007). The present study has provided an assessment of rainfall trends and variability in Setema-Ageyo districts of Jimma southwestern Ethiopia.

## RESEARCH METHODOLOGY

### Study area descriptions

The research was conducted in two districts of Oromia region (Setema and Gumay) in the southwestern, Ethiopia. Geographyically, the study area is located between 8° 4' to 8° 2' North latitude and 30° 20' to 30° 28' East longitude. The study area is located at about 450 kilometers away from Addis Ababa, capital city of Ethiopia and 100 km in North West of Jimma town (Figure 1). The altitudinal range of the study district is between 1450 and 2400 meters above sea level (m.a.s.l). These two districts were selected because the availability of long term meteorological data. The mean annual rainfall in the study area is 1665 mm/year. Western and southwestern parts of the country experience a unimodal rainfall pattern. October to January (Birra) denotes the time when the long rainfall season comes to an end to be followed by a medium to short dry season during the same period. February to May (Bona) is the start of the long rainy season. Over the western parts of the country in region also the rainy season starts during March/April. June to September (Main season) is a long and heavy summer rain, normally called the big rain or Gannaa, which falls from June to September (http://www.meteo-ethiopia.net/climate. htm October 2014). Study area annual average maximum temperature is 27.9°c and minimum temperature is 11.9°c. Change in time/quantity of seasonal and annual rainfall is an important factor in the agriculture activities of the study areas.

Agriculture is the main economic activities and is dominated by small-scale and mixed crop and livestock farmers. Crop production is mainly rain-fed. Coffee plays a major role in income generation in the areas. Maize, Teff (*Eragrostis teff*) and sorghum (*Sorghum bicolor)* are the major crops grown in the area. Pulses crops, such as, beans and pea are grown to a lesser extent in the area (JZAO, 2013).

### Approach

In this study, annual and seasonal patterns of the rainfall are examined for two meteorological stations based on inter-seasonal spread of rainfall: June to September (Gannaa), October to January (Birraa) and March to April (Bona). Daily rainfall record for the selected stations (Table 1) where obtained from Ethiopia National Meteorology Agency for the period of 1983 to 2013 for Gatira and 1979 to 2011 for Setema. Monthly, seasonal and annual rainfalls were derived from the daily data of those stations. Data was used to analyze the trends and variability in rainfall for the stations.

### *Rainfall trend and variability analysis*

In this particular study, Mann-Kendall's test was employed. Mann-Kendall's test is a non-parametric method, which is less sensitive to outliers (Mann, 1945). Mann-Kendall's test checks the hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

$$S=\sum_{i-1}^{N-1}\sum_{J=I+1}^{n}\operatorname{sgn}(xj-xi)$$

**Table 2.** SAI value classification table.

| SAI value | Category |
|---|---|
| 2.0+ | Extremely wet |
| 1.5 to 1.99 | Very wet |
| 1.0 to 1.49 | Moderately wet |
| -0.99 to .99 | Near normal |
| -1.0 to -1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2 and less | Extremely dry |

Source: McKee (1993).

**Table 3.** Annual rainfall trends for *Gatira and Setema* meteorological stations.

| Stations | Annual rainfall trends | | | | Standard deviation (mm) |
|---|---|---|---|---|---|
| | Trends | p value | Sen.'s slope | Mean | |
| Gatira | 0.187 | 0.145 | 5.089 | 1928.456 | 156.573 |
| Setema | -0.081 | 0.530 | -4.716 | 1665.253 | 394.583 |

*=significant at p< 0.05.

Where S is the Mann-Kendal's test statistics; *x*i and *x*j are the sequential data values of the time series in the years *i* and *j* ( *j* > *i* ) and *N* is the length of the time series.

$sign(xj - xi)$ =-1 if ($x_j$-$x_i$) <0, 0 if ($x_j$-$x^i$) = 0 and +1 if ($x_j$-$x_i$) > 0

Standardized rainfall anomaly index, rainfall concentration index and coefficient of variation were used as descriptors of rainfall variability. The rainfall variability for representative meteorological stations was determined by calculating the coefficient of variation (CV) as the ratio of the standard deviation to the mean rainfall in a given period (CV%, when expressed as a percentage) as used by (Belay, 2014; Ayelow et al., 2012). Standardized Anomaly Index was calculated as the difference between the annual total of a particular year and the long term average rainfall records divided by the standard deviation of the long term data. This characteristic of the SAI have contributed to its popularity for application drought monitoring and also makes possible the determination of the dry and wet years in the record (WMO, 2012). Its formula is given as:

$$Z = \frac{(x - \mu)}{\delta}$$

Where, *Z* is standardized rainfall anomaly; x is the annual rainfall total of a particular year; μ is mean annual rainfall over a period of observation and δ is the standard deviation of annual rainfall over the period of observation. Standardized anomaly index value was categorized according to McKee (1993) classification (Table 2). This study used also precipitation concentration index (PCI) to investigate heterogeneity of monthly rainfall (Oliver, 1980).

$$PCI = \frac{( \sum_{i-1}^{12} \mathrm{pi2} )}{( \sum_{i-1}^{12} \mathrm{pi} )2} * 100$$

Where pi is the monthly rainfall in month i. The seasonal scale of Rainfall Concentration Index was calculated using the equation:

$$x = \frac{( \sum_{i-1}^{3} \mathrm{pi2} )}{( \sum_{i-1}^{3} \mathrm{pi} )2} * 25$$

Annual and seasonal rainfall concentration index according to Oliver's classification11: i. PCI < 10 indicates uniform rainfall distribution (low rainfall concentration), ii. PCI >11 and <15 indicates moderate rainfall concentration; iii. PCI >16 and < 20 indicates irregular distribution, iv. PCI > 20 indicates a strong irregularity (that is, high rainfall concentration) (Oliver, 1980).The main aims of analysis of annual and seasonal Precipitation Concentration Index (PCI) is to characterize spatial and temporal distribution of rainfall, I and PCI value of 16.7 will indicate that the total precipitation was concentrated in ½ of the period and a PCI value of 25 will indicate that the total precipitation occurred in $^1$/3 of the period (Luis et al., 2011).

## RESULT AND DISCUSSION

### Annual and seasonal rainfall trend analysis.

The results of statistical analysis at 95% confidence level for annual rainfall data using Mann-Keld test have both positive and negative trends. The results obtained for rainfall series indicated that *Setema* revealed negative trends while *Gatira* showed positive trends for annual rainfall series. Positive value of sen's slops indicates an upward or increasing trend in *Gatira*, while *Setema* negative value of sen's slop gives a downward or decreasing trend in the time serious (Table 3).

Annual rainfall trend analysis is not statistically significant. Findings from national and regional level rainfall trends analysis reported both increasing and

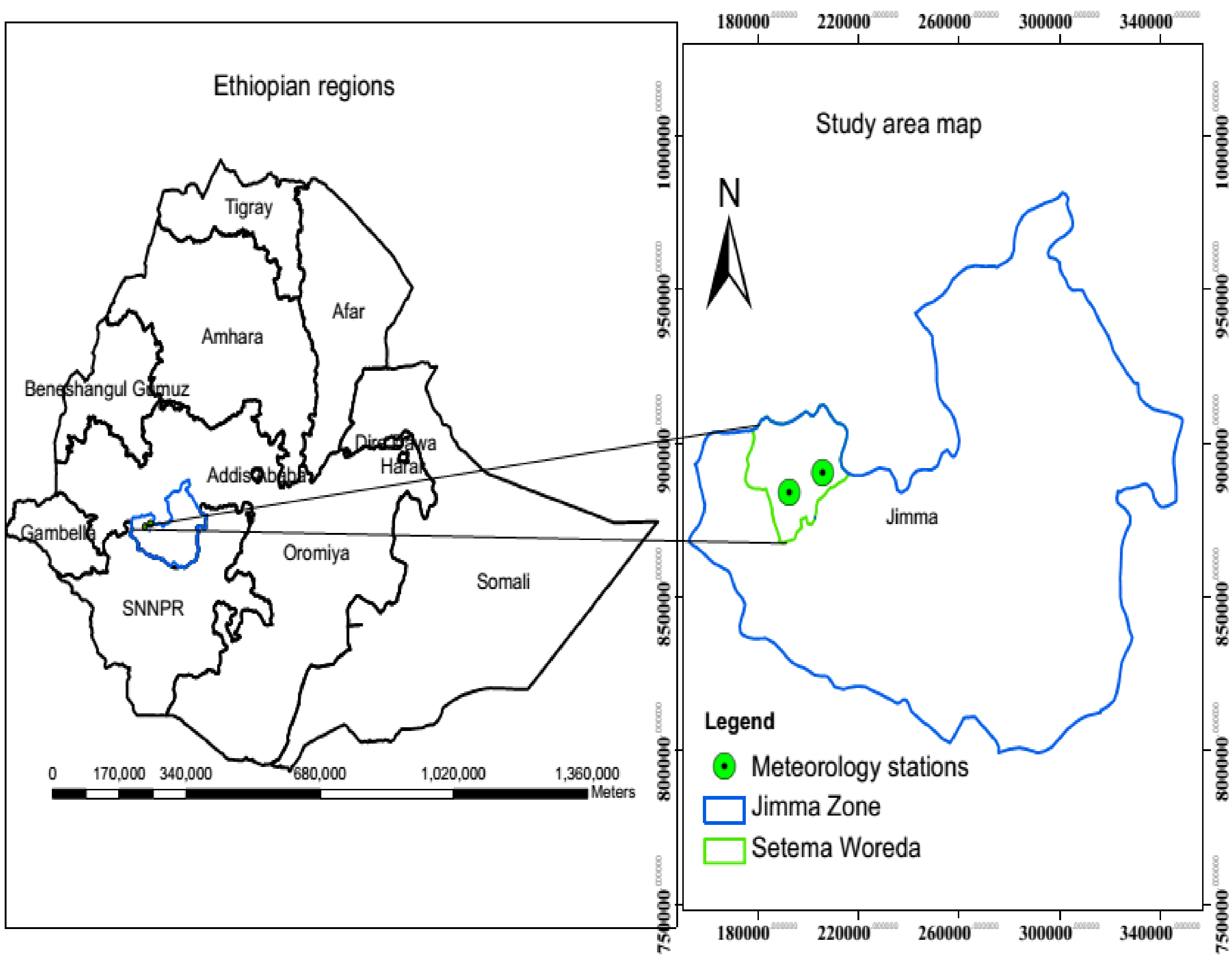


**Figure 1.** Study area.

decreasing trends (Wing et al., 2008; Belay, 2014; Kebede and Adane, 2011; and Rao and Solomon, 2013). Wind et al (2008) reported significant decline in rainfall in southwestern Ethiopia. Similarly, Rao and Solomon (2013) who reported that analysis of the historical rainfall records in North Central Ethiopia revealed that there has been trend of decreasing rainfall, However, the trend analysis of annual rainfall showed that rainfall remained more or less constant when averaged over the whole country for 1951 to 2006 (NMA, 2007). Parry et al. (2007) confirmed that regional variations can be much larger, and considerable spatial and temporal variations may exist between climatically different stations.

The deviation of annual mean temperature in Setema from 1979 to 2011 gives a strike indicator of change on climate on the study area (Figure 2). The main season (June to September) season revealed negative trends at Setema while positive at Gatira. This season contributes the largest amount of rainfall to annual series (Table 3). Similarly, seasonal rainfall trend analysis result from March to May season which showed negative trend in Setema (Table 4). However, analysis of seasonal rainfall trend analysis for the period of (1981 to 2011) shows rising trend for March to April at Gatira and the trend is statistically significant. Rising trends of March to April rainfall will provide moisture for main season land preparation.

### Rainfall variability analysis

The annual weighted average rainfall for studied stations is 1796.5 mm. spatially, mean annual rainfall of study area is ranged from 1665 mm in Setema to 1928 mm in Gatira (Table 5). The main rainy season (June to September) contributes 52 to 60% to the annual rainfall totals while March to April season rainfall also contributes 25 to 30% to the annual rainfall (Table 5). The main (long) rainy season (June to September) total mean rainfall ranges between 1045 and 1010 mm.

