OPEN ACCESS

African Journal of
Agricultural Research

17 May, 2018
ISSN 1991-637X
DOI: 10.5897/AJAR
www.academicjournals.org

ACADEMIC
JOURNALS
expand your knowledge

ABOUT AJAR

The African Journal of Agricultural Research (AJAR) is published weekly (one volume per year) by Academic Journals.

African Journal of Agricultural Research (AJAR) is an open access journal that publishes high-quality solicited and unsolicited articles, in English, in all areas of agriculture including arid soil research and rehabilitation, agricultural genomics, stored products research, tree fruit production, pesticide science, postharvest biology and technology, seed science research, irrigation, agricultural engineering, water resources management, marine sciences, agronomy, animal science, physiology and morphology, aquaculture, crop science, dairy science, entomology, fish and fisheries, forestry, freshwater science, horticulture, poultry science, soil science, systematic biology, veterinary, virology, viticulture, weed biology, agricultural economics and agribusiness. All articles published in AJAR are peer- reviewed.

Contact Us

Editorial Office:	ajar@academicjournals.org
Help Desk:	helpdesk@academicjournals.org
Website:	http://www.academicjournals.org/journal/AJAR
Submit manuscript online	http://ms.academicjournals.me/

Editors

Prof. N.A. Amusa
Editor, African Journal of Agricultural Research
Academic Journals.

Dr. Panagiota Florou-Paneri
Laboratory of Nutrition,
Faculty of Veterinary Medicine,
Aristotle University of
Thessaloniki, Greece.

Prof. Dr. Abdul Majeed
Department of Botany, University of
Gujrat,India, Director Horticulture,
and
landscaping.
India.

Prof. Suleyman TABAN
Department of Soil Science and Plant
Nutrition, Faculty of Agriculture,
Ankara University,
06100 Ankara-TURKEY.

Prof.Hyo Choi
Graduate School
Gangneung-Wonju National University
Gangneung,
Gangwondo 210-
702, Korea.

Dr. MATIYAR RAHAMAN KHAN
AICRP (Nematode), Directorate of
Research, Bidhan Chandra Krishi
Viswavidyalaya, P.O. Kalyani, Nadia, PIN-
741235, West Bengal.
India.

Prof. Hamid AIT-AMAR
University of Science and Technology,
Houari Bouemdiene, B.P. 32, 16111 EL-Alia, Algiers,
Algeria.

Prof. Sheikh Raisuddin
Department of Medical Elementology and
Toxicology,Jamia Hamdard (Hamdard University)
New
Delhi,
India.

Prof. Ahmad Arzani
Department of Agronomy and Plant Breeding
College of Agriculture
Isfahan University of Technology
Isfahan-84156, Iran.

Dr. Bampidis Vasileios
National Agricultural Research Foundation
(NAGREF), Animal Research Institute 58100
Giannitsa,
Greece.

Dr. Zhang Yuanzhi
Laboratory of Space Technology,
University of Technology (HUT) Kilonkallio Espoo,
Finland.

Dr. Mboya E. Burudi
International Livestock Research Institute
(ILRI) P.O. Box 30709 Nairobi 00100,
Kenya.

Dr. Andres Cibils
Assistant Professor of Rangeland Science
Dept. of Animal and Range Sciences
Box 30003, MSC 3-I New Mexico State University
Las
Cruces,
NM 88003 (USA).

Dr. MAJID Sattari
Rice Research Institute of
Iran, Amol-Iran.

Dr. Agricola Odoi
University of Tennessee,
TN., USA.

Prof. Horst Kaiser
Department of Ichthyology and Fisheries Science
Rhodes University, PO Box
94, South Africa.

Prof. Xingkai Xu
Institute of Atmospheric Physics,
Chinese Academy of
Sciences, Beijing 100029,
China.

Dr. Agele, Samuel Ohikhena
Department of Crop, Soil and Pest
Management, Federal University of
Technology
PMB 704,
Akure,
Nigeria.

Dr. E.M. Aregheore
The University of the South Pacific,
School of Agriculture and Food Technology
Alafua Campus,
Apia, SAMOA

Editorial Board

Dr. Bradley G Fritz
Research Scientist,
Environmental Technology Division,
Battelle, Pacific Northwest National Laboratory,
902 Battelle Blvd., Richland,
Washington,
USA.

Dr. Almut Gerhardt LimCo
International, University of
Tuebingen, Germany.

Dr. Celin Acharya
Dr. K.S.Krishnan Research Associate (KSKRA),
Molecular Biology Division,
Bhabha Atomic Research Centre (BARC),
Trombay, Mumbai-85,
India.

Dr. Daizy R. Batish Department
of Botany, Panjab University,
Chandigarh,
India.

Dr. Seyed Mohammad Ali Razavi
University of Ferdowsi,
Department of Food Science and Technology,
Mashhad,
Iran.

Dr. Yasemin Kavdir
Canakkale Onsekiz Mart University,
Department of Soil Sciences, Terzioglu
Campus 17100
Canakkale
Turkey.

Prof. Giovanni Dinelli
Department of Agroenvironmental Science and
Technology
Viale Fanin 44 40100, Bologna
Italy.

Prof. Huanmin Zhou
College of Biotechnology at Inner Mongolia
Agricultural University,
Inner Mongolia Agricultural University, No. 306#
Zhao Wu Da Street,
Hohhot 010018, P. R. China, China.

Dr. Mohamed A. Dawoud

Water Resources Department,
Terrestrial Environment Research Centre,
Environmental Research and Wildlife Development Agency
(ERWDA),
P. O. Box 45553,
Abu Dhabi,
United Arab Emirates.

Dr. Phillip Retief Celliers
Dept. Agriculture and Game Management,
PO BOX 77000, NMMU,
PE, 6031,
South Africa.

Dr. Rodolfo Ungerfeld
Departamento de Fisiología,
Facultad de Veterinaria,
Lasplaces 1550, Montevideo 11600,
Uruguay.

Dr. Timothy Smith
Stable Cottage, Cuttle Lane,
Biddestone, Chippenham,
Wiltshire, SN14 7DF.
UK.

Dr. E. Nicholas Odongo,
27 Cole Road, Guelph,
Ontario. N1G 4S3
Canada.

Dr. D. K. Singh
Scientist Irrigation and Drainage Engineering Division,
Central Institute of Agricultural Engineeinrg
Bhopal- 462038, M.P.
India.

Prof. Hezhong Dong
Professor of Agronomy,
Cotton Research Center,
Shandong Academy of Agricultural Sciences,
Jinan 250100
China.

Dr. Ousmane Youm
Assistant Director of Research & Leader,
Integrated Rice Productions Systems Program
Africa Rice Center (WARDA) 01BP 2031,
Cotonou,
Benin.

African Journal of Agricultural Research

Table of Contents: Volume 13 Number 20, 17 May, 2018

ARTICLES

Vol. 13(20), pp. 1001-1009, 17 May, 2018
DOI: 10.5897/AJAR2017.12932
Article Number: E2240D657129
ISSN 1991-637X
Copyright©2018
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Doses of cattle manure and levels of irrigation with wastewater in the cultivation of peppers

V. F. Silva[1*], E. C. S. Nascimento[1], V. L. A. de Lima[1], C. V. C. Bezerra[1] and L. O. Andrade[2]

[1]Agricultural Engineering Academic Unit, Federal University of Campina Grande, Brazil.
[2]Graduate in Agroecology, State University of Paraíba, Campina Grande, Brazil.

Received 11 December, 2017; Accepted 1 February, 2018

In areas with water scarcity, recycled water and cow manure in organic substrate makes the cultivation of peppers possible, supplying water and nutrition to pepper. The present research was conducted to evaluate the effect of cattle manure doses and levels of irrigation using wastewater on pepper cultivation (*Capsicum frutescens* L.). The treatments include: three replacement levels of wastewater treated, based on the need of water culture (NWC): 100% NWC (LI1), 75% NWC (LI2) and 50% NWC (LI3); they were combined with six doses of cattle manure tanned: D1 (0% manure and 100% soil), D2 (10% manure and 90% soil), D3 (20% manure and 80% soil), D4 (30% manure and 70% soil), D5 (40% manure and 60% soil) and D6 (50% manure and 50% soil) based on volume. Growth parameters evaluated were plant height, stem diameter, number of leaves and leaf area, from 45 days after sowing (DAS). At 150 DAS the peppers irrigated with 50% NWC had mean of 40.9 cm (plant height). The increment in 10% of manure showed there is an increase of more than 10% in the average value of the variables studied.

Key words: Need of water, chili pepper, *Capsicum frutescens* L., water scarcity.

INTRODUCTION

Peppers are widely used for ornamental purposes in various sectors such as pharmaceuticals, cosmetics, and food products; they are consumed fresh or processed into sauces, jellies, and preserves, and also add value to the products (Silva et al., 2016). Peppers of the genus *Capsicum* (Dutra et al., 2010) comprise an important part of the fresh vegetable market in Brazil and in condiments, seasonings and canned food worldwide.