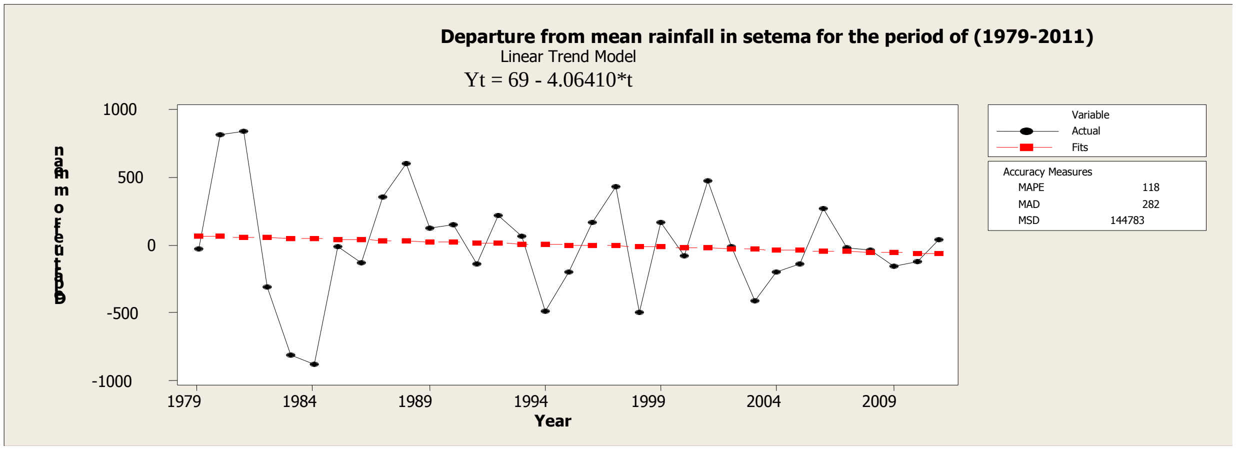


**Figure 2.** Departure from mean rainfall in Setema for the period of (1979-2011).

**Table 4.** Seasonal rainfall trends for Gatira, Jimma and Setema metrological stations.

| Stations | ***Main season*** **(June to September)** | | | ***Bona*** **(March to April)** | | | ***Birraa*** **(October-January)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Trend (mm/year)** | **P-value** | **Sen's slope** | **Trend (mm/year)** | **P-value** | **Sen's slope** | **Trend (mm/year)** | **P-value** | **Sen's slope** |
| Gatira | 0.05 | 0.71 | 0.94 | 0.05* | 0.71 | 0.94 | | | |
| Setema | -0.08 | 0.51 | -2.42 | -0.05 | 0.68 | -1.40 | 0.011 | 0.939 | 0.018 |

*=significant at p< 0.05.

**Table 5.** Annual and seasonal rainfall variability (coefficient variation) for Gatira and Setema.

| **Stations** | **Annual** | | ***Main season*** **(June to September)** | | | **Bona (March to April)** | | |
|---|---|---|---|---|---|---|---|---|
| | **Mean** | **CV** | **Mean** | **%** | **CV** | **Mean** | **%** | **CV** |
| **Gatira** | 1992 | 8.1 | 1045.3 | 52.5 | 24 | 526.1 | 26.4 | 38.5 |
| **Setema** | 1665.2 | 23.6 | 1010.1 | 60.6 | 38.5 | 419.6 | 25 | 63.2 |

## Coefficient of variation

The coefficient of variation in stations revealed that rainfall in the region has low inter-annual variability (Table 5). The result indicated that rainfall variability at Setema (CV=23%) while Gatira (CV=8%). Main season (June to September) rainfall contributed the highest Percentages (52 to 60%) of rainfall to annual rainfall and March to April season rainfall also contributes 25%. This result agreed with the findings of (Koricha et al., 2012) who reported that main seasons contributed the highest contribution to the annual rainfall in the country.

Moreover, main season (Gannaa) rainfall coefficient variation range was 24 at Gatira while 38.5 at Setema (Table 5). In line with other studies in Ethiopia, Hadgu et al. (2013) reported that high coefficient annual variation in main season was (CV 30%) and March to April (CV 50%) in northern Ethiopia. Moreover, Baley (2014) who reported that inter-annual rainfall coefficient variation (18 to 40%), main season (CV 17 to 39%) and March *to* April (CV 27 to 57%) for rift valley of Ethiopia which is high annual variability as compare to this study. The analysis of coefficient of variation for March to April *(Bona)* season variability in this region is higher than main season rainfall which agreed with many other authors (Belay, 2014, and Hadgu et al., 2013). These suggest that inter-annual and annual variability in rainfall distribution influenced agriculture activities in the study area which was totally rainfall dependant. Small change in amount and distribution of main season (June to September) rainfall could negatively influence crop production which is already impacted by the current climate variability, which may likely cause further challenges in the future climate change.

**Table 6.** Annual and seasonal rainfall index for Gatira and Setema stations.

| Stations | Annual and Seasonal PCI | | | | | |
|---|---|---|---|---|---|---|
| | <10 | < 16 | > 16 | % of years above 16 PCI | *Keremt* PCI | *Belg* PCI |
| **Gatira** | 0.0 | 30.0 | 0.0 | 0 | 25-26 | 33-48 |
| **Setema** | 0.0 | 17 | 6 | 35 | 25-41 | 46-66 |

**Table 7.** Standardized rainfall indices with the frequency and percentages of occurrence over the period of 1979 to 2011 in the Setema and Gatira (1981- 2011).

| Drought category | Standard anomaly index value range | Percentage and frequency of occurrence (Years) | | | |
|---|---|---|---|---|---|
| | | Setema | | Gatira | |
| | | Frequency | % | Frequency | % |
| Extreme drought | -2.0 or Less | 5 | 15.15 | 0.00 | 0 |
| Severe drought | -1.5 to -1.99 | 2 | 6.06 | 0.00 | 0 |
| Moderate drought | -1.0 to -1.49 | 2 | 6.06 | 0.00 | 0 |
| Mild drought | -0.99 to 0 | 8 | 24.24 | 15 | 48.39 |
| Normal | + 0.01 to + 1.49 | 9 | 30.30 | 16 | 51.61 |
| Severe wet | +1.5 to +1.99 | 1 | 3.03 | 0.00 | 0 |
| Extreme wet | +2.0 or more | 5 | 15.15 | 0.00 | 0 |

## Rainfall concentration index

The Rainfall Concentration Index values for the annual and seasonal rainfall were calculated based on the equations. The analysis result indicted that the rainfall concentration index (PCI) value ranged from 12 to 18 for most of the stations. The rainfall concentration index calculated at annual level showed values >16 in the Setema station which is moderate rainfall irregularity (Table 6). Rainfall concentration index (PCI) values of less than 10 indicated uniform monthly distribution of rainfall, values between 11 and 20 indicate high concentration, and values above 21 indicate very high concentration (Oliver, 1980).

On the contrary, Ayelew et al. (2012) reported that moderate to high inter-annual rainfall concentration in Amahara region and similarly Belay (2014) study revealed that there is moderate to high in Central Rift Valley in Ethiopia. Furthermore, Hagdu et al. (2013) reported that high and very high concentration in Northern Ethiopia (Tigray) indicates poor monthly distribution of the rainfall. The lowest value of PCI (<10) indicating the perfect uniformity in precipitation distribution or same amount of precipitation occurs in each month of the year. It can be concluded that study area ranges from moderate to high monthly rainfall concentration, which implies that total rainfall of the study area concentrated in ½ of the period (Table 6).

## Standardized anomaly index (SAI)

Analysis of the standard anomaly index for the stations is presented in Table 7. This study used SAI to demonstrate the intensity and frequency of drought and inter-annual variation at various time scales and area. The negative anomalies of Gatira station was 48% during the period of 1983 to 2013. In Setema, 52% of years revealed negative anomalies over the period of 1979 to 2011. The differences between the frequencies of occurrence of the dry and wet years range for the studied area were small difference. Negative anomaly index (dry) was observed in 1983, 1984, 1994, 2002, and 2003 in all stations (Figures 3 and 4). In line with this, Quinn and Neal (1987) and Webb and Braun (1994) cited in NAM (2007) reported that Ethiopia experienced drought years in 1983 to 1984, 1987 to 1988, 1990 to 1992, 2000, and 2002 to 2003.

This study indicated that standard anomaly values of (-2 or less) categorized as extremely drought was occurred in 1983, 1984, 1994, 1998, and 2008 years in Setema. The result showed that 2009 and 2008 were the driest years in setema (Table 1). In agreement with this finding, Koricha et al. (2012) also found that nationally, 2009 was the second driest year, surpassed only by the historic year 1984. Moreover, severe drought period standard anomaly values (SAI value -1.5 to -1.99) were observed in 2003 in Setema. On the other hand, severe wet (SAI value of +1.5 to +1.99) period occurred 1987 and 1992 in Setema and extreme severe wet period occurred in 1980 (SAI value 3.21) and 1981 (SAI value 3.84). However, there were no observed extreme and severe drought characteristics in Gatira over the period of 1981 to 2013 (Table 7).

This is in harmony with the findings of (NMA, 2007) who reported that there was increase in the dry year frequency in Ethiopia. The rainfall pattern in the studied

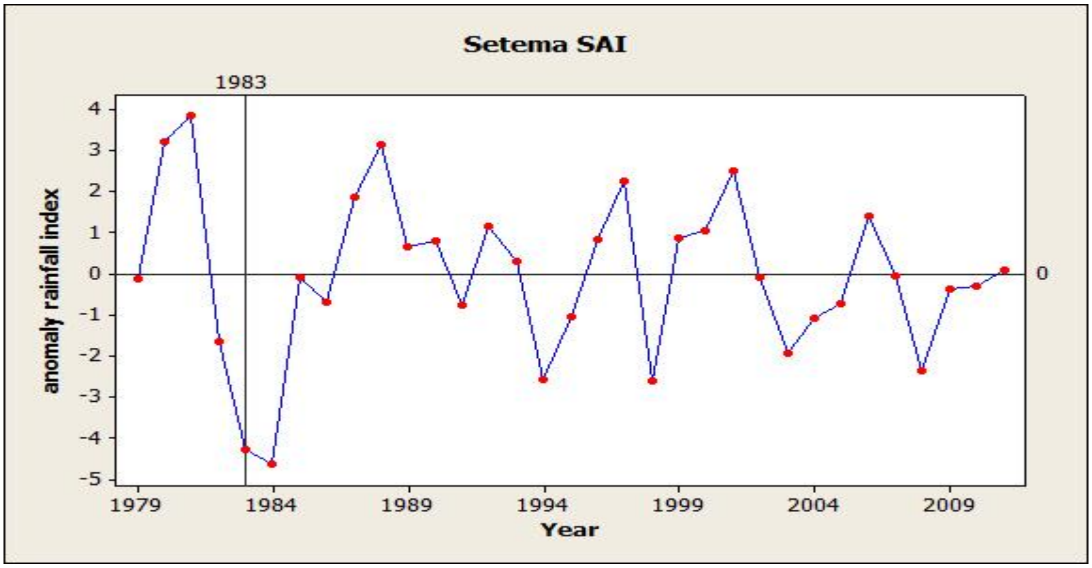


**Figure 3.** Setema Standard anomaly index over the period of (1979-2011).

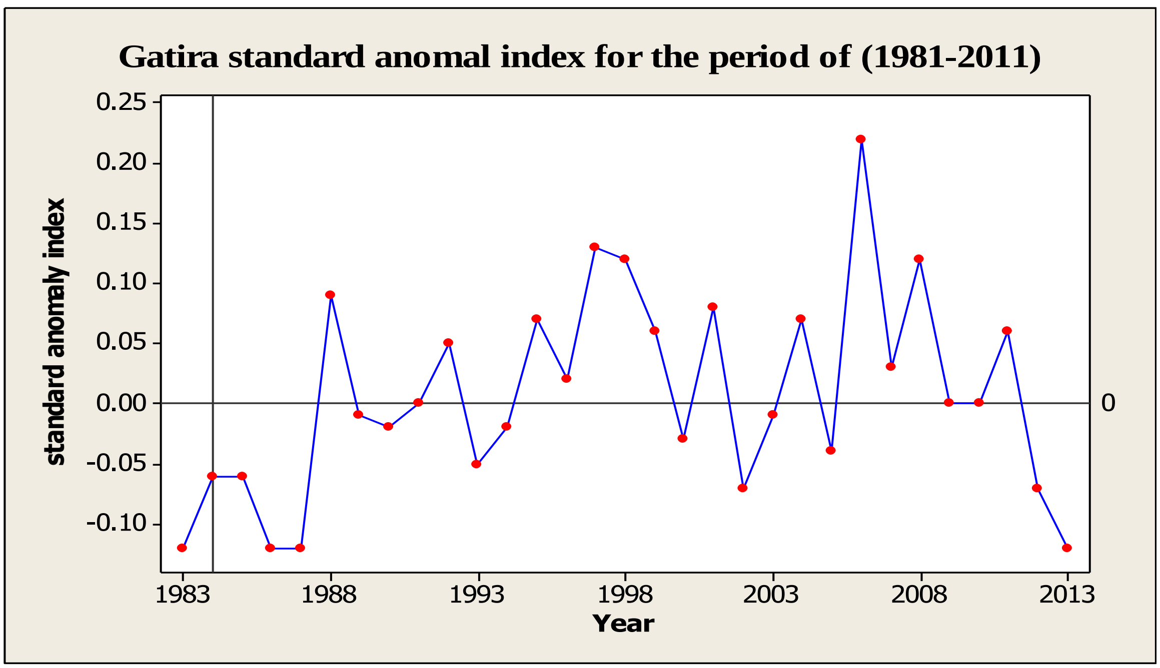


**Figure 4.** Gatira standard anomaly index over the period of (1981-2011).

stations showed the characteristics that a dry year is followed by another two or three dry years and vis-à-vis for the wet years (Figures 3 and 4). In fact, the mean annual rainfall in studied station exceeds 1737.9 mm which is greater than result in other part of Ethiopia (Kebede and Habtamu, 2011). World Bank (2003) reported that Ethiopian mean annual rainfall range more than (2,700 millimeters) occurs in the southwestern highlands to less than 100 millimeters in northeast.