The increasing demand from intern and foreign markets for pepper is due mostly to family farming initiatives, expanded acreage in the Brazilian States (Filgueira, 2000). Pagliarini et al. (2011) claim that the cultivation of pepper is a great example of family agriculture and the integration of small farmers with agribusiness. For satisfactory development of pepper, the systems of cultivation and irrigation management are essential (Lima et al., 2013). In regions with water shortages, such as semi-arid, with irregular rainfall and high rates of evapotranspiration, water reuse in irrigation is an alternative to living in the semi-arid (Azevedo, 2012); it

*Corresponding author. E-mail: flordeformosur@hotmail.com.

provides sufficient nutrients and water to the crops (Alves et al., 2011).

To produce pepper, the quantity and quality of water are important factors. However, to ensure satisfactory production the substrate needs to provide nutrients and fitness culture, in addition to being easy to obtain (Almeida et al., 2012). According to Silva et al. (2015), the use of organic substrates is a strategy for reducing costs in cultivation, reduction in cultivation and consumption of inputs such as chemical fertilizers, pesticides, and labor (Fermino and Kampf, 2003). Also, addition of cow manure helps to improve substrate chemical qualities (Silva et al., 2010).

In this context, the present research was conducted to evaluate the effect of doses of cattle manure and levels of irrigation with wastewater on the cultivation of pepper (*Capsicum frutescens* L.).

MATERIALS AND METHODS

The experiment was developed in an open area of 17 x 6 m, of Campus II of Paraiba State University, Lagoa Seca, Paraíba Marsh; it has the following geographical coordinates: 7° 10' 11 "S and 35° 51' 13" W and an altitude of 634 m. The climate is tropical humid, with an annual average temperature of 22°C; it has a minimum of 18°C and maximum of 33°C, annual average relative humidity of 66% and annual average rainfall of 950 mm (Pereira et al., 2015).

The experimental design was randomized block, in a factorial scheme (3 x 6) + 1 (witness: supply water and absence of cow manure tanned), with 3 replications and two plants per pot. The treatments were: three replacement levels of wastewater treated, based on the need of water culture (NWC): 100% NWC (LI1), 75% NWC (LI2) and 50% NWC (LI3), combined with six doses of cattle manure tanned: D1 (0% manure and 100% soil), D2 (10%manure and 90% soil), D3 (20% manure and 80% soil), D4 (30% manure and 70% soil), D5 (40% manure and 60% soil) and D6 (50% manure and 50% soil) based on volume. The control was compared with the treatment A2N1D1.

The soil used was a Neossolo Regolítico Distrófico Sandy Franc, taken from the surface layer (0-20 cm) of Lagoa Seca-PB, with the following composition: Calcium (3.30 $cmol_c/dm^3$); Magnesium (1.70 $cmol_c/dm^3$); Sodium (0.35 $cmol_c/dm^3$); Cation exchange capacity (6.47 $cmol_c/dm^3$); Hydrogen (0.74 $cmol_c/dm^3$); Aluminum (0.00 $cmol_c/dm^3$); Potassium (148.39 mg/dm^3); Sum of Bases (5.73 $cmol_c/dm^3$); Phosphorus (105.19 mg/dm^3); Organic Matter (10.64 g/kg) and pH (6.81). The tanned cow manure was sifted and mixed with the soil in the composition of the substrate, with the following composition: Calcium (5.8 $cmol_c/dm^3$); Magnesium (2.1 $cmol_c/dm^3$); Sodium (0.7 $cmol_c/dm^3$); Cation exchange capacity (11.3 $cmol_c/dm^3$); Hydrogen (0.21 $cmol_c/dm^3$); Aluminum (0.00 $cmol_c/dm^3$); Potassium (974.29 mg/dm^3); Sum of Bases (11.09 $cmol_c/dm^3$); Phosphorus (593.03 mg/dm^3); Organic Matter (32.3 g/kg) and pH (7.6). In soil, only different concentrations of cattle manure were tanned.

The experimental units composed of 114 search plastic vases (white color), with 20 cm, 28 cm and 29 cm dimensions for smaller diameter, larger diameter, and height, respectively; it has a capacity of 12 L, with 6 holes in the bottom. The plant material used in the experiment was propagated from seeds of chili peppers (*C. frutescens*), developed by ISLA seeds. Sowing was carried out with ten seeds, distributed by equidistant way directly into the vessel, after soil saturation. For the sowing, we applied the recommended depth of 0.5cm suggested by the company for sowing.

Irrigation management used was the water balance, based on the difference between the average volume applied and the average volume collected in lysimeters, that is, obtained by lysimeters of drainage, according to Andrade et al. (2012) and Lima et al. (2015), with 2 days watering shift during the trial period. The wastewater was treated by an anaerobic biological filter, with a hydraulic detention time of two days, according to a survey carried out by Silva et al. (2005). For irrigation of the control, local water was supplied from the Water and Sewage Company of Paraíba, located in Campina Grande, PB.

For the treated wastewater used for irrigation, physico-chemical and microbiological analysis was done in the lab from Basic Sanitation Program with the following composition: pH (6.04); Electric conductivity (1.53 dS/m); Calcium (2.19 meq/L); Sodium (8.63 meq/L); Magnesium (3.15 meq/L); Potassium (0.67 meq/L); Carbonates (0.00 meq/L); Bicarbonates (0.69 meq/L); Chlorides (11.72 meq/L); Sulfates (missing); Sodium Adsorption ratio (5.29); Coliforms thermotolerant (<0.3 10^2 NMP); Total coliforms (<0.3 10^2 NMP).

From 45 days after sowing (DAS), fortnightly, evaluations of growth variables, together with the dynamics of the ontogeny and biometric characteristics of pepper chili were carried out; the plant height (PH) was measured from the ground level up to the apex of the plant; stem diameter (SD) was low to the ground; for the number of leaves (NL), only the number of sheets with length > 1 cm was considered; for the leaf area (LA), three leaf length and width were obtained at random, per plant. The first leaf was taken from the top, the second leaf from the mid and third from the bottom of the crown of the plant, thereby getting medium length and width, based on the methodology of Lima (2013). For the estimation of leaf area, the regression equation obtained by Rezende et al. (2002) was used.

The data obtained were evaluated by analysis of variance, and averages compared by Tukey test at 5% of significance with the aid of the System computer program for analysis of variance – SISVAR 5.6 (Ferreira, 2014).

RESULTS

In summary of the analysis of variance for plant height, there was statistically significant effect of factor levels of irrigation at 75 days after sowing (DAS) up to 150 DAS; while for the doses of manure, there was statistical difference at 1% at all times. The use of wastewater and 50% of water that requires replacement resulted in a larger medium for plant height, in all the evaluations, with continued growth (Table 1).

The major averages were obtained to replace the need of water by 50% where it turns out that the lowest water availability of the plant provided better development time; the peppers at 150 DAS of 40.9 cm were compared with the peppers irrigated with 100% NWC; there was a decrease of 4.76 cm; for that irrigated with 75% NWC, there was 2.74 m reduction. By reducing irrigation levels there is an increase in plant height of peppers irrigated with treated wastewater.

In Figure 1, the regression analysis of plant height of chili peppers in relation to doses of cattle manure applied in the composition of the substrate, the linear model was what best fit in all the evaluations, with coefficients of 0.9.

By increasing the concentration of cow manure in the composition of the substrate for the cultivation of chili pepper, there was an increase in plant height in all

Table 1. Mean value of the analysis of variance for the variable plant height (PH) of chili peppers, at different levels of irrigation and doses of cow manure.

Levels of irrigation	Mean value							
100% NWC (LI1)	9.11^a	19.58^a	28.48^b	32.19^b	33.67^b	34.68^b	35.64^b	36.14^b
75% NWC (LI2)	10.15^a	21.48^a	30.72^{ab}	34.9^{ab}	36.2^{ab}	37.35^{ab}	37.9^{ab}	38.16^{ab}
50% NWC (LI3)	10.57^a	22.73^a	33.62^a	37.00^a	38.57^a	39.59^a	40.57^a	40.9^a

^{ns} Non-significant; * significant ($P<0,05$); ** significant ($P<0,01$); C.V.: coefficient of variation; medium followed by the same letter in column, do not differ by Tukey test; 1variável with transformation into square root - SQRT (Y); Reviews:45 DAS (PH_1), 60 DAS (PH_2), 75 DAS (PH_3), 90 DAS (PH_4), 105DAS (PH_5), 120 DAS (PH_6), 135 DAS (PH_7), 150 DAS (PH_8). A1N1D1- witness with 100% NWC with water supply and without manure; A2N1D1-wastewater treatment with 100% NWC and without dung.

evaluations. So, in applying 50% of cow manure and 50% ground, it was found that the composition of substrate with the major averages was 15.9 cm (PH_1). The lowest average height of plants was obtained in the pepper grown with 0% and 100% dung. At 45 DAS with 10% manure, there is an increase of 10.93% compared to the doses: D2 to D1, 19.11%; D3 to D2, 23.3%; D4 with D3, 26.6%; D5 with D4, 25.59%. In another trial period, at 105 there was approximately 8% increase in plant height with 10% of cow manure; While at 165 comparing D6 with D1, there was an addition of 43.3% in plant height. The addition of cow manure as the composition of a substrate is an alternative source that adds nutritional values for better growth of the culture. In relation to the cultivation of chili pepper, the dose that results to better averages during the evaluation period was 50% concentration of cow manure in the substrate (Figure 1).