The present study revealed rainfall fluctuation was occurred both in annual variability (Table 5) and inter-annual variability. Such inter-annual variability problems in rainfall would negatively affect the ability of farmers to cope with climate change and variability (Ayalew et al., 2012). Similarly, IPCC (2014) reported that in next few decades and the second half of the 21st century and beyond, there will be risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings. It is obvious that drought phenomenon will create more vulnerable environment for the subsistence farming sector.

## Conclusion

This study was undertaken to understand rainfall variability in Jimma, southwestern Ethiopia. The study employed Mann-Kendall's test to detect change in rainfall trends. Results for rainfall trend analysis for Setema indicated decreasing trends, while Gatira revealed increasing trends. Overall, the observed trends were not statistically significant. Coefficient of variation revealed that rainfall in the region has low inter-annual variability as compare to studies done over other part of Ethiopia. The standardized anomalies of annual rainfall revealed negative anomalies 42% at Setema, 52% over 1979 to 2011 at Jimma during 1990 to 2013 and 50% of years at Gatira during 1983 to 2013. All most in both stations annual rainfall has shown negative anomalies for much of the 1983/4 and 1994. Present study demonstrated rainfall trend and variability analysis for two meteorological stations in southwestern part of the Ethiopia, however, a comparison was done with result from nationwide and different data ranges. These will provide information on rainfall variability of the districts and could be used as input for the local adaptation planning and to develop adaptation strategies for the study areas.

## Conflict of interests

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

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African Journal of Agricultural Research

*Full Length Research Paper*

# Assessing the financial viability for small scale fish farmers in Namibia

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**The aim of this study is to assess the financial viability of small-scale fish farmers in central northern Namibia, namely Oshikoto Region, Oshana Region, Omusati Region and Ohangwena region; who receive fingerlings on a continuously basis from the Ministry of Fishery and Marine Resources Ongwediva extension office. Out of the 76 active farmers, two-third (37) farmers were randomly selected and interviewed for this research. The data was analysed using cost benefit analysis and situational analysis. The situational analysis was carried out to assess the farmer's situation, (that parameters included training opportunity transport and marketing). The cost benefit for this study shows that aquaculture will not be sustainable if not managed and planned well. Therefore, this study is recommended to strengthen the technical and organisational aspect of farmers, and also what is required to support the farmers.**

**Key words:** Small scale fish farming, financial viability and central northern Namibia.

## INTRODUCTION

Globally, the number of people who lack access to minimum dietary requirements has risen from 824 million to 1020 million, in between 1990 to 2014 (Food and Agriculture Organization (FAO), 2015b). Furthermore, it is estimated that about 795 million people (world-wide), or one in nine persons, were suffering from chronic undernourishment in the year 2014 to 2016, this phenomena in Sub-Saharan Africa is severe; for example in 15 African countries more than 35% of their population suffer from hunger, with children being the most affected (FAO, 2015a).

Food crises in Africa is attributed to the decline in agricultural productivity; that resulted from water being a major transient resource through space and time (Ryan and Spencer, 2001; Twomlow et al., 2002). In addition to this negative effects of climate change, there is decline in land productivity, insufficient rainfall, soil infertility, inappropriate farming techniques, poor market infrastructure, poor access to farm inputs, and war and conflicts (FAO, 2015a).

Namibia is not an exception from the above-mentioned phenomenon, as about two-thirds of the population (1.5 million people) are living in communal lands dependent on rain-fed agriculture (National Planning Commission, 2008). Despite of the perception of economic growth, Namibia ultimately upgraded to upper-middle income

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status, however, the nation still faces a number of social and economic challenges that includes: High income inequality, with a Gini coefficient of 0.62. High poverty and high cost of living with poverty incidence estimated at 29 % of the population, with an unemployment rate of 27.4%, and about half the population estimated being under severe poverty. Relatively high human immunodeficiency virus (HIV)/AIDS prevalence rate standing at 18.2%. High infant and under-five mortality rates, estimated to be 32 and 42 deaths per 1000 live births, respectively; and a high adult literacy rate of 89% (Namibia Statistics Agent, 2012, 2013). In addition to these, Namibia is lagging behind on achieving better records for the Human Development Index (HDI). In 2011, Namibia's HDI of 0.625 was below the world's HDI average of 0.682. Namibia also ranks 120 out of 187, while the country is classified as an upper middle-income country and the government target was to achieve 0.70 HDI.

To address the earlier complicated challenges the government has embarked on a few number of developmental plans; such as the Harambee Prosperity Plan which complement the long-term goal of the National Development Plans (NDPs) known Vision 2030 (Harambee Prosperity Plan 2016/17 to 2019/20) (Namibia Commission of Panning, 2015).

In the development plan, aquaculture sought as new developmental opportunities to address current challenges. As there are existing aquiculture research centers and Small Scale Fish Farming (SSFF) ventures have been established close to fresh water bodies, such as rivers, lakes and reservoirs, dams, floodplains, wetlands, boreholes and canal. In 2001, the Ministry of Fisheries and Marine Resources (MFMR) – Ongwediva Inland Aquaculture Centre (OIA) registered 568 small scale farmers within the four regions under study. However, over the past five (5) years, only 76 farmers were continously operating and receiving (which accounted only for 13%) as compared to 87% of farming activities been discontinued due to different reasons (Ministry of Fisheries and Marine Resources, 2014).

The government has therefore engaged communities in promoting fish farming, through a pro-poor focus. The fish farming initiative is expected to provide a safety-net to the most vulnerable households, that could be a potential substitute to staple crops such as maize and pearl millet, yet lack nutrients such as iron and proteins.

Therefore, the aim of this study is to assess the financial viability (using Net Present Value and Cost Benefit Analysis (NPV and CBA)) of small-scale fish farming of the rural aquaculture communities in the central north part of Namibia.

## MATERIALS AND METHODS

### The study area

The study was conducted in central northern regions of Namibia; Oshana, Omusati, Ohangwene and Oshikoto regions. The regions represent high rates of unemployment, poverty and malnutrition. Consequently, the regions have the highest number of fish farmers as per the MFMR database (MFMR, 2014). Although the regions provide a good representative of fish farming activities in Namibia, over the years some of the farmers had to discontinue due to lack of resources, such as water and land availability, which are one of the most constraint factors in aquaculture (Figure 1).

### Data source and sampling procedure

The study was conducted from April to August 2014 in the four selected central north regions of Namibia. The choice of the study area was based on the following reasons: firstly, the number of fish farming projects operating in the regions and the high rate of poverty (reported to be 56% of the population). About 76 farmers in the respective regions have been continously farming and receiving fingerlings, over the past six years. Only two-thirds of the 76 fish farmers who were chosen for this study believed sufficient observation and also, considering the limited data available. A systematic random sampling approach was used to select the respondents from each region and the data from the coded questionnaire were transferred into Excel spread-sheet, statistical package for social sciences (SPSS) and analysed using a Cost Benefit Analysis.

## METHODOLOGY

The approach that the study took is a "pragmatic approach" that utilizes both qualitative and quantitative analysis (Denzin, 2010). In the quest to improve the success rate of SSF enterprises, one aspect that has to be examined concerns the conditions within which smallholder enterprises are carried out. One way of assessing how promising or successful an aquaculture enterprise might be is conducting a cost-benefit analysis. CBA for an aquaculture enterprise essentially involves comparing initial start-up costs and operational costs with revenue streams that accrue over time, usually at the end of each production cycle (Cobbina, 2010). However, CBA may be subjected to numerous constraints, from the accuracy of the data used in the estimation process to uncertainty about values to be employed in the analysis; furthermore, it is difficult to assess economic and social benefit of the enterprise. The total cost involved in an aquaculture operation is the total sum of money invested in two forms: fixed costs and variables costs. The costs are inherently different both with respect to the cost structure itself and to the timing of accrual. Variable cost is the sum of the quantity of variable inputs used multiplied by the price per input unit as shown in Equation (1):

$$VC(t) = \sum w(j,t) * x(j,t) \quad (1)$$

Where *VC* is the variable cost in period t, *w( j,t)* is the price of inputs j in period t and *x( j,t)* is the quantity of input j in period t. The total cost of investment in any given period and the benefits that are involved in aquaculture operations are attributed to financial gain from selling the finished product at the end of each production cycle (Cobbina, 2010). This could be described as the sum of the quantity of outputs at the end of the period multiplied by the price of the output at that period as shown in Equation 2:

$$B(t) = \sum p(i,t) * q(i,t) \quad (2)$$

Where *B(t)* are the benefits in period t, p(i,t) is the price of output *i* in period *t* and *q(I,t)* is the quantity sold of outputs *i* in period *t* (Cobbina, 2010).

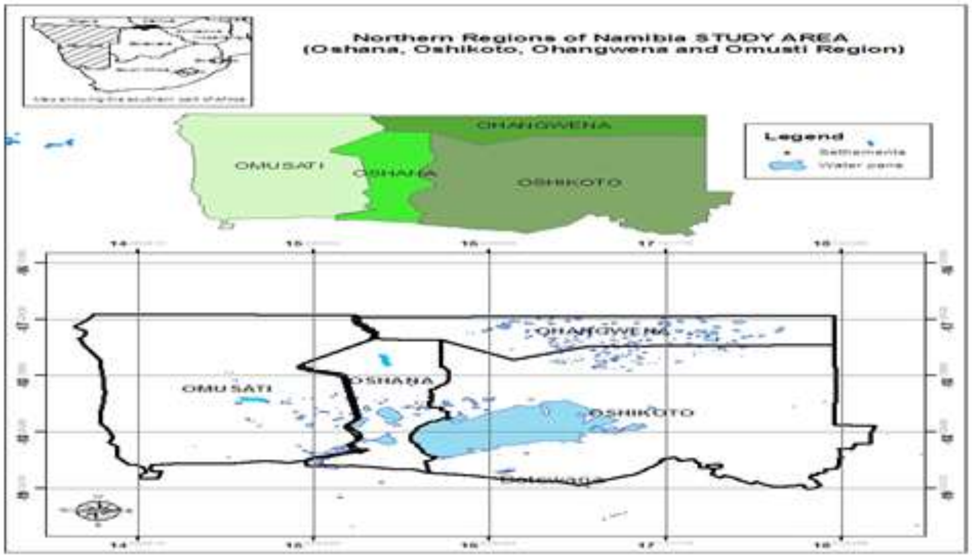


**Figure 1.** Location of study area (Source: Ministry of Fisheries and Marine Resources (2014)).

The net benefits in each period can be found by subtracting total costs from the benefits (Equation (3)), which in terms of financial viability can also be stated as Equation (4).

$$\text{Net benefits} = \text{Benefits} - \text{Total cost} \tag{3}$$

$$\text{Net revenue (Profit)} = \text{Total revenue} - \text{Total cost} \tag{4}$$

Estimated by the total sum of money involved in both fixed and the variable costs. The NPV is given by the difference between the sum of the discounted cash-flow, that is, the net benefits, which is expected from the investment and the amount which was initially invested in the project as shown in Equation (5) (Cobbina, 2010).

$$NPV = -INV + \frac{P_1}{(1+r)^1} + \frac{P_2}{(1+r)^2} + \ldots + \frac{P_n}{(1+r)^n} \tag{5}$$

When NPV is positive (that is, >0) then the rate of return exceeds the defined discount rate and the investment would be viable. If NPV is less than zero (<0), the investment is not viable at the given rate discount rate and if NPV equals zero (NPV = 0) it would be a break even situation where the farmer would be indifferent to investing (Okechi, 2004).