Based on the analysis of variance, in stem diameter (SD), there was no significant difference in levels of irrigation; it is only the manure doses that had significant effect ($P < 0.01$) in all the evaluations. There was no significant effect of the A2D1N1 treatment and the control (Table 2).

In Figure 2, in regression analysis, the substrate compound of 50% cow manure and 50% ground (D6) had the higher averages in all seasons, with linear growth of peppers.

The cultivated plants without manure had lower averages in all the evaluations in terms of diameter of stem, indicating the importance of introducing the substrate organic sources, with additions of 11.1% compared to the doses (D2 to D1), 13.3% (D3 to D2), 14.7% (D4 with D3), 12.82% (D5 with D4) and 16% (D6 to D5). While at 105 there was increment of approximately 8.8% compared to the doses (D2 to D1), 7.0% (D3 to D2), 6.6% (D4 with D3), 6.2 (D5 with D4) and 5.8% (D6 to D5). This was also verified by Baloch et al. (2016) who evaluated chili peppers in three stages; there was stem diameter reduction with 10% cow manure; there were 15.2%, 13.3% and 9.7% losses using 50% and 40% manure treatment at 60, 75 and 90 DAS.

Table 3 verifies the summary of the analysis of variance for the number of leaves (NL); there was no significant effect of the levels of irrigation; For the doses of manure there was a significant effect ($P < 0.01$) in all the evaluations. The interaction was significant at 5% level of probability in NF2 (60 DAS), indicating that there was influence of irrigation levels and doses of cow manure at the time of evaluation. In relation to the control, although there is no statistical difference for most ratings, only at 150 DAS (NF8) was there a significance at 5%. This time the peppers irrigated with water supplied expressed lower average compared to the wastewater. The peppers irrigated with wastewater presented a higher amount of leaves when compared to the peppers irrigated with water supply (witness), both at levels of 100%NWC and 0% cow manure. The plants irrigated with water supply showed, on average, 29 leaves less in relation to receiving wastewater.

Analyzing the decline of the number of sheets (Figure 3), by increasing the concentration of cow manure of constitution of the substrates there was an increase in number of leaves, with the lowest averages in all evaluations observed in the peppers grown on substrates with 0% and 100% ground beef manure. At 45 DAS, in D1 to D6 with addition of 50% manure there was an increases of 174.4% in the leaves of the chili peppers; with this same concentration of manure at 60 DAS, there was an increase of 281.7%; at 75 DAS, 148.4%; 90 DAS, 128.2 %; 105 DAS, 71.34%; 120 DAS, 113.5%; 135 DAS, 112.4% and 150 DAS, 91.1%. The results make it clear of the importance of implementation of manure on cultivation of chili peppers. The chili peppers with organic substrate compound with 50% cow manure produced an average of 22.5 sheets at 45 DAS, realizing that the manure used favorable conditions for the culture (Figure 3).

In Table 4, the source of variation in levels of irrigation for the leaf area of the chili pepper was significant only at 1% on LA_1 (45 DAS), LA_5 (105 DAS) and LA_8 (150 DAS); it is statistically significant ($P<0.05$); for dose of manure the factor had a significant effect ($P<0.01$) in the first three evaluations. In the first two evaluations, irrigation with 50% NWC (LI3) provided peppers with greater leaf area; however, during cultivation there is a decrease of this leaf area in the pepper grown with LI3. In plants irrigated with 100% NWC (LI1) there was increased foliar area until at 150 DAS. In relation to the control, the water quality did not influence the cultivation of pepper, and it is

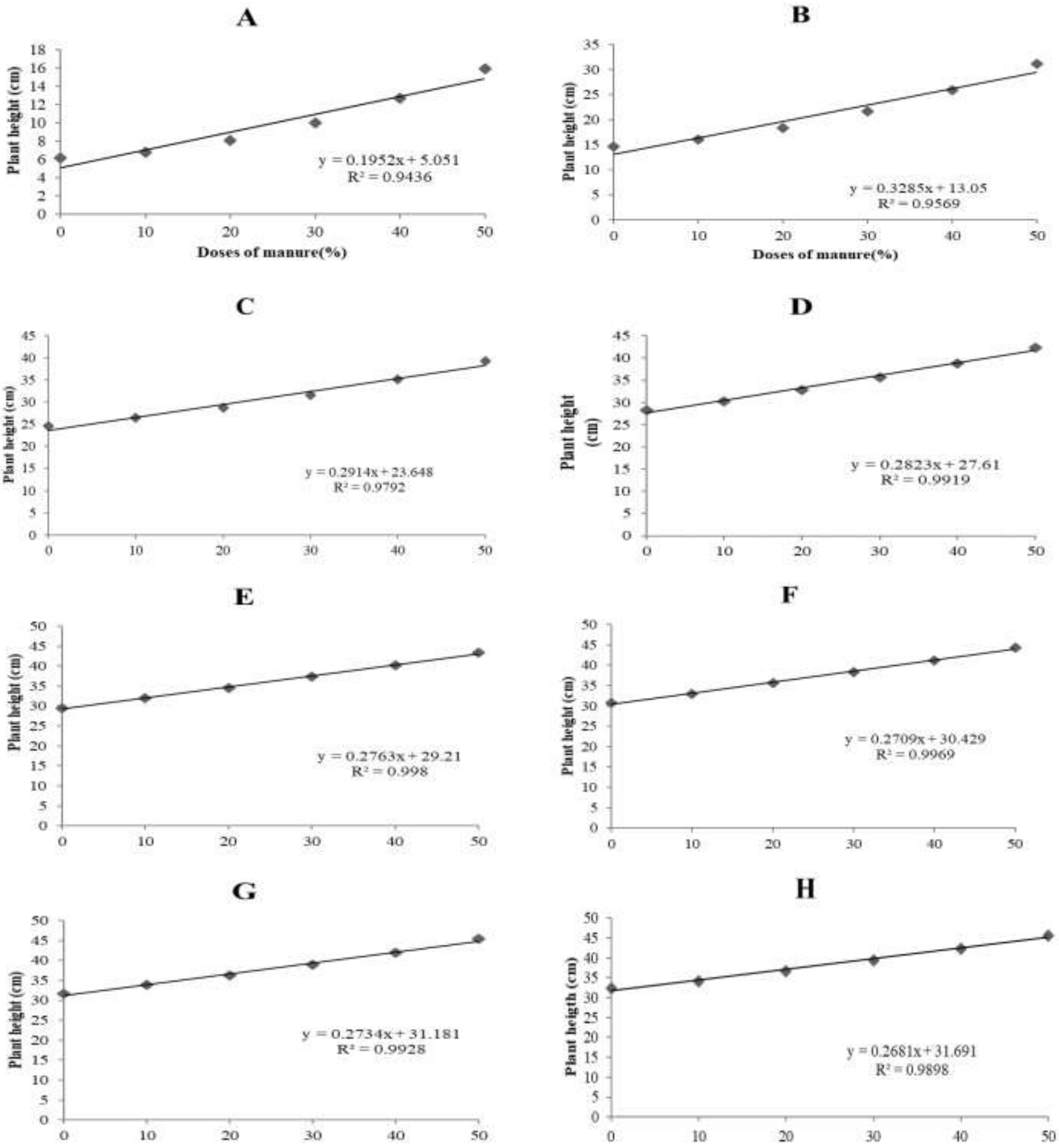


Figure 1. Regression of variable plant height (AP) of chili pepper subjected to levels of irrigation of treated wastewater and doses of cow manure, the periods of the evaluation of (A) 45, (B) 60 (C) 75, (D) 90, (E) 105, (F) 120, (G) 135 and (H) 150 DAS.

important to highlight the need for recycled water in the semi-arid; local rainfall has irregular distribution in the region.

In Figure 4 there was a linear trend in the regression of foliar area, being influenced by doses of cattle manure; by adding cow manure to organic substrate composition

Table 2. Summary the variance analysis to stem diameter (SD) of the chili peppers, at different levels of irrigation and doses of cow manure.