## RESULTS AND DISCUSSION

### Situational analysis on SSFF

In this study, about 86.5% were male and 10.8% female. This demonstrates that male farmers were dominating the fish farming system; mainly due to the nature of the farming system is more labour instensive. As indicated in Veliu et al. (2009), women are not major players in agricultural production. In terms of households that participated in fish farming, 4 to 9 household members dominated (45.9%), followed by 10 to 12 household members. The result implies that households with more members are more likely to take up fish farming technology, as it diversifies their source of income and have more access to more labour. Educational qualifications in this study found to be primary, secondary and tertiary education were about 27, 46 and 24%, respectively. It is widely believed that education creates a favourable mental attitude for the acceptance of new technology and practices.

### Financial viability of SSFF

For this analysis farmers were categorised into two groups; those operating along the river canal and the second group were operating from rain-fed ponds. All calculations were based on the following assumption:

#### *Initial investment costs*

Construction of one square pond measurement and less than 400sq metres the construction uses manual labour, whereas pond measuring more than 400sq. meters requires machinery. Construction based on an average labour requirement and raw materials cost USD 200 for pond more than 200 sq. meters and construction requires work of five personnel at a rate of USD2 per day, and it takes 20 days to complete (exchange rate assumed one USD equivalent to N$15 based on April 2016). For bigger pond size, use of machinery is estimated at cost of USD67 per day, with completion period of five days for a 200 sq. meter pond size.

**Table 1.** Descriptive statistics of profit earned along the river-canal under government market price (in USD).

| **Mean** | **250.6281333** |
|---|---|
| Standard error | 74.38673333 |
| Median | 118.45 |
| Mode | 46 |
| Standard deviation | 297.547 |
| Minimum | 46 |
| Maximum | 920 |
| Observation | 16 |

Source: own computation from fish farmers data.

### *Input supplies*

Stocking Rate ~ 50 g fingerlings, per square meter =USD0.033 per fingerling

Feeding requirement of 150 kg per 200 square meters (based on research of government institutions) for three months at a feed price of USD 0.23 per kg. The stocking rate per cycle of about 1 000 fingerlings, with a survival rate of 40%.

The price of fish is USD1.00 per kg, based on government research, and also USD2.33 per kg, based on open market prices.

Labour costs is assumed to be zero (as family members involved during the construction), because the labour of family members is not considered in the calculations.

### *Other considerations*

The financial analysis was carried out, considering that the farmers started their operations in 2002 to introduce fishponds. Calculations for NPV were considered from 2002 to 2014, with 4, 6 and 8% being the inflation rate fluctuations in Namibia.

Price and costs were assumed to be constant during the period of evaluation consideration (from 2002 to 2014) in the calculations (USD 1.00 per kg in government price market and USD2.33 per kg in open market prices).

Using the earlier mentioned assumptions and information, partial income statements were compiled within a CBA-framework for each of the two group data sets within two price scenarios (government market price and open market price). To compute NPV, initial investment costs were considered with different possible discounting factors (inflation factors to capture time value of money).

## Scenario one (Government market price)

### *Profit earned along the river-canal*

As indicated in Table 1, the descriptive statistics for farmers operating along the canal, the mean profit calculated was about USD2531.62 per year, with the minimum profit of USD 46.00 and maximum profit of USD 920.00. This indicates that lowest SSFF profitability average would be USD3.87 per month, and the highest earnings would be USD77.00.

Figure 2 shows that only four farmers are earning more than USD 340 per year, whereas the remaining are earning below USD 340 per year. This shows clearly that farmers require much more support to make SSFF sustainable.

### *Profit earned by farmers dependent on rain-fed*

As indicated in Table 2, the rain-fed SSFF are incurring losses, on average, at around USD132 with the extreme highest recorded of loss around USD 1420. As indicated in Figure 3, those farmers depending on the rain fed and incurring massive loss, it is estimated to be around USD 4500; when this is compared to the per capita income in sub Saharan Africa is much higher to different income categorisation of Africa. For example, high income categories nations where oil is sufficiently important as an export commodity (like Angola) their average income is estimated to be US$ 4,000; middle-income countries and World Bank classified this group based on their per capita income level and institutional quality (such as Botswana, Cape Verde, Lesotho, Mauritius, Namibia) record of 2010 average per capita income estimated to be at US$ 1,500 and the third category is known as low and fragile countries classified on the basis of a relatively low rating of their institutional quality; their per capita income estimated to be between U.S.$400 and U.S.$500 (IMF, 2015).

Table 3 shows the NPVs for SSFF systems (rain-fed and along canal fish farming), when this was discounted in between 2002 to 2014 (13 years) at discount rates of 4, 6 and 8% of inflation. The figures show that canal-SSFF records shows at about $572 , $324.00 and $122, respectively, which implies that profits per annum would be at about $44.00, $25.00 and $10.00. This means that the canal-fed SSF system is not encouraging for continuation.

On the other hand, rain fed-farming system is found be the worst, and with time value of money taken into consideration, it is estimated that about $33592.00, $3389.00 and $3208.00 losses are incurred, respectively.

## Scenario two (Open market price)

### *Profit earned by farmers dependent on river-canal*

As with the analysis indicated in Table 4, similarly with scenario two, the mean average profit is estimated to be at about $483, with minimum and maximum profits earned estimation about $87 and $1773 per year,

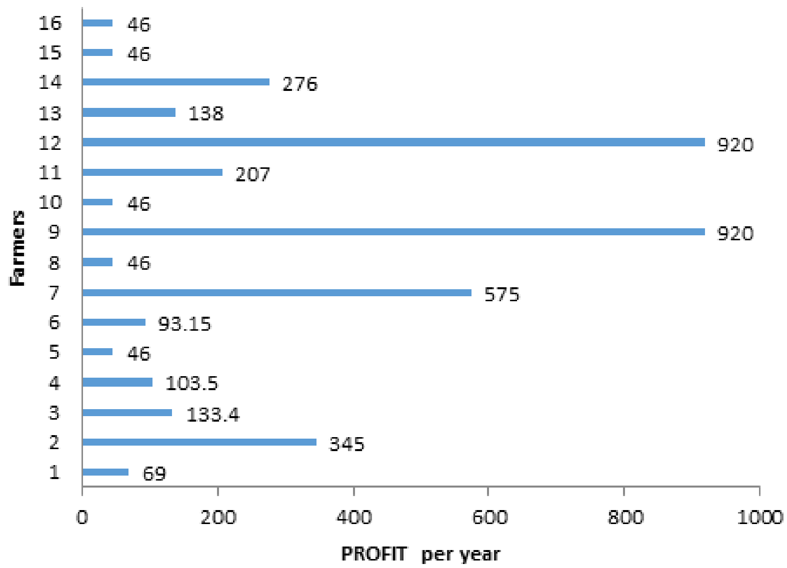


**Figure 2.** Profit of farmers earned for the year 2014 along the river-canal (in USD) (Source: own computation from fish farmers data).

**Table 2.** Descriptive statistics of profit earned along the rain-fed ponds under government market price (in USD).

| **Mean** | **-131.65** |
|---|---|
| Standard error | 110.01 |
| Standard deviation | 504.13 |
| Minimum | 2206.17 |
| Maximum | -1419.5 |
| Observation | 21 |

Source: Own computation from fish farmers data.

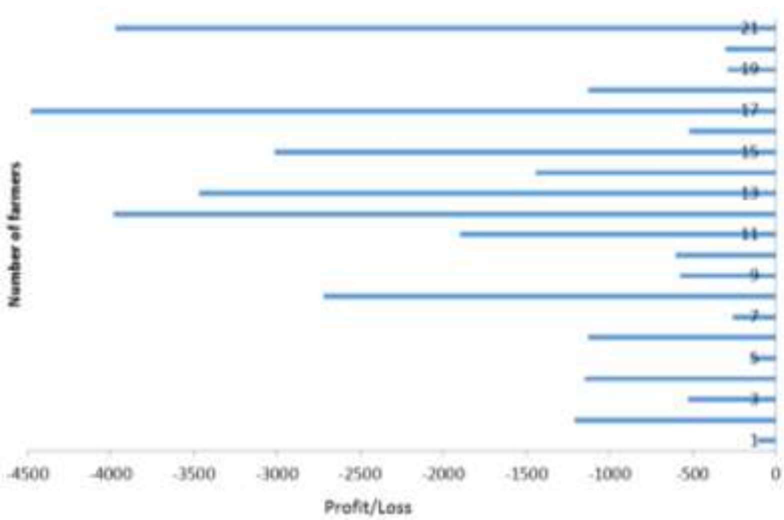


**Figure 3.** Individual SSFF profit earned for rain-fed ponds under government market price (Source: Own computation from fish farmers data).

**Table 3.** NPV for river-canal and rain-fed SSFF under Government market price.

| Variable | 4 % | 6 % | 8 % |
|---|---|---|---|
| NPV-canal ($1 equivalent to N$15) | $572 | $324. 20 | $121.4 |
| NPV –rain-fed | ($3592.00) | ($3389.00) | ($3208.00) |

Source: own computation from fish farmers data.

**Table 4.** Descriptive statistics along the river-canal.

| Mean | 483.07 |
|---|---|
| Standard error | 143.40 |
| Median | 228.33 |
| Mode | 88.67 |
| Standard deviation | 573.53 |
| Minimum | 88.67 |
| Maximum | 1773.33 |
| Observation | 16 |

Source: own computation from fish farmers data.

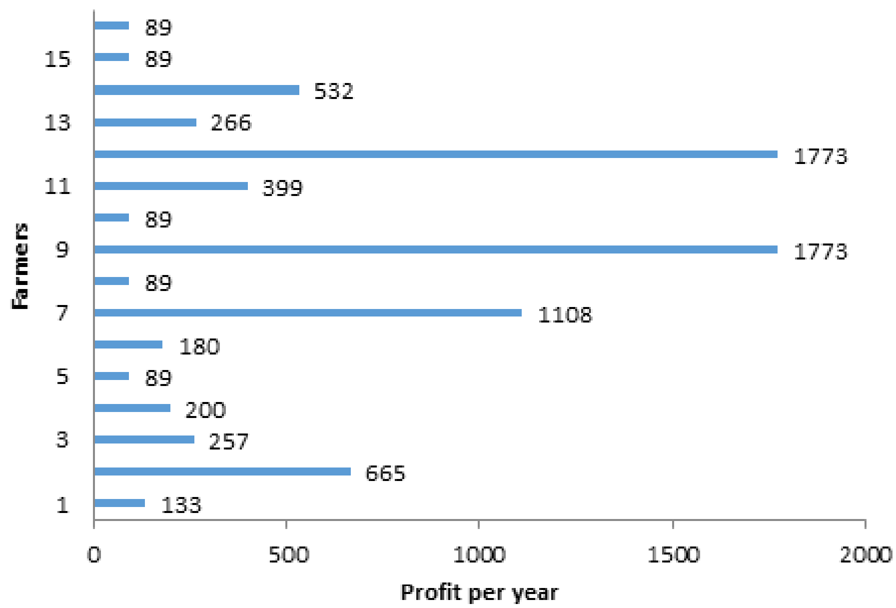


**Figure 4.** Profit of farmers earned for the year 2014 along the canal (Source: Own computation from fish farmers data).

respectively.

As shown in Figure 4, only three farmers managed to earn profit of more than $1 0000, and the remaining farmers below $700. This shows clearly that there is capacity, and that other support systems such as government technical and direct support and or financial assistance from the funding systems would have changed the situation.

***Profit earned by farmers dependent on rain-fed***

Although assuming an open market, it has been observed that not every farmer would have that access to have operations running at a loss (Table 5).

As indicated in Figure 5, for farmers depending on rain-fed with the second scenario, the individual profitability shows that half of the farmers are making marginal

**Table 5.** Descriptive statistics along the rain-fed operations.

| Mean | -131.67 |
|---|---|
| Standard error | 110.00 |
| Median | -91.33 |
| Standard deviation | 504.13 |
| Minimum | -1419.53 |
| Maximum | 786.67 |
| Observation | 21 |

Source: own computation from fish farmers data.