Levels of irrigation	Mean value (mm)							
100% NWC (LI1)	3.62^a	5.89^a	8.22^a	9.51^a	10.69^a	11.24^a	11.79^a	12.03^a
75% NWC (LI2)	3.94^a	6.24^a	8.63^a	9.91^a	11.04^a	11.55^a	12.05^a	12.31^a
50% NWC (LI3)	3.83^a	6.42^a	8.57^a	9.83^a	11.22^a	11.90^a	12.37^a	12.66^a

^{ns} Non-significant; * significant (P<0.05); ** significant (P<0.01); C.V.: coefficient of variation; medium followed by the same letter in column, do not differ by Tukey test; 1variável with transformation into square root - SQRT (Y); Reviews: 45 DAS (SD$_1$), 60 DAS (SD$_2$), 75 DAS (SD$_3$), 90 DAS (SD$_4$), 105DAS (SD$_5$), 120 DAS (SD$_6$), 135 DAS (SD$_7$), 150 DAS (SD$_8$), 165 DAS (SD$_9$). A1N1D1- witness with 100% NWC with water supply and without manure; A2N1D1-wastewater treatment with 100% NWC and without dung.

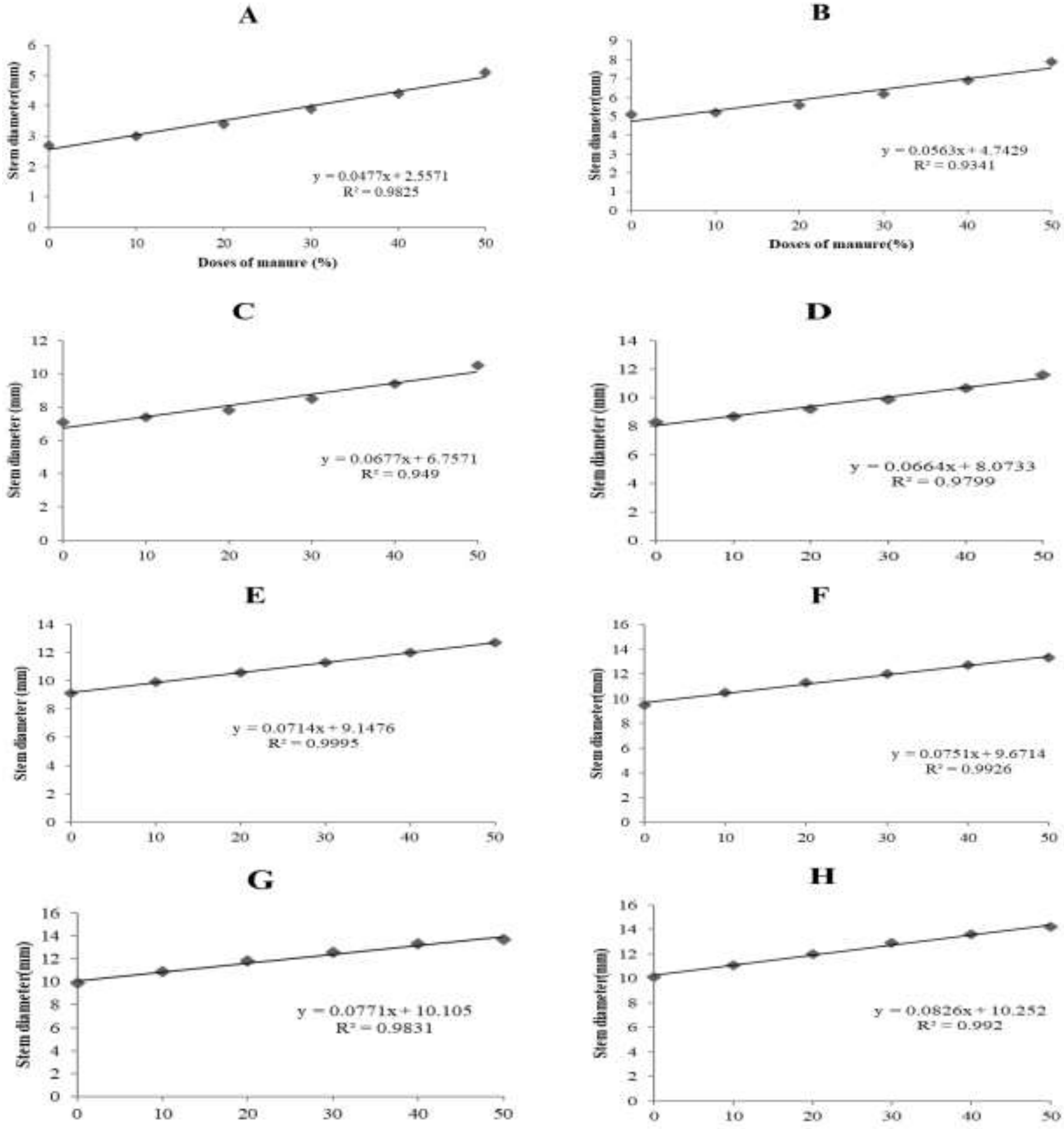


Figure 2. Regression of the stem diameter (SD) of chili pepper subjected to levels of irrigation of treated wastewater and doses of cattle manure, the periods of the evaluation of (A) 45, (B) 60 (C) 75, (D) 90, (E) 105, (F) 120, (G) 135, (H) 150 and (I) 165 DAS.

Table 3. Summary of the analysis of variance for the variable number of leaves (NL) of chili peppers, at different levels of irrigation and doses of manure.

Levels of irrigation	Mean value (Unid)							
100% NWC (LI1)	11.81^a	37.11^a	60.31^a	86.05^a	140.7^a	143.63^a	159.86^a	176.08^a
75% NWC (LI2)	13.08^a	37.80^a	66.33^a	89.16^a	133.1^a	165.14^a	183.36^a	201.58^a
50% NWC (LI3)	13.33^a	35.78^a	71.16^a	92.81^a	153.5^a	147.08^a	166.72^a	186.36^a
Y	-	-	-	-	-	-	-	-29.0

^{ns} Non-significant; * significant (P<0.05); ** significant (P<0.01); C.V.: coefficient of variation; medium followed by the same letter in column, do not differ by Tukey test; 1variável with transformation into square root - SQRT (Y); Reviews: 45 DAS (NL_1), 60 DAS (NL_2), 75 DAS (NL_3), 90 DAS (NL_4), 105DAS (NL_5), 120 DAS (NL_6), 135 DAS (NL_7), 150 DAS (NL_8). A1N1D1- witness with 100% NWC with water supply and without manure; A2N1D1- wastewater treatment with 100% NWC and without dung.

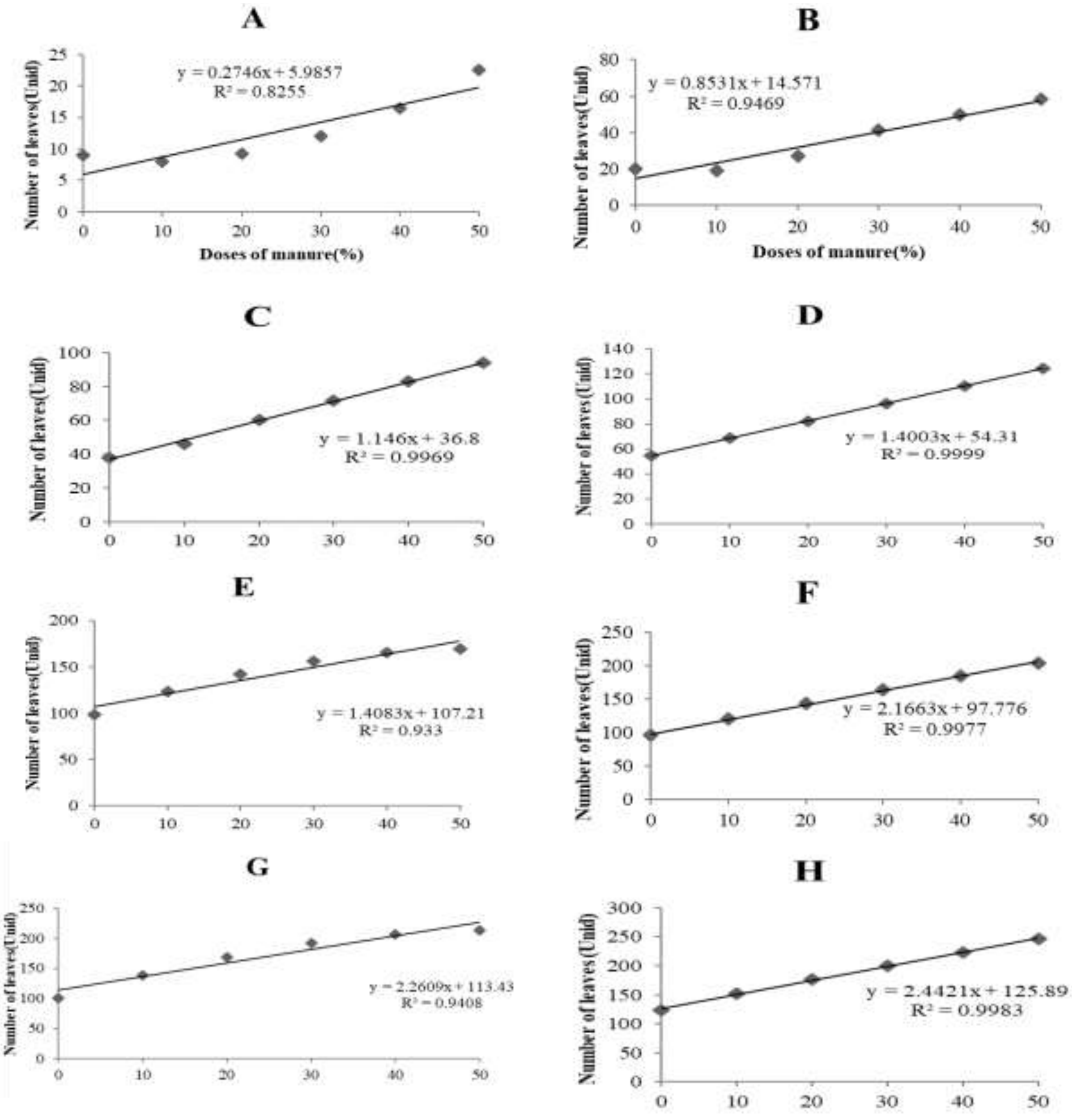


Figure 3. Regression of variable number of leaves (NL) of chili pepper subjected to levels of irrigation of treated wastewater and doses of manure, the periods of the evaluation (A) 45 DAS, (B) 60 DAS, (C) 75 DAS, (D) 90 DAS, (E) 105 DAS, (F) 120 DAS, (G) 135 DAS, and (H) 150 DAS.

Table 4. Summary of the analysis of variance for the variable leaves the area (LA) of chili peppers, at different levels of irrigation and doses of cow manure.

Levels of irrigation	Mean (cm^2)							
100% NWC (LI1)	14.38^{b}	23.50^{a}	35.71^{a}	43.65^{a}	52.55^{a}	63.76^{a}	68.39^{a}	73.01^{a}
75% NWC (LI2)	19.72^{a}	23.08^{a}	29.47^{a}	26.44^{a}	23.41^{b}	21.52^{b}	21.60^{b}	21.69^{b}
50% NWC (LI3)	20.35^{a}	25.61^{a}	30.19^{a}	27.79^{a}	25.40^{ab}	24.82^{ab}	24.29^{b}	23.76^{b}

^{ns} Non-significant; * significant ($P<0.05$); ** significant ($P<0.01$); C.V.: coefficient of variation; medium followed by the same letter in column, do not differ by Tukey test; 1variável with transformation into square root - SQRT (Y); Reviews: 45 DAS (LA_1), 60 DAS (LA_2), 75 DAS (LA_3), 90 DAS (LA_4), 105DAS (LA_5), 120 DAS (LA_6), 135 DAS (LA_7), 150 DAS (LA_8). A1N1D1- witness with 100% NWC with water supply and without manure; A2N1D1- wastewater treatment with 100% NWC and without dung.

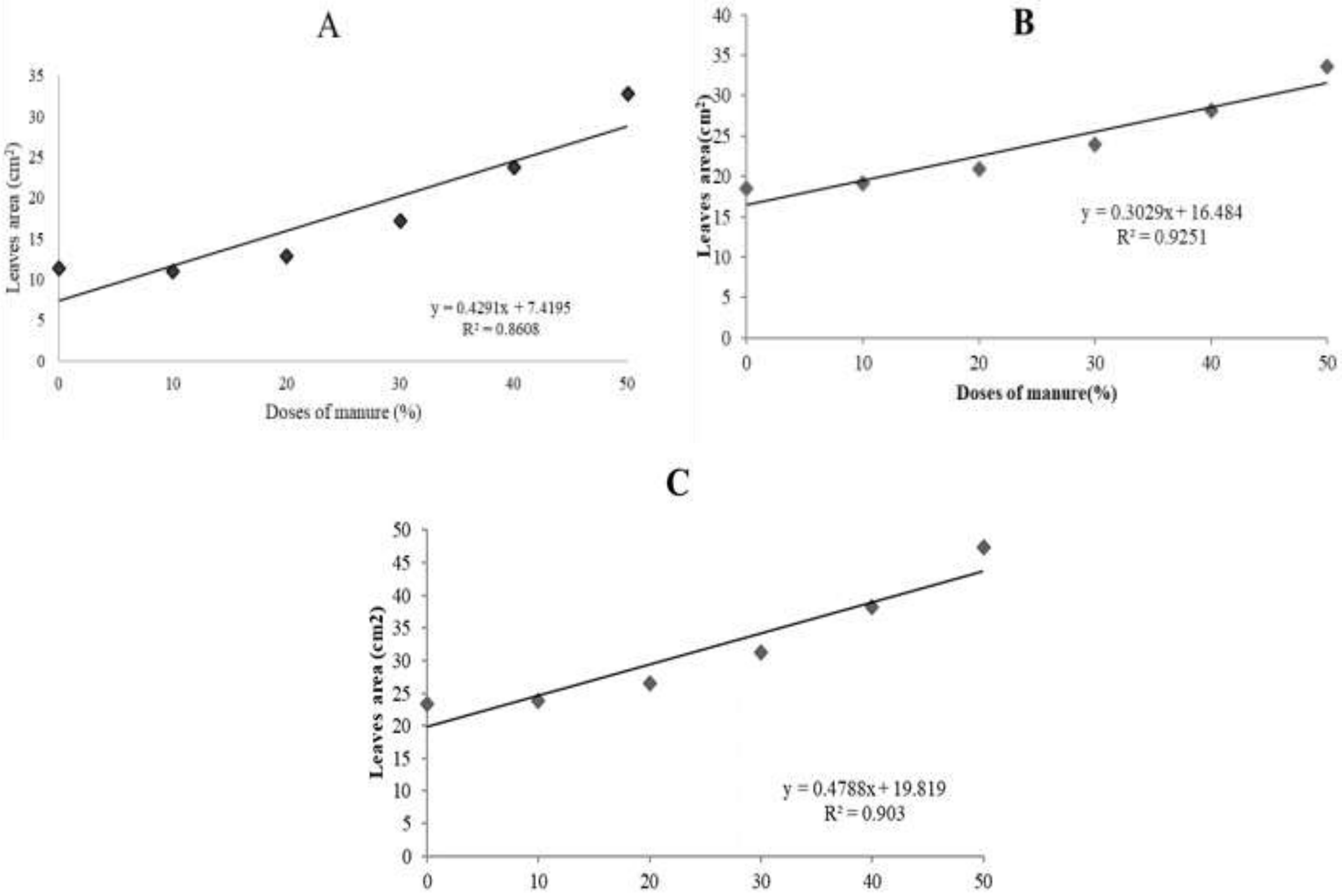


Figure 4. Regression of foliar area (LA) of pepper subjected to levels of irrigation of treated wastewater and doses of cattle manure, the periods of the evaluation (A) 45 DAS, (B) 60 DAS, and (C) 75 DAS include effect on yield attributes and yield, and post-harvest soil physico-chemical parameters.

there was increment in the foliar area of peppers, making important the insertion of manure in the cultivation of this cultivar. 50% dose had the best average assessments examined, compared to the other doses applied, with the addition of 183.9% (45 DAS), 85% (60 DAS), 102.3% (75 DAS) for pepper cultivated with 50% manure (D6) and 0% manure (D1).

DISCUSSION

Oliveira et al. (2012), studying different concentrations of water supply and wastewater in chili peppers and tequila, have stated that the lowest averages in all the variables analyzed were obtained when applied in irrigation, and 100% of water supply. Corroborating with the results obtained by Silva et al. (2014a), cultivating pepper red with goat manure, and Oliveira et al. (2012) in the production of pepper, okra, and tomatoes, all plants irrigated with wastewater provide plants with greater heights.

In the production of pepper genotypes (Guajarina, Iaçara, and Singapore), Serrano et al. (2012) observed that, with the use of a substrate with slow-release fertilizer, heights averaged 30.7, 27.0 28.0 cm. Analyzing the growth of chili subjected to substrate compound with cow manure and sand washed in 2:1 proportion, Araujo et al. (2015) obtained higher results for plant height in the treatment with the addition of cattle manure to the substrate. Cunha et al. (2014) evaluated various alternative substrates in the cultivation of lettuce and cabbage, and found that an alternative to the commercial substrate composition: 50% of cow manure, as an option for reducing production costs and better development of vegetables. Silva et al. (2015) cultivating peppers with 50% of cow manure and 50% of soil obtained satisfactory results compared to the peppers grown with 100% beef ground manure.

The data obtained in this experiment were superior to those obtained by Silva et al. (2014b) who researched on different concentrations of effluent of tekila red goat on pepper. They obtained the following average values of stem diameter with the application of irrigation: 100 blades; 75 and 50% at 11.50 mm, 10.81 mm and 11.92 mm, respectively. Comparing the values of the culm diameter of each pepper under different types of fertilizers obtained by Pagliarini et al. (2014), there was an average of 3.07 to 4.44 mm, being the values obtained in this experiment with veal substrate under different water that requires reruns. According to Silva et al. (2016), 30% of cow manure on the basis of volume, in the composition of the substrate for the cultivation of peppers, stem diameter nozzle with better averages (5.96 mm). While Ferreira et al. (2014) studying the performance of peppers under different vermicomposts had a variation in stem diameter of 1.35 to 1.6 mm.