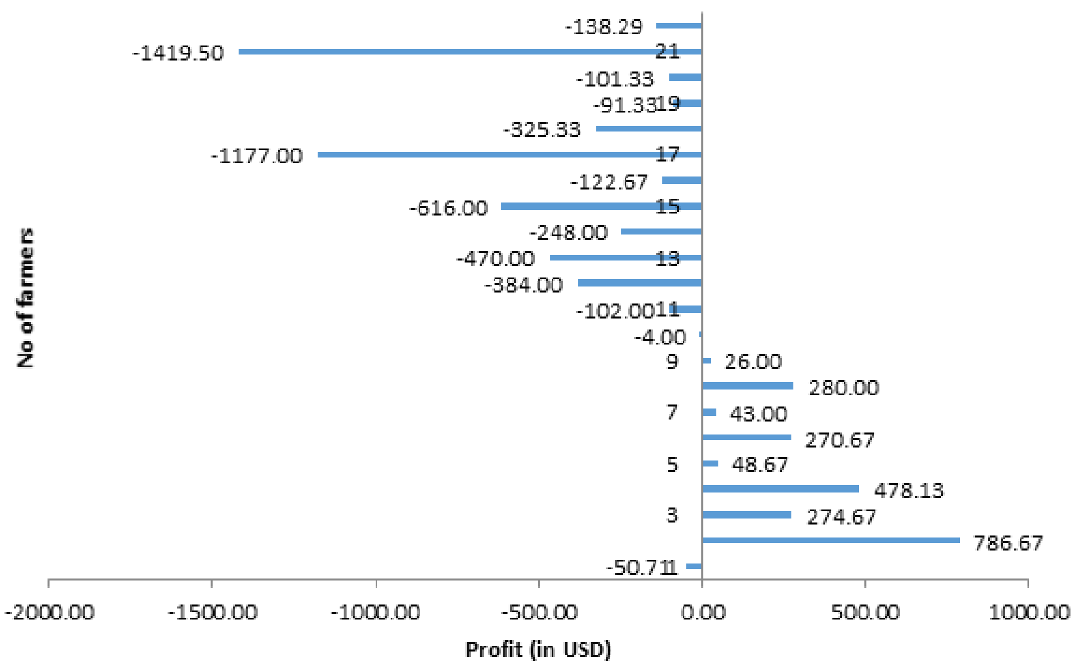


**Figure 5.** Profit of farmers earned for the year 2014 along the rain-fed operations (Source: own computation from fish farmers data).

profits, with a maximum of about $787, while the other half of the farmers (11 farmers) are making losses, with the biggest loss made at about $1420.

Table 6 shows that when the time value of money is considered in the calculation, discounted over 13 years, the NPV for the canal site area are relatively low, with earnings for example at 4 % of about $3718.40 (on average, around N$318.25 per annum). However, the picture of the farming system for the rain-fed operations continues to incur loss.

Similar to this, Ahmed (2004), Carney (1998), Devereux and Maxwell (2001), Martinez-Espinosa (1995), Edwards et al. (2002) and Muir (1999) have found the major constraints of small-scale aquaculture in third world countries:

**Table 6.** NPV for river-canal and rain-fed SSFF (in USD).

| Variable | 4 % | 6 % | 8 % |
|---|---|---|---|
| NPV-Canal | $3 718.40 | $3 082.14 | $2 554.61 |
| NPV –Rain-fed | ($1 273.42) | ($1 256.02) | ($1 238.66) |

Source: own computation from fish farmers data.

The need to have stable access to water and/or land for cages or ponds, implying that a lack of stable access to water and/or land is a widespread feature of poverty in many rural areas.

Possible market limitations – seasonal gluts/high prices in other circumstances.

Wealth creation dynamics may be disadvantage to poorest sectors. A frequently encountered feature of poverty is the difficulty that the poor have in maintaining control of assets that acquire value. For example, open or underutilised water bodies may be of no interest to wealthier groups until their value is demonstrated, in which case the poor may have great difficulty in maintaining control.

The need to address potential resource access conflicts; the poor are able to exert little influence over decision-making and conflict resolution mechanisms because of their lack of political capital.

The technical skills involved may be relatively complex; because the poor are almost entirely engaged in ensuring their day-to-day survival, they have little time to invest in education and often lack the skills required for activities that are more complex. Similarly, access to information, including technical information on how to conduct aquaculture, may represent a significant challenge for the poor.

The risks involved in adopting a new activity may be perceived as (and on occasions actually are) high. The poor tend to be, of necessity, risk averse as any increase in risk can have disastrous implications for those already living on the borderline of destitution.

Another study from West Africa by Sofoluwe et al. (2011), and that by Nzeadibe et al. (2011), record how the authors applied multinomial logit model and descriptive statistics to show evidence on the linkage between perceptions, and factors determining farmers' adoption. Furthermore, gender, age of farmer, years of farming experience, household size, years of education, access to credit facilities, access to extension services, and off-farm income activities are among the significant determinants for adaptation of aquaculture in the context of Africa.

The major question that comes with this result is that if farmers continue to incur loss, why do the farmers continue to farm? As a result, about 87% of the farmers have decided to stop farming system operations before incurring further damage. However, when a query was made as to why those 13% of the original registered farmers under MFMR have continued to farm, the following reasons were given as their motivation to continue:

Farmers believe fish farming is more of a personal choice than a requirement. The driving force for fish farming is more of a status symbol than of economic benefit.

During times of severe drought, fish resources are exploited. Therefore, farming is undertaken for nutritional benefits or as a supplement to their diets.

Farmers are engaged in fish farming as a result of cultural development; the farmers want to promote the consumption of fish to curb the high rates of cholesterol and gout.

Government intervention in the development of the region (or rural communities) profoundly influences the way in which farmers respond to new technologies. In this case, the farmers are motivated to continue because of the benefits associated with fish farming, e.g. subsidised fish feed and fingerlings, technical assistance, and for some farmers, the benefit of gaining donor aid through government programmes to assist them.

Government of Namibia and freshwater aquaculture development in Namibia has been shortlisted as a viable means for food security and poverty alleviation in rural areas by the post-independence government of Namibia. As a result, a comprehensive and detailed framework to achieve this goal has since been developed and currently, the Namibian Aquaculture Act (2002) is in place and readily available to interested parties who wish to become a participant in this sector (Ministry of Fisheries and Marine Resources, 2014).

However, the weakest link of freshwater aquaculture in the Northern Namibia fails to integrate fresh water to crop and poultry production. Poultry manure can be used to fertilise the fish pond water to encourage natural production which aids in the maintenance of water quality, oxygenation and natural food supplement. In turn, nutrient rich effluent water from freshwater aquaculture systems has been proven beneficial in all types of crop production which eliminates the use of artificial fertilisers; however, due to the missing link in majority of Northern part of Namibia the aquaculture initiative either from rain-fed or along the cannel could not be sustainable as indicated in the financial viability of the project.

The Northern part of Namibia fresh water projects could not be sustainable due to semi-arid and possess no perennial rivers, natural lakes or man-made reservoirs. The only viable source of freshwater should have been by means of underground water extraction. In addition to the extreme climatic conditions (0 to 40°C temperatures are commonly experienced in winter and summer respectively), it is deemed environmentally unsustainable to have an aquaculture setup in open air for reasons of high evaporation rates and unsuitable water conditions to grow tropical food fish such as *Oreochromis mossambicus* species that possibly can adapt the hot Northern Namibia. Therefore, the aquaculture should have been constructed in an indoor greenhouse environment to curb the high evaporation rates and maintain suitable environmental conditions for the fish, which could have been possible only through sustainability with it being thoroughly research for environmental impact assessment in collaboration with research institution; and also government and NGOs could have support financially.

Recirculating systems are deemed economically unsustainable due to the high capital input required for start-up and maintenance as well as the high feed costs and high demand for technical expertise. Open air earthen ponds on the other hand will not be suitable due to the relative high water requirements (loss through evaporation) and extreme climate conditions. Therefore, ponds constructed in greenhouses will be best suited for Namibian weather conditions.

Greenhouse constructed with heavy duty transparent plastic will cover the pond. This will ensure elevated water temperatures during winter and reduced evaporation rates during the summer. Furthermore, the transparent plastic will allow natural sunlight to penetrate the water which will ensure natural food production (phyto- and zooplankton). The pond will be lined with a heavy duty and chemically inert plastic to prevent drainage. The pond water will be continuously agitated by means of electrical air blowers and water circulation will be achieved by means of single two phase electrical water pump to aid water quality maintenance. Drainage of the pond will be achieved by means of a single outlet connected to a series of valves inline to the pump used for water circulation. Electrical components in this system will depend on solar generated electricity and will run 24 h daily.

As indicated in MFMR (2004), in the Namibia aquaculture strategic plan, Current policy for this developing sector is laid out in the policy paper: Towards the Responsible Development of Aquaculture (2001). Under this policy, Namibia is committed to observe the principle of optimum sustainable yield in the exploitation of living natural resources and ecosystems. The Government therefore has an obligation to promote and regulate responsible and sustainable development and management of aquaculture within national water bodies of all types.

The main objective of Namibia’s aquaculture policy is the responsible and sustainable development of aquaculture to achieve socio-economic benefits for all Namibians and to secure environmental sustainability. The policy rests on four strategies:

- Establishing an appropriate legal and administrative framework for aquaculture, including establishing systems of tenure for commercial aquaculture;
- Establishing appropriate institutional arrangements for aquaculture;
- Maintaining genetic diversity and the integrity of the aquatic ecosystem; and
- Ensuring responsible aquaculture production practices.

However, the economic support to the industry should also be incorporated as an objective to ensure that seed money to stimulate the industry is made available.

In 2002, the Aquaculture Act was passed by Parliament and came into force in June 2003. This prescribes, *inter alia*, the procedure for obtaining aquaculture licences, monitoring, regulation, processing, marketing, environmental safety measures and consumer health and safety issues

While the aquaculture industry continues its strong growth overseas, Africa in general and Namibia in particular continues to lag far behind in the development of its industry. To remedy this, the Government will endeavour to provide this fledgling industry with opportunities for start-up capital, research and development funds, marketing and promotion support, and education and training. These efforts must take an approach whereby the State uses industry expertise and experience to help it identify germane areas of applied research that will actively promote the development of the national aquaculture industry. Likewise, the industry can help guide and develop useful financing programs, appropriate education programs, and effective marketing and promotion efforts.

## CONCLUSION AND RECOMMENDATIONS

The study shows that out of 568 registered farmers, only 76 farmers continued farming, which is clearly attributable to the continued financial losses due to drought (specifically in rain-fed areas) rendering the majority unable to farm. As this study indicates, the poor support systems in terms of farming infrastructure, training opportunity, transport and marketing means that aquaculture will not be sustainable, if not managed well. This includes management incorporating production, processing, storage and distribution. Production, marketing and infrastructure include cold-chain storage, the lack of which has hampered the SSFF production system.

In conclusion, small-scale farming systems require a total reform, for all actors in the sector. It is very important to assess the small-scale farming system in Namibia, and to make it more sustainable. Government should assist farmers so that they can make a real contribution to the sector. Furthermore, it is very important to assess the social, economic and environmental components before approving SSFF operations.

As indicated in the discussion, the missing link on the aquaculture initiative, depending on the rain fed or depending on the cannel, due to high extreme climatic conditions up to 40°C temperatures are commonly experienced during summer, it is deemed environmentally unsustainable to have an aquaculture setup in open air due to high evaporation; as a result using underground water recycling integrating with crop and poultry; which is the only viable source of freshwater; in addition to the extreme climatic conditions. It is deemed environmentally unsustainable to have an aquaculture setup in open air for reasons of high evaporation rates and unsuitable water conditions to grow tropical food fish such as *O. mossambicus* species that possibly can adapt the hot Northern Namibia; in doing so research institution is required to support with skill and knowledge; whereas, government and NGOs with financing could make the fish farming viable.

With the policy implication of this study, networks and social capital related policy are important; thus networks of community groups are also important for those already operating SSFFs, therefore, government needs to assist through policy instruments to configure the problem (for example, climate risk). Local savings scheme policies are also important, that is, providing useful financial 'stores', to be drawn down during times of stress.

Commercialisation of SSFF is important and involves the government designing a framework that is not focused on a "pro-poor" angle, but rather on a bigger scale. Therefore, designing an economically viable model should be more focused on commercialising the sector than on small-scale operations, so that the government might reach their objectives of food production, income generation and job creation.

## Conflict of interests

The authors have not declared any conflict of interests.

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# Agronomic performance and industrial yield of sugarcane under water-saving irrigation in cerrado soil

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**The objective of this study was to evaluate the growth and gross yield of sugar and ethanol of first-year sugarcane with water-saving irrigation via hose-drawn traveller using a line of sprinklers. The experimental design was randomized blocks, analyzed in a split plot scheme with four replications. The factors evaluated in the plots consisted of five levels water-saving irrigation applied after planting (0, 30, 45, 60 and 75 mm). The subplots were represented by four evaluation periods (90, 170, 250 and 330 days after planting - DAP). The sugar yield and gross alcohol yield were evaluated punctually at the end of the cycle to 330 DAP. In the central lines of the subplots, the morphological characteristics relative to plant height, culm diameter, internodes length, number of sugarcane plants, number of leaves, leaf area, leaf length and leaf width, were evaluated. The gross yields of sugar and alcohol were calculated using the raw sugar value determined by technological analysis of the broth from a sample with 12 culms per experimental unit. Water-saving irrigation provides a positive effect on leaf length, leaf area, plant height and number of sugarcane plants. Water-saving irrigation of 75 mm definitely promotes an increase of 30% in gross sugar and alcohol yield.**

**Key words:** *Saccharum officinarum* L., hose-drawn traveller, alcohol yield, water deficit.

## INTRODUCTION

Currently, increases in productivity of sugarcane have been achieved combined with a higher quality and gross yield of sugar and alcohol from sugarcane raw material, in large part due to the use of irrigation (Simões et al., 2015).

The use of irrigation in the culture of sugarcane is essential for growth, development and increased crop productivity (Souza et al., 2015). Irrigation provides productivity expectation well above the minimum required for renewal of the area favoring much greater potential of longevity of sugarcane (Silva et al., 2014).

There is a strong correlation between levels irrigation

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and the variables that define the quality of the raw material of sugarcane, mainly the content of total recoverable sugars, the total soluble solids (Brix°), the pol, the purity and the pol percent cane (PCC) increased in proportion with the irrigation water levels (Farias et al., 2009).

In the sugarcane culture, different types of irrigation are used, including irrigation by mechanized spraying, self-propelled, center pivot and subsurface drip irrigation (Quintana, 2010).

In self-propelled irrigation systems currently available in the domestic market, there are two distinct forms of water spray for crops: Irrigation bar or hydraulic cylinder (Prado, 2008). The use of self-propelled spraying with an irrigation bar is highlighted. The irrigation bar can replace the cylinder spray in lower slope areas, with the advantage of a more uniform distribution of water and droplets with a smaller diameter (Marouelli et al., 2013).

From the different investments aiming to increase the yield of sugarcane, water-saving irrigation should be highlighted, as it may result in an increased production without expanding the agricultural area (Dalri et al., 2008; Dalri and Cruz, 2002, 2008; Quintana, 2010). Thus, water-saving irrigation of sugarcane is one of the technological alternatives that pursue the increase in production in areas previously marginalized by water deficit (Teixeira et al., 2012).

Throughout its growth, sugarcane needs good soil moisture conditions to express all its productive potential (Silva et al., 2008). Consequently, the yield and the production of sugar and ethanol from irrigated sugarcane depend on the amount of water applied and on the irrigation management (Dantas Neto et al., 2006). Therefore, the hypothesis is that water-saving irrigation promotes a greater efficiency in the culture of sugarcane.

The objective of this study was to evaluate the growth and gross yield of sugar and ethanol of first-year sugarcane with water-saving irrigation via hose-drawn traveller using a line of sprinklers.

## MATERIALS AND METHODS

The experiment was carried out in July 2013, during the crop cycle of the cane plant of the variety SP83-5073 in the Boa Vista mill located in the municipality of Quirinópolis – GO, which has a soil classified as distroferric Red Latosol cerrado phase, according to Embrapa (2013). The climate is () classified according to Köppen and Geiger (1928) climate classification as tropical savanna with dry winter and rainy summer (Aw), with an annual rainfall between 1430 and 1650 mm, and drought period well defined between May and October.

The experimental design was randomized blocks, analyzed in a split plot scheme with four replications. The factors evaluated in the plots consisted of five levels water-saving irrigation (WSI) applied after planting (0, 30, 45, 60 and 75 mm). The subplots were represented by four evaluation periods (90, 170, 250 and 330 days after planting - DAP).

The experimental plots, in virtue of the proportion of the area wetted by the irrigation equipment, were 50.0 m long and 50.0 m wide (33 crop lines with 1.5 m spacing), with a total area of 2500.0 $m^2$. The subplots were composed of 5.0 m of 2 lines, located in the center of the plot.

The application process was made according to the management adopted in every area of commercial cultivation of the mill. During soil preparation, spread fertilization was carried out with incorporation by average grade for the layer 15 cm deep. The planting fertilizer used was according to the soil analysis (Table 1) in accordance with the recommendations of Sousa and Lobato (2004). The recommendation was 200 kg $ha^{-1}$ of $P_2O_5$ in the form of simple superphosphate. As for the K and N sources, the concentrated stillage enriched with urea, totaling 180 kg $ha^{-1}$ $K_2O$ and 100 kg $ha^{-1}$ nitrogen was used. For micronutrients, the dose of 100 kg $ha^{-1}$ in the form of granulated Fritted Trace Elements (FTE), being 4 kg $ha^{-1}$ zinc, 2 kg $ha^{-1}$ boron and 2 kg $ha^{-1}$ copper was used. The nitrogen coverage fertilization was performed 60 days after planting, where 120 kg $ha^{-1}$ N (urea) were applied on both sides of the lines.

Water-saving irrigation was carried out by a self-propelled reel winder, model 140/GSV/350-4RII, coupled to an irrigation bar, model 48/54; MDPE tube with 140 mm outer diameter and length of 350 m; wall thickness of 10.3 mm, with lattices 24.5 m long on each side, totaling 49.0 m of adjustable structure, allowing the irrigation of sugarcane to 4.0 m high, with height compensation system through telescopic wheels installed along the lattices, the central car of the bar was operated with 3.0 m width. The emitters spaced at 1.85 m were used, totaling 26 emitters; the working pressure in the bomb was 10 Kgf $cm^{-2}$ and in the reel was 5 Kgf $cm^{-2}$; the reel was operated with an average wind speed of 14.5 m $s^{-1}$. The application of the water volume was located between the lines of the varieties of sugarcane, but the wetness of the experimental area was total.

During the crop cycle, variety SP83-5073, weather data were collected daily, obtained by the meteorological station of the mill; being the reference evapotranspiration ($ET_0$) calculated according to the equation of Penman-Monteith-FAO/56 (Allen et al., 1998) (Table 2).

The number of leaves was determined by counting the fully expanded leaves with a minimum of 20% of green area, counted from the +1 leaf; the leaf area was determined by counting the number of green leaves (fully expanded leaf with minimum of 20% green area, counted from the +1 leaf) and the measurements on +3 leaves, being obtained the leaf length and width in the middle portion, according to the methodology described by Hermann and Câmara (1999):

$$\mathrm{LA} = 0.75 \times \mathrm{L} \times \mathrm{W} \times (\mathrm{NF} + 2) \quad (1)$$

Where, L = length of the +3 leaf; W = width of the +3 leaf; 0.75 = correction factor for the leaf area of the culture; NF = number of expanded leaves with at least 20% green area.

The number of sugarcane plants was determined by counting all plants in the parcel containing more than six fully expanded leaves. The sugar yield and gross alcohol yield were evaluated punctually at the end of the cycle to 330 DAP.

The gross yields of sugar and alcohol were calculated using the raw sugar value determined by technological analysis of the broth from a sample with 12 culms per experimental unit. Equations 2 and 3 according to the methodology described by Caldas (1998) were used:

$$YSu = \left( \frac{\mathrm{PCC} \times \mathrm{PC}}{100} \right) \quad (2)$$

Where: YSu = sugar yield in t $ha^{-1}$; PCC = percentage of raw sugar contained in the culms and determined in the laboratory; PC = culm production in t $ha^{-1}$.

**Table 1.** Physical, water and chemical characteristics of the soil in the experiment area.

| Physical and water characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Layer | FC | PWP | Micro | Macro | TP | PD | Sd | PR |
| m | ----------%---------- | | | | $cm^3$ | ------g $cm^{-3}$------ | | MPa |
| 0.00-0.20 | 66.5 | 45.39 | 67.28 | 24.30 | 42.97 | 2.24 | 1.28 | 5.04 |
| 0.10-0.20 | 70.75 | 41.14 | 71.16 | 23.68 | 47.47 | 2.39 | 1.25 | 3.17 |
| 0.20-0.40 | 56.5 | 34.92 | 56.84 | 13.33 | 43.51 | 2.27 | 1.28 | 5.19 |

| | Granulometry | | | Textural class |
|---|---|---|---|---|
| | Clay | Silt | Sand | |
| | ------%------ | | | |
| 0.00-0.20 | 27.50 | 6.90 | 65.60 | Sandy |
| 0.20-0.40 | 45.06 | 4.04 | 50.90 | Sandy |

| Chemical characteristics | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Layer | pH | O.M | P | K | Ca | Mg | Al | H+Al | SB | CTC | V |
| m | in $H_20$ | g $kg^{-1}$ | mg $dm^{-3}$ | ------(mmol $dm^{-3}$)------ | | | | | | | (%) |
| 0.00-0.20 | 6.1 | 60.4 | 8.2 | 3.0 | 21.3 | 15.7 | 0.0 | 55.7 | 45.8 | 95.5 | 45.9 |
| 0.20-0.40 | 6.3 | 45.5 | 2.1 | 4.2 | 15.4 | 14.2 | 0.0 | 45.5 | 35.7 | 75.2 | 40.5 |

FC, Field capacity; PWP, permanent wilting point; Micro, microporosity; Macro, macroporosity; TP, total porosity; PD, particle density; Sd, soil density; PR,penetration resistance; pH in distilled water. P and K, extractor Mehlich$^{-1}$. O.M, organic matter; T, Cation exchange capacity; SB, sum of bases; V, saturation per base.

**Table 2.** Monthly data of temperature (maximum, minimum and average), relative humidity, Rainfall and reference evapotranspiration.

| Year | Month | Temperature (ºC) | | | RH | Rainfall | $ET_0$ |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Average | % | mm | mm $day^{-1}$ |
| 2013 | 6 | 31.08 | 17.94 | 24.51 | 66.91 | 11 | 4.12 |
| | 7 | 29.11 | 13.94 | 21.53 | 60.90 | 0 | 3.99 |
| | 8 | 31.12 | 14.02 | 22.57 | 45.47 | 0 | 4.61 |
| | 9 | 33.41 | 18.60 | 26.00 | 58.44 | 13 | 5.05 |
| | 10 | 33.47 | 20.92 | 27.20 | 55.66 | 121 | 5.18 |
| | 11 | 32.20 | 21.07 | 26.64 | 79.25 | 105 | 4.88 |
| | 12 | 32.52 | 22.30 | 27.41 | 84.13 | 235.6 | 5.00 |
| 2014 | 1 | 29.4 | 20.4 | 23.21 | 77.99 | 206.0 | 5.3 |
| | 2 | 30.4 | 19.7 | 23.64 | 74.39 | 376.0 | 5.1 |
| | 3 | 28.7 | 19.14 | 23.11 | 82.54 | 315.0 | 4.8 |
| | 4 | 27.9 | 18.8 | 23.20 | 81.37 | 165 | 4.7 |
| | 5 | 26.7 | 18.4 | 21.37 | 70.49 | 40 | 4.5 |

In the central lines of the subplots, the morphological characteristics relative to plant height (PH); culm diameter (CD); internodes length (IL); number of sugarcane plants (NSP); number of leaves (NL); leaf area (LA); leaf length (LL) and leaf width (LW). The plant height was measured, with the aid of a tape measure, from the ground to the collar of the +1 leaf (+1 leaf is that in which the collar can be completely visualized), and expressed in cm; the culm diameter was determined with the aid of a caliper rule in the middle third of the plant, and expressed in mm.

$$Ay = ((PCC \times F) + ARL) \times Glf \times 10 \times PC \quad (3)$$

Where: Ay = gross alcohol yield in liters per ton of sugarcane in $m^3$ $ha^{-1}$; PCC = percentage of raw sugar contained in the culms and determined in the laboratory; F = stoichiometric conversion factor of glucose to a sucrose molecule plus another fructose molecule, equal to 1.052; ARL = percentage of free reducing sugars, whose values range from 0.7 to 0.85% (the distillery uses 0.7 for a high PCC); GLf = Gay Lussac factor of 0.6475; PC = culms production in t $ha^{-1}$.