Ferreira et al. (2014) recommend, in the composition of the organic substrate for chili, 30% of manure and 80% of small ruminant manure and, for Aubergines, 80% of cow manure and 20% of manure of small ruminants, as best options for proper development of cultures. Also, Maia Filho et al. (2013) did an experiment in soils consisting of compost cow manure; they found better results compared to using soils consisting of chemical fertilizers.

Pagliarini et al. (2011), analyzing the application of liquid effluent in peppers of the same variety studied in this research, they realized that the growth of this fertilizer doses was significant for the number of sheets, with averages of about 7.5 leaves per plant at 60 DAS, a value below that obtained at this same time in this experiment. Oliveira et al. (2014), applying different nutrient solutions in varieties of peppers, obtained the following foliar results for each cultivar: volcano pepper (75.78 cm^2), chili (80.69 cm^2), Tekila pepper (37.07 cm^2), Gold (25.09 cm^2) pepper, sweet pepper long (96.72 cm^2), Cayenne Pepper (85.50 cm^2), Salar pepper (25.75 cm^2) and Smell pepper Luna (21.12 cm^2). Applying gradual concentration of liquid effluent management of pepper, Pagliarini et al. (2011) obtained in regression analysis quadratic equations for the leaf area as well as Oliveira et al. (2014), found similar results to those found in this research.

Conclusion

Chili peppers had better average in all the variables with 50% NWC (LI 3) and 50% of manure in the composition of the substrate (D6). For cultivation the followings are recommended: saving water and reusing organic compounds. The treated wastewater is a viable alternative to farmers on irrigation of peppers, mainly in regions with water shortage.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Almeida LVB, Marinho CS, Muniz RA, Carvalho AJC (2012). Disponibilidade de nutrientes e crescimento de porta-enxertos de citros fertilizados com fertilizantes convencionais e de liberação lenta. Revista Brasileira de Fruticultura, 34:289-296.

Alves MS, Soares TM, Silva LT, Fernandes JP, Oliveira MLA, Paz VPS (2011). Estratégias de uso de água salobra na produção de alface em hidroponia NFT. Rev. Bras. Eng. Agríc. Ambient. 15:491-498.

Andrade LO, Gheyi HR, Nobre RG, Dias NS, Nascimento ECS (2012). Crescimento de girassóis ornamental em sistema de produção orgânica e irrigada com água residuária tratada. Rev. Irrig. 1:69-82.

Araujo DL, Véras MLM, Melo Filho JS, Irineu THS, Andrade R (2015). Desempenho do pimentão (*Capsicum annuum* L.) sob fertilizante e adubação orgânica, Terceiro incluído, 5(2):275-284.

Azevedo DCF (2012). Água: Importância e gestão no semiárido nordestino. Questões contemporâneas. 11:1-10.

Cunha C, Gallo AS, França GN, Silva RF (2014). Substratos alternativos para produção de mudas de alface e couve em sistema orgânico. Sci. Plena 10:1-9.

Dutra FLA, Branco IG, Madrona GS, Haminiuk CWI (2010). Avaliação sensorial e influência do tratamento térmico no teor de ácido ascórbico de sorvete de pimenta. Rev. Bras. Tecnol. Agroind. 4:243-251.

Fermino MH, Kampf AN (2003). Uso do solo Bom Jesus com condicionadores orgânicos como alternativa de substrato para plantas. Pesqui. Agropecu. Gaúcha 9:33-41.

Ferreira DF (2014). Sisvar: a Guide for its Bootstrap procedures in multiple comparisons. Ciênc. Agrotec. 38(2):109-112.

Ferreira LL, Almeida AES, Costa LR, Bezerra FMS, Lima LA, Porto VCN (2014). Vermicompostos como substrato na produção de mudas de berinjela (*Solanum Melogena*) e pimentão (*Capsicum annuum*). HOLOS. 30:269-277.

Filgueira FAR (2000). Novo Manual de Olericultura – Agrotecnologia moderna na produção e comercialização de hortaliças. Viçosa: UFV. 402 p.

Lima GS (2013). Deficiência hídrica em plantas de pimentão (*Capsicum annuum* L.) fertirrigadas e seus efeitos sobre a produção de massa e parâmetros bioquímicos. Dissertação de Mestrado (Pós-graduação em Agronomia) Faculdade de Ciências Agronômicas da Universidade Estadual Paulista Júlio de Mesquita Filho, Botucatu, SP. 78p.

Lima GS, Nobre RG, Gheyi HR, Soares LAA, Silva AO (2015). Produção da mamoneira cultivada com águas salinas e doses de nitrogênio. Rev. Ciênc. Agronom. 46:1-10.

Lima IB, Santos AB, Fonseca JJS, Takane RJ, Lacerda CF (2013). Pimenteira ornamental submetida a tratamentos com daminozide em vasos com fibra de côco ou areia. Semina: Ciênc. Agrár. 34(6):3597-3610.

Maia Filho FCF, Pereira RF, Alves, FIS, Cavalcante SN, Mesquita EF, Suassuna TC (2013). Crescimento e fitomassa do girassol variedade ‘Embrapa 122/V-2000’ adubado com esterco bovino em dois solos. Agropecu. Cient. Semiárido 9(4):67-75.

Oliveira FA, Medeiros JF, Linhares PSF, Alves RC, Medeiros A, Oliveira MK (2014). Pepper seedlings production fertigated with various nutrient solutions. Rev. Hortic. Bras. 32(4):458-463.

Oliveira JFO, Alves SMC, Ferreira Neto M, Oliveira RB, Paiva LAL (2012). Produção de mudas de pimenta malagueta e pimenta tequila sunrise fertirrigadas com efluente doméstico tratado. Enciclopédia Conhecer 8(5):1400-1411.

Pagliarini MK, Gordin CRB, Santos AM, Brandão Neto JF, Biscaro GA (2011). Uso de fertilizantes líquido via fertirrigação em mudas de pimenta malagueta. Rev. Tecnol. Ciênc. Agropecu. 5(4):13-18.

Pagliarini MK,Castilho RMM, Mariano FAC (2014). Desenvolvimento de mudas de pimenta de bico em diferentes fertilizantes. Rev. Bras. Hortic. Ornamental 20:35-42.

Pereira JS, Guimarães JP, Farias MSS (2015). Diagnóstico da poluição ambiental em área de preservação no município de Lagoa Seca, Paraíba. Rev. Verde Agroecol. Desenvolv. Sustent. 10:11-14.

Rezende FC, Frizzone JA, Pereira AS, Botrel TA (2002). Plantas de pimentão cultivadas em ambiente enriquecido com CO_2. II. Produção de matéria seca. Acta Sci. 24:152-1533.

Serrano LAL, Marinato FA, Magiero M, Sturm GM (2012). Produção de mudas de pimenteiras-do-reino em substrato comercial fertilizado com adubo de liberação lenta. Rev. Ceres 59(4):512-517.

Silva ER, Silva AB, Araújo JTL, Oliveira SJC (2015). Produção de mudas de pimentão com diferentes tipos de substratos. Cadernos Agroecol. 10:2.

Silva VF, Nascimento ECS, Andrade LO, Lima VLA, Baracuhy JGV (2014a). Diferentes lâminas de água no crescimento inicial da pimenta biquinho (*Capsicum chinense*). *In:* IX Congresso de Educação Agrícola Superior.

Silva LL, Carvalho CM, Souza RPF, Feitosa HO, Feitosa SO, Filho RRG (2014b). Utilização de efluentes domésticos no crescimento da pimenta (*Capsicum chinense*) cultivar tekila bode vermelha. Rev. Agropecu. Técn. 35:121-133.

Silva OS, Souza RB, Takamori LM, Souza WS, Silva GPP, Sousa JMM (2010). Produção de mudas de pimentão em substratos de coco verde fertirrigadas com biofertilizante em sistema orgânico. Rev. Hortic. Bras. 28(2):2714-2720.

Silva VF, Lima VLA, Nascimento ECS, Andrade LO, Oliveira H, Ferreira AC (2016). Effect of different irrigation levels with different qualities of water and organic substrates on cultivation of pepper. Afr. J. Agric. Res. 11(15):1373-1380.

Silva VF, Sousa JT, Vieira FF, Santos KD (2005). Tratamento anaeróbio de esgoto doméstico para fertirrigação. Rev. Bras. Eng. Agríc. Ambient. 9:186-190.