The data were submitted to analysis of variance by F test at 5% probability, and in cases of significance, regression analysis was performed to the water-saving irrigation depths and the evaluation dates, using the statistical software SISVAR (Ferreira, 2011).

**Table 3.** Summary of ANOVA of number of leaves (NL), leaf length (LL), leaf width (LW) and leaf area (LA) of sugarcane in different times of evaluation with water-saving irrigation, Quirinópolis - GO, 2013/14.

| SV | DF | MS[1] | | | |
|---|---|---|---|---|---|
| | | NL | LL | LW | LA |
| WSI | 4 | 0.354$^{ns}$ | 403.35$^{*}$ | 0.035$^{ns}$ | 1,016,979.1$^{**}$ |
| Block | 3 | 0.361$^{ns}$ | 342.36$^{ns}$ | 0.259$^{ns}$ | 91,181.3$^{ns}$ |
| Residue (a) | 12 | 0.442 | 112.13 | 0.219 | 78,320.7 |
| DAP | 3 | 16.76$^{**}$ | 3,775.5$^{**}$ | 5.287$^{**}$ | 19,385,684.7$^{**}$ |
| WSI *DAP | 12 | 0.529$^{ns}$ | 343.36$^{*}$ | 0.243$^{ns}$ | 52,316.6$^{ns}$ |
| Residue (b) | 45 | 0.284 | 164.03 | 0.354 | 55,598.7 |
| $CV_1$ (%) | - | 10.24 | 7.52 | 11.02 | 7.39 |
| $CV_2$ (%) | - | 8.21 | 9.10 | 13.99 | 6.23 |

[1]Water-saving irrigation (WSI); Days after planting (DAP). Source of variation (SV), Degree of freedom (DF), mean square (MS) and coefficient of variation (CV). ** and * - significant at 1 and 5% probability, respectively; $^{ns}$ not significant by F test at 5% probability.

## RESULTS AND DISCUSSION

In the summary of analysis of variance, it is observed that there was a significant interaction between the factors water-saving irrigation (WSI) and days after planting (DAP) for the variable leaf length, and there was a significant isolated effect for leaf area regarding WSI and DAP. Concerning the number of leaves and leaf width, there was a significance only for DAP (Table 3). Silva et al. (2015) also found that there were no significant effects of irrigation on number of leaves in the early stage of sugarcane, while for leaf area they found an effect of irrigation at all stages of sugarcane. Farias et al. (2007) also noted that there was a great influence of irrigation on leaf area index during the growing season.

The number of leaves of sugarcane plants at every 80 days had an increase of 9.1% (Figure 1A). The maximum leaf width sugarcane plants was observed at 225 days after planting (approximately five leaves), which is 21.7, 3.6, 0.72 and 12.9% higher than that observed at 90, 170, 250 and 330 DAP, respectively (Figure 1B). Silva et al. (2012) observed that the maximum area of individual leaves respond to the length of the leaves as soon as the width tends to stabilize.

Leaf length and leaf area adapted to linear growth in function of water-saving irrigation in sugarcane plants. According to the regression equation obtained, there was an increase of 4.9 and 3.2% for each 15 mm increase for leaf length (at 90 DAP) and leaf area of sugarcane by using water-saving irrigation (Figure 2A and C). The leaf area had an increase of 14.7% every 80 days in function of days after planting (Figure 2D).

The maximum leaf length found in water-saving irrigation (0, 30, 45 and 60 mm) was virtually equal. It was an average of approximately 1.54 m, which was observed at 276, 240, 222 and 229 days after planting, respectively. The maximum leaf length showed a difference of 39.7, 12.9, 0.78 and 3.3% (0 mm water-saving irrigation), 16.9, 3.7, 0.07 and 6.1% (30 mm water-saving irrigation), 16.9, 2.6, 0.74 and 11.2% (45 mm water-saving irrigation) and 17.9, 3.3, 0.39 and 9.3% (60 mm water-saving irrigation), compared to leaf length observed at 90, 170, 250 and 330 DAP, respectively (Figure 2B).

The water-saving irrigation in general, provided a major growth of leaves, mainly in length; when compared the treatments with and without water-saving irrigation it was verified accented differences in relation to the size of the leaves, resulting in lower leaf area which occurred preferentially in the initial stages. For better productivity, yields of sugar and alcohol to sugarcane needs a shoot well-developed, for this is very important that the differences in leaf size (initial stages) with respect to the maximum leaf growth will be smaller, the longest time possible, thus obtaining a major rate development of shoot.

The culture yield of sugarcane and the expansion of its leaf area are directly related because rapid growth of leaf area maximizes the interception of solar radiation and accumulation of biomass, increasing the yield of sugarcane (Inman-Bamber, 1994; Hanauer, 2011).

The water-saving irrigation in sugarcane plants was significant at 1% probability for plant height and number of sugarcane plants, as well as days after planting. There was a significant effect at 1% probability in relation to DAP for internode length and culm diameter (Table 4). Souza et al. (2015) found a significant effect of irrigation on plants' growth in height and on culm phytomass of sugarcane (variety SP 79-1011). Silva et al. (2009) found in this variety that the sugarcane growth parameters values, related to the number of culms, culm length, culm diameter, number of internodes and culm weight, responded significantly to irrigation.

The number of sugarcane plants and plant height with water-saving irrigation indicated a total increase of 19.8 and 18.7% compared to 0 and 75 mm water-saving irrigation (Figure 3A and C). Farias et al. (2008) verified lower values of plant height (1.53 m) and increase of only

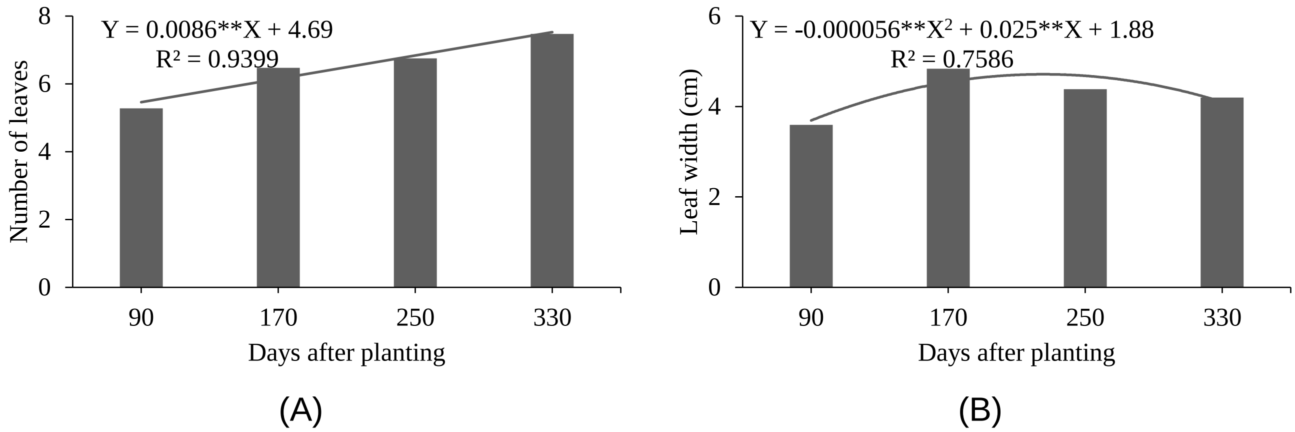


**Figure 1.** Number of leaves (A) and leaf width (B) of sugarcane in function of days after planting, Quirinópolis - GO, 2013/14. ** and *, significant at 1 and 5% probability, respectively by F test at 5% probability.

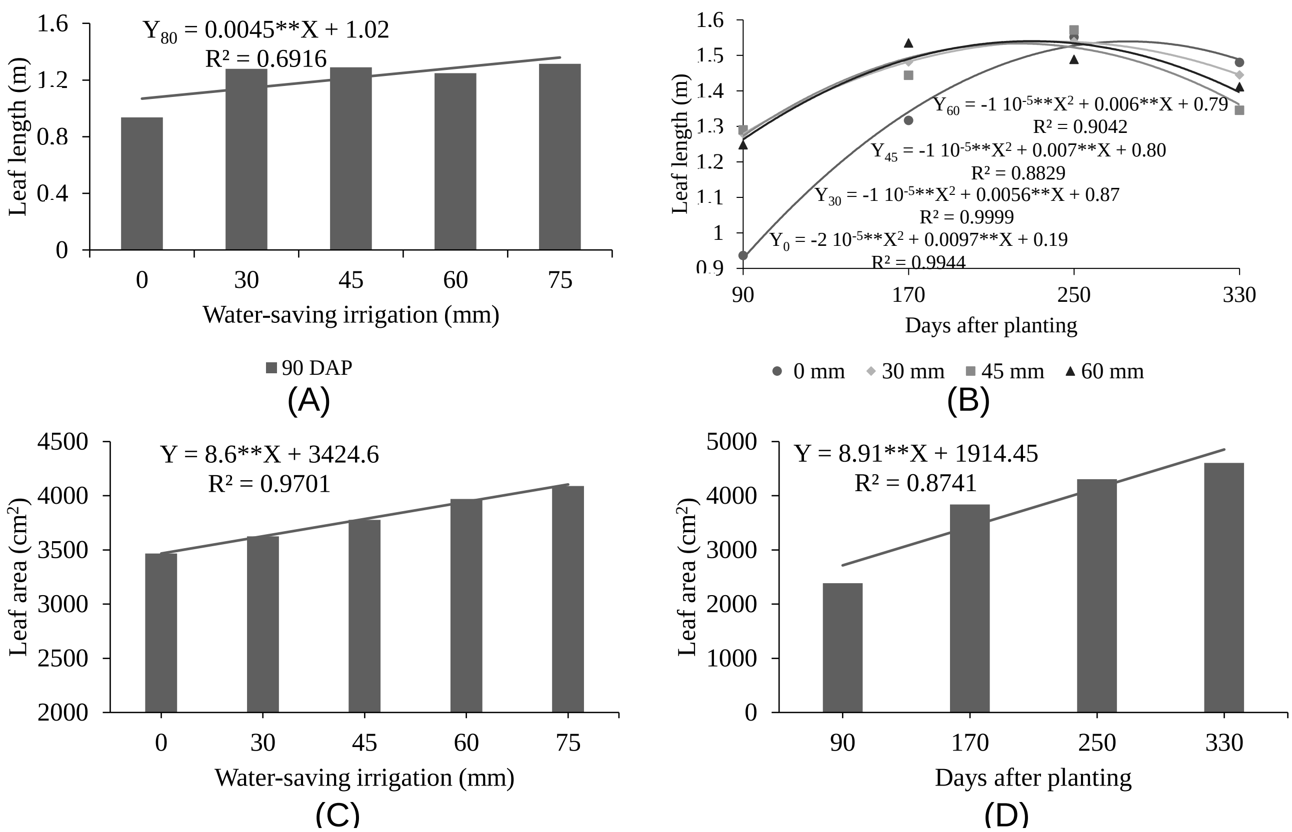


**Figure 2.** Leaf length and leaf area of sugarcane in function of water-saving irrigation (A and C) and of days after planting (B and D), Quirinópolis - GO, 2013/14. ** and *, significant at 1 and 5% probability, respectively by F test at 5% probability.

4 cm in plant height compared with cultivation rainfed. The number of plants and plant height in function of days after planting in sugarcane plants adapted to a linear model, indicating an increase of 11.4 and 24.2% every 80 days (Figure 3B and D).