Vol. 13(20), pp. 1010-1017, 17 May, 2018
DOI: 10.5897/AJAR2017.12888
Article Number: 33A4CE957131
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Nutritional and fermentative quality of sugarcane (*Saccharum officinarum*) top ensiled with or without urea and molasses

Getahun Kebede[1*], Ashenafi Mengistu[2], Getnet Assefa[3] and Getachew Animut[4]

[1]Debre Zeit Agricultural Research Center, Ethiopian Institute of Agricultural Research, Debre Zeit, Ethiopia.
[2]College of Veterinary Medicine and Agriculture, Addis Ababa University, Debre Zeit, Ethiopia.
[3]Ethiopian Institute of Agricultural Research, Head quarter, Debre Zeit/Addis Ababa, Ethiopia.
[4]Agricultural Transformation Agency, Addis Ababa, Ethiopia.

Received 15 November, 2017; Accepted 30 January, 2018

This study was conducted to evaluate the effect of urea and molasses addition on physical properties, pH, temperature, dry matter loss and chemical composition of sugarcane top (SCT) silage. Treatments were arranged as 2*4 factorial, with two SCT types (green and burnt) and four silage treatment types (without additive, 4% molasses, 1% urea and 1% urea + 4% molasses) in a completely randomized design. Forages were chopped into 2 to 3 cm, treated with the additives and ensiled in 1.09 L mini silos for 45 days. The best average score values for smell, color, texture, mold appearance and pH was noted in silages made without additive or with molasses. The desirable pH (3.7 to 5.0) was obtained in all silages, except in green SCT ensiled with urea-based additives, while lower (P<0.0319) total dry matter loss (2.31%) and temperature (26°C) were noted in green SCT ensiled with molasses alone. Silage protein content increased (P<0.0001) with urea addition, but not ($P>0.05$) with molasses alone. Fiber fractions (NDF, ADF and ADL) of burnt SCT were not affected ($P>0.05$) by additives, while NDF increased with urea based additives and ADF decreased with molasses based additives in green SCT silage. The highest (P<0.0001) *in vitro* dry matter digestibility (53.68%), organic matter digestibility (48.34%) and metabolizable energy (7.74 MJ/kg DM) content were observed contained in burnt SCT silage treated with urea-molasses mix, whereas a significant reduction (P<0.0001) in non-fiber carbohydrate content was observed in green SCT ensiled with urea (8.4%) and urea + molasses (1.65%). In conclusion, both burnt and green SCT can be adequately fermented and preserved as silage without additive; however silage nutritive value, particularly of burnt SCT can be further enhanced by ensiling with urea and molasses.

Key words: Sugarcane top, molasses, urea, silage.

INTRODUCTION

Feed deficit is a critical bottleneck to livestock production in Ethiopia. The root causes are shrinkage of natural grazing land, underdeveloped forage production, low availability and poor quality of feeds, high cost of feeds and frequent drought occurrence. However, there are potentially available unconventional feedstuffs that if properly exploited, can support livestock production. Sugarcane top (SCT) is one of such feed resources largely available at sugar factories and in private farms in Ethiopia. At factory level, it is often available in burnt form, after cane harvesting, representing 15 to 25% of plant biomass (Suttie, 2000) or 25 to 30% of cane yields that is equivalent to 5 to 6 tons DM per hectare. Recently, a number of new sugar factories are emerging in Ethiopia, generating large amount of sugarcane top for livestock feeding mainly for farms close to the factories. Also, over 31,236 hectares of land are covered by business-oriented private cane plantation (CSA, 2017) of diverse germplasm and production potential (Tena et al., 2016), which significantly contributes to farm level green SCT production.

Sugarcane top is highly palatable with good intake characteristics for livestock (Suttie, 2000). It is comparable with average quality grass hay, but deficient in protein, mineral and energy (Leng and Preston, 1985). A notable problem with SCT is that it loses quality through time, becoming rough and less palatable to animals during drying and storing. When stored for longer period, it forms mold and deteriorates in quality. Studies have shown that ensiling is a possible means of conserving SCT (Siqueira et al., 2009; Akinbode et al., 2017). .Sugarcane top is rich in water soluble carbohydrate (155 g/kg DM (Khanal et al., 1995), 82.5 g/kg DM (Chaudhry and Naseer, 2008)), which is of a desirable characteristic for successful ensiling. Therefore, fresh SCT silage making might have a comparative advantage over hay making for ruminant livestock feeding.

Application of additives in silage making is one of the management practices crucial at ensiling time, storage and feed-out phase to reduce nutrient loss and improve its nutritive value. Various chemical and biological additives have been used to control undesirable microorganisms (e.g, aerobic bacteria and fungi) and improve aerobic stability in silages (Pedroso et al., 2008; Pedroso et al., 2011; Siqueira et al., 2011). The most useful additives are molasses, which is a source of fermentable carbohydrate, and urea that provides fermentable nitrogen for microorganisms in the silage and rumen of the animal. Also, urea has buffering capacity by raising the pH of the silage at early stage of fermentation that might inhibited yeast growth. Various studies have illustrated the beneficial effect of urea and/or molasses applications in silage making (Suárez et al., 2011; Kaensombath and Lindberg, 2013; Kung and Shaver, 2001; Khanal et al., 1995; Tadesse et al., 2014).

In Ethiopia, surplus SCT is often available during dry season when cane harvesting is practiced and green fodder for livestock feeding is most limited. Therefore, a proper conservation practice to optimize its use for livestock feeding has to be investigated. Moreover, limited studies have been done on SCT silage manufacture in the country. Hence, this study was aimed to evaluate the role of urea and molasses application on physical properties, fermentative quality and nutritive value of burnt and green SCT silages.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Debre-Zeit Agricultural Research Centre (DZARC), livestock research farm, located at 45 km southeast of Addis Ababa (08°44'N latitude, 38°58'E longitude; altitude of1900 m above sea level). The area is known for bimodal rainfall, with average annual rainfall of 814 mm and minimum and maximum temperature of 10.9 and 28.3°C, respectively (DZARC, unpublished data).

Treatments and design

The treatments were set in a 2 x 4 factorial arrangement of treatments (2 sugarcane top forms (green and burnt) and 4 silage treatment types (no additive, 4% molasses, 1% urea, and 1% urea + 4% molasses) in a completely randomized design. A polyethylene container ("*mini silo"*) with a volume of 1.09 L was used in 5 replicates per treatment, making a total of 40 experimental silos.

The additives were added on the basis of forage dry matter. Fertilizer grade urea was used for this purpose. The levels of application were adopted from research reports (Suárez et al., 2011; Khanal et al., 1995).

Sampling and ensiling procedure

Sugarcane top of mature cane (variety N-14, or Natal) were collected from Wonjishoa sugar factory plantation before and after burning at harvesting. The cane field was often burnt to ease the harvesting practices and add ash to the soil. The sugarcane was grown on heavy black soil (Vertisols), aged 23 months and harvested at 1st stage of cutting after planting. Sampling was done randomly at six marked specific sites (at equal interval) along the gradient line (diagonally and horizontally) in one hectare cane field.
The green SCT were sampled overnight before burning, while the burnt samples were taken in the next morning from the same site. The cutting point for SCT sampling was used by staff (cutters) of the sugar factory for cane harvesting. Immediately after cutting, the respective samples were put into polyethylene sheet and transported to the research center. After arrival, the burnt and green samples were mixed thoroughly and independently, chopped using electrically operating machine (Ethio-chopper, Ethiopia) into 2 to 3 cm length. The amount of chopped SCT (green/burnt) used for ensiling was weighed and wilted under shade, to attain about 35% DM for both burnt and green SCT (Table 5). Urea was diluted with water at a ratio of 1:1.5 when used as sole additive. When molasses alone, or urea and molasses were mixed, the amount of water used for dilution equaled the amount of molasses used by weight (Suárez et al., 2011).

*Corresponding author. E-mail: getkeb2000@yahoo.com.

Table 1. Description of physical characteristics and scale (1-4) used as indices of silage quality assessment.

Rating scores	Smell	Color	Texture	Moldiness	pH
1 (Bad)	Rancid and musty smell /pungent/	Dark/deep brown	Putrefactive and agglutinative	Highly moldy	>5.0
2 (Moderate)	Irritative /offensive; alcohol, acidic	Brown (Medium)	Slightly viscous /slimy	Medium	4.4-5.0
3 (Good)	Light acidic (*pleasant*)	Brown yellow	Medium (loose and soft, firm)	Slightly moldy	4.1-4.3
4 (Excellent)	Pleasant and sweet- acidic (*very pleasant*)	Light /greenish yellow/Olive green	Loose and soft, Firm	Without mold	≤4.0

Source: BAPH (1996);Ososanya and Olorunnisomo (2015)

The chopped materials were weighed, except for the control all were thoroughly mixed with the respective additive on polyethylene sheet laid on concrete floor. The forages were filled into the mini silos lined inside with polyethylene sheet. All silos were filled at similar packing density (767 g per 1.09 L plastic bottle) by hand filling and pressing with a wooden stick. The tightly packed silos were immediately closed, tightly sealed and placed under shade which is allow to ferment for 45 days at room temperature. Adequate samples of the respective untreated and treated materials were taken at ensiling, put in polyethylene bags, sealed and stored in deep freezer (-20°C), awaiting for laboratory analysis.