The internode length increased by 6.4% every 80 days. Thus, a total increase of 19.3% between 90 and 330 days after planting can be seen (Figure 4A). Culm diameter in function of days after planting adapted to a quadratic model with $R^2$ = 98.8%. There was an increase in culm

**Table 4.** Summary of ANOVA of plant height (PHe), internode length (IL), culm diameter (CD) and number of sugarcane plants (NSP) in different times of evaluation with water-saving irrigation, Quirinópolis - GO, 2013/14.

| SV | DF | MS[1] | | | |
|---|---|---|---|---|---|
| | | PHe | IL | CD | NSP |
| WSI | 4 | 3,422.46** | 7.295$^{ns}$ | 6.43$^{ns}$ | 533.52** |
| Block | 3 | 913.552* | 0.612$^{ns}$ | 4.96$^{ns}$ | 310.00* |
| Residue (a) | 12 | 195.2121 | 2.957 | 5.09 | 77.18 |
| DAP | 3 | 124,357.6** | 21.29** | 32.6** | 4,026.52** |
| WSI *DAP | 12 | 74.7027$^{ns}$ | 1.433$^{ns}$ | 3.78$^{ns}$ | 65.16$^{ns}$ |
| Residue (b) | 45 | 345.6377 | 3.511 | 4.59 | 100.01 |
| $CV_1$ (%) | - | 8.84 | 12.17 | 8.25 | 11.48 |
| $CV_2$ (%) | - | 11.76 | 13.26 | 7.83 | 13.07 |

[1]WSI, Water-saving irrigation; DAP, days after planting; SV, source of variation; DF, degree of freedom; MS, mean square; CV, coefficient of variation (). ** and * - significant at 1 and 5% probability, respectively; $^{ns}$ not significant by F test at 5% probability.

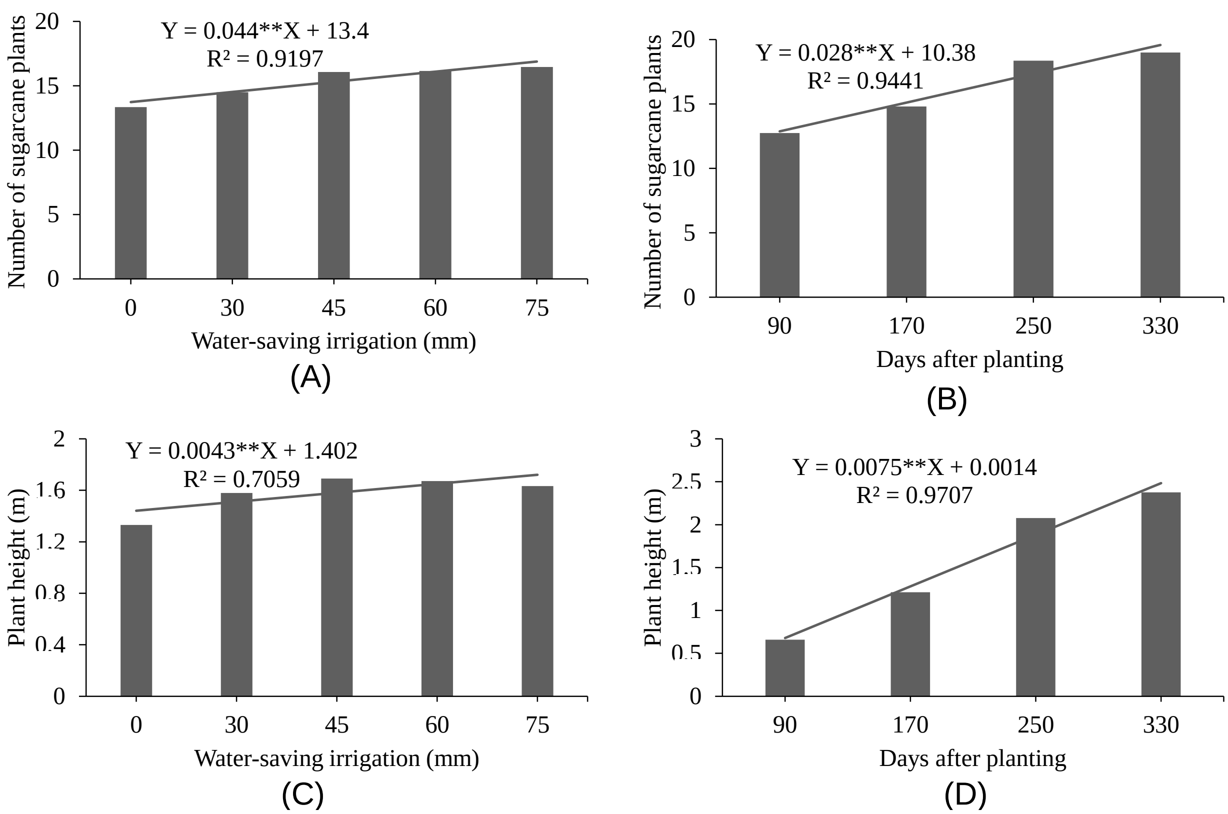


**Figure 3.** Number of sugarcane plants and plant height in function of water-saving irrigation (A and C) and of days after planting (B and D) of sugarcane, Quirinópolis - GO, 2013/14. ** and *, significant at 1 and 5% probability, respectively by F test at 5% probability.

diameter up to 256 DAP. In this period, a culm diameter of approximately 28.4 mm was reached. The maximum culm diameter verified at 256 DAP was 10.2, 2.7 and 2% larger than the culm diameter observed at 90, 170 and 330 DAP, respectively (Figure 4B). Silva (2007) and Oliveira et al. (2010) observed culm diameter of approximately 27 mm in the RB867515 and RB72454 varieties.

With water-saving irrigation, it was verified a major number of sugarcane plants. Water-saving irrigation did not influence the culm diameter; however, it should be highlight that the plant height has a major effect on

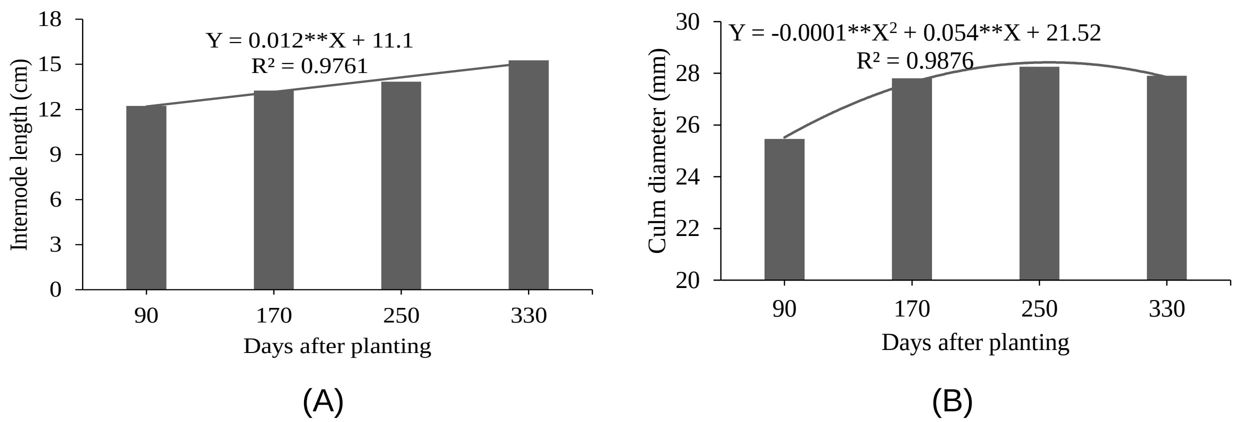


**Figure 4.** Internode length (A) and culm diameter (B) of sugarcane in function of days after planting, Quirinópolis - GO, 2013/14. ** and *, Significant at 1 and 5% probability, respectively by F test at 5% probability.

**Table 5.** Summary of ANOVA of gross alcohol (GAY) and sugar yield (GSY) of sugarcane plants with water-saving irrigation (WSI), Quirinópolis - GO, 2013/14.

| SV | DF | MS[1] | |
|---|---|---|---|
| | | GSY | GAY |
| WSI | 4 | 19.59* | 9.884* |
| Block | 3 | 15.09$^{ns}$ | 7.583$^{ns}$ |
| Residue | 12 | 5.144 | 2.601 |
| CV (%) | - | 14.30 | 14.33 |

[1]SV Source of variation; DF, degree of freedom; MS, mean square; CV, coefficient of variation. ** and *, significant at 1 and 5% probability, respectively; $^{ns}$ not significant by F test at 5% probability.

productivity and yield of sugar and alcohol of sugarcane than the culm diameter, being responsible for increments quite considerable consequently verified that plants of sugarcane with water-saving irrigation demonstrated best performance in this variable.

The water-saving irrigation was significant at 5% probability for gross sugar yield and gross alcohol yield in sugarcane plants (Table 5). Carvalho et al. (2009) also observed a significant influence of irrigation on yield of sugar and alcohol.

The regression analysis showed a linear behavior for gross sugar and alcohol yield in function of water-saving irrigation ($R^2$ > 91%) for first-year sugarcane plants. Consequently, the maximum gross yield of sugar and alcohol was obtained with a 75 mm water-saving irrigation, indicating a difference of 30% in average yield in relation to absence of water-saving irrigation (Figure 5A and B).

Campos et al. (2014), evaluating varieties of sugarcane submitted to water-saving irrigation in the Cerrado of Goiás, concluded that water-saving irrigation of sugarcane in the Cerrado proved to be generally highly practicable, with a great response by most varieties, verified increases in average productivity of culms.

The gross sugar yield found in 60 and 75 mm water-saving irrigation was 17.2 and 18.3 t $ha^{-1}$. The gross sugar yield, according to the regression equation, obtained a 6.1% increase for each 15 mm increase of water-saving irrigation, thus demonstrating an increase in gross sugar yield of 0.07 t $ha^{-1}$ for every 1 mm increase in water-saving irrigation in sugarcane plants (Figure 5A).

The gross alcohol yield observed in the 60 and 75 mm water-saving irrigation was 12.2 and 12.98 $m^3$ $ha^{-1}$, soon verifying an increase of 6%, due to the 15 mm increase, which shows an increase in gross alcohol yield of approximately 0.05 $m^3$ $ha^{-1}$ for each 1 mm increase in water-saving irrigation in sugarcane plants (Figure 5B). Carvalho et al. (2009) noted that the increase in irrigation levels resulted in increases in the production of culm, the gross income of sugar and alcohol in gross income.

## Conclusion

Water-saving irrigation provides a positive effect on leaf length, leaf area, plant height and number of sugarcane plants. Water-saving irrigation of 75 mm definitely promotes an increase of 30% in gross sugar and alcohol

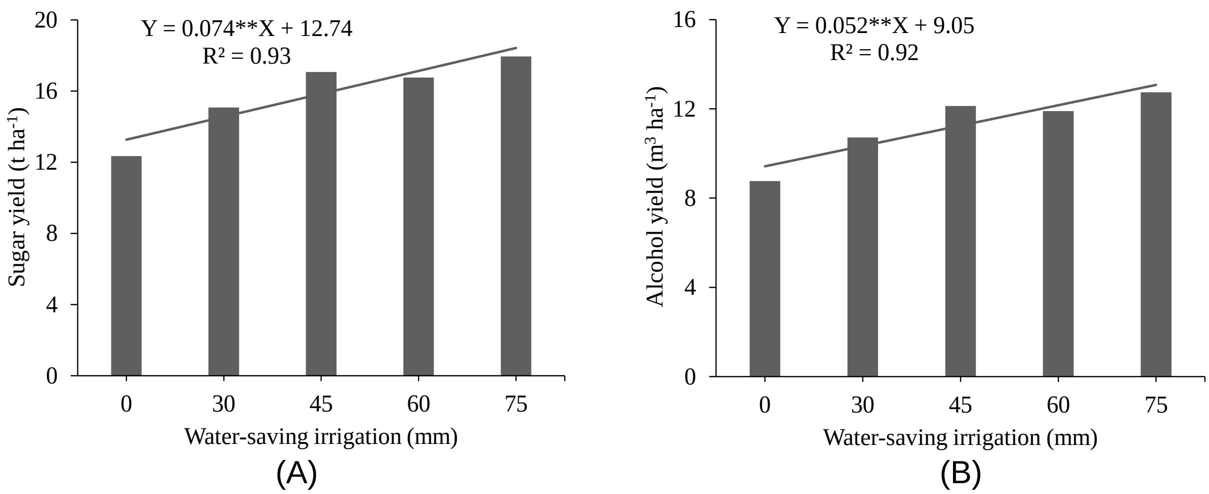


**Figure 5.** Yield of sugar (A) and alcohol (B) of sugarcane in function of water-saving irrigation, Quirinópolis - GO, 2013/14. ** and *, significant at 1 and 5% probability, respectively by F test at 5% probability.

yield. The results of this study demonstrate the viability of adopting the practice of water-saving irrigation. This suggests the need of more studies in the conditions edaphic and climatic of the region of southwest Goiano.

## Conflict of Interests

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

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