Silage temperature and pH

On day 45 of ensiling, all silos were weighed. Temperature after opening each silo was measured using a laboratory thermometer inserted into silo's center. After observation for mold occurrence, the silages were removed, homogenized and sampled in two parts where one part was immediately frozen, while the remaining was used for physical characteristics assessment.

About 20 g of frozen silage sample per treatment was taken in a beaker to which 100 ml of distilled water was added (AFIA, 2011). The samples were blended using a glass stirrer and left for 1 h before filtering with filter paper. Silage pH was measured from the extract using a conventional digital pH meter (Hanan Bench top pH meter), calibrated with buffer solutions (pH 4 and 7).

Visual appraisal of silage quality

The contents of the silos were evaluated for physical attributes by a panel discussion involving six trained personnel on the indices and scales of silage quality characterization. The panelists were all from the Department of Livestock Research with different professional background, but had experience on silage making. They were trained on how to apply the criteria set (subjective score 1-4; Table 1) and exercised them before commencing the actual evaluation, independently.

Observation for mold formation was done starting from the silo opening time, while color, smell and texture were evaluated after silo content extraction. The visual observation for color assessment was also aided by standard color charts. The score values of each individual for all attributes were used in the statistical analysis.

Chemical analyses of samples

Sugarcane top samples (intact green, burnt and silages) were dried in a forced air oven at 60°C for 72 h and ground to 1.0 mm size in a Wiley mill. For all silage samples, dry matter (DM), crude protein (CP=N * 6.25), ash, ether extract (EE), calcium (Ca) and phosphorus (P) contents were determined according to AOAC (1990), while neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) contents were analyzed according to Van Soest and Robertson (1985). The *in-vitro* organic matter and dry matter digestibility coefficients (IVOMD and IVDMD) were determined according to Tilley and Terry (1963) by applying a two-stage digestion process, in which samples were first fermented in rumen fluid obtained from donor animals, followed by acid digestion.

Total dry matter loss (TDML) was calculated by DM weight loss in the silage ((DM of forage -DM of silage)/DM forage*100) (Pedroso et al., 2011), Non-fibre carbohydrate by (% NFC) = 100–% (CP + Ash + EE + NDF) (Hall, 2000) metabolizable energy by (ME, MJ/kg DM) = IVDOMD (g/kg DM) *0.016 (McDonald et al., 2010) and Hemicelluloses = NDF-ADF.

Statistical analysis

The data were subjected to analysis of variance using General Linear Model procedure of SAS program (SAS, 2004). When interaction between factors was non-significant, only main effect means were presented and discussed, otherwise simple effect means were presented. Mean separation was done using Tukey test at 5% probability.

The statistical model used was: $Yij = \mu + \alpha i + Tj + (\alpha T)ij + \varepsilon ij$; where; Yij is the response variable; μ = Overall mean, αi = the effect of cane top type (i = burnt and fresh); Tj = Effect of silage treatment type (j = ± additive), (αT)ij = Interaction effect of cane top type "i" with silage treatment type "j" and εijk = the experimental error.

RESULTS AND DISCUSSION

Chemical composition of SCT and molasses

The chemical composition of sugarcane top and molasses is indicated in Table 2. The burnt and green SCT did not differ markedly in nutrient contents.

However, burnt SCT had slightly lower contents of CP and NFC and higher in other parameters, except ADF, than the green SCT. The losses of moisture and some organic matter, occurred during burning probably elevate the concentration of some nutrients in burnt SCT.

Table 2. The average chemical composition (% DM unless specified) of sugarcane top and molasses.

Parameters	Green SCT(n=5)	Burnt SCT (n=5)	Molasses (n=2)
Dry matter (%)	23.05	27.34	75.07
Crude protein	2.77	2.45	3.15
Ash	10.80	11.70	14.04
Ether extract	1.22	1.42	ND
Neutral detergent fiber	68.40	68.80	0.30
Acid detergent fiber	39.20	39.20	0.11
Acid detergent lignin	5.40	6.40	0.12
Hemicelluloses	29.20	29.60	0.19
Calcium	0.38	0.56	1.30
Phosphorus	0.19	0.33	0.90
In vitro dry matter digestibility	52.03	53.22	ND
In vitro organic matter digestibility	47.03	48.22	ND
Metabolizable energy (MJ/kg DM)	7.52	7.71	ND
Non-fiber carbohydrate	16.81	15.63	ND

n= number of replicates; ND= not determined.

Similar to the present finding, a slight increase in DM, ash and hemicelluloses, but reduced NDF, ADF and ADL were reported in burnt than green SCT (Magaña et al., 2009). On the other hand, Ramírez-Cathí et al. (2014) researched on green and burnt SCT of four mature sugarcane varieties and found no difference (*P*>0.05) in DM, CP, NDF, ADF, ash and *in-vivo* digestibility values among varieties and harvest types.

The present average CP content of green SCT was lower than the reported values by other studies (Akinbode et al., 2017; Sharma et al., 2012; Khanal et al., 1995). However, Sharma et al. (2012) stated that various green SCT varieties when sampled at 3rd stage of cutting had a CP content as low as 1.5%, while other researchers reported a level ranged from 2.5 to 3.6% CP (Tadesse et al., 2014; Ramírez-Cathí et al., 2014; Anteneh, 2014). The variation in CP values may be associated with the differences in varieties, stage of growth and/or nitrogen fertilizer application.

Nevertheless, all of them had CP values below the optimum level for rumen fermentation. Similarly, contents of the fiber components (NDF, ADF and ADL) and EE were within the range of values reported in previous studies (Tadesse et al., 2014; Sharma et al., 2012; Gendley et al., 2002). However, significantly higher ADL contents (14%DM) of green SCT than the present results were reported by Akinbode et al. (2017) and Anteneh (2014). Hemicelluloses and P content of green SCT in the present study were close to the values reported by Gendley et al. (2002).

Silage pH, physical properties, temperature and dry matter loss

The pH of pre-ensiled materials (treated/ untreated SCT) was higher (P< 0.05) for sole urea treated SCT compared to untreated one (control), but not varied among other treatments (Table 3), partly indicating the buffering effect of urea even at the initial stage. Regardless of the treatments used, initial pH was higher (*P*=0.0025) in green than in burnt SCT. The pH of SCT after 45 days of fermentation was affected by the interaction of treatment and SCT type (*P*<0.05); with the burnt SCT being unaffected by treatment while values for urea containing treatments were higher as compared to untreated and 4% molasses treatments in green SCT silage.

On the other hand, except for SCT treated with urea and molasses combination where the pH was lower for the burnt SCT, the pH of the burnt and green SCT were similar for the other three treatments containing urea. The results signify that, both the green and burnt SCT has adequate soluble sugar for satisfactory fermentation. Similarly, low pH value of SCT silage ensiled without additive was reported (Khanal et al., 1995). Furthermore, Heikkilä et al. (2010) reported that, wilting pre-ensiled grass to DM content above 30% restricted the extent of fermentation resulting in well-preserved silage at no use of additive. Except for green SCT that ensiled with urea containing additive, the rest of the silages had pH within the range 3.7 to 5.0 acceptable for good to average quality silage (McDonald et al., 2010). The drop in pH at the end of ensiling from the initial value is presumably a consequence of production of organic acids (McDonald et al., 1991).

While molasses was exclusively added, silage pH was similar to that of control, probably indicating that SCT had the threshold soluble carbohydrate to trigger the production of lactic acid. However, when SCT was ensiled with urea exclusively, the levels of pH were significantly increased (*P*<0.05) over that of control silage

Table 3. pH, Temperature and total DM loss of sugarcane top ensiled with or without urea, molasses and their combination.

		Treatment (T)					SCT type			Effect (*P-value*)		
Parameter	**SCT type**	**Control**	**Mol- 4%**	**Urea- 1%**	**1%Urea + 4%Mol**	**SEM**	**Burnt**	**Green**	**SEM**	**SCT type**	**T**	**SCT type x T**
pH*i*		5.54^{b}	5.64^{ab}	5.72^{a}	5.64^{ab}	0.03	5.58^{b}	5.69^{a}	0.02	0.0025	0.0051	0.7953
pH @45d	Burnt	4.13^{b}	4.19^{b}	4.69^{ab}	4.18^{b}	0.15	-	-	-	0.0007	<.0001	0.0007
	Green	4.04^{b}	4.14^{b}	5.30^{a}	5.28^{a}	-	-	-	-	-	-	-
TDML (%)	Burnt	3.13^{bc}	6.06^{abc}	5.95^{abc}	5.00^{abc}	1.17	-	-	-	0.1651	0.0319	0.0149
	Green	5.81^{abc}	2.31^{c}	8.19^{ab}	8.50^{a}		-	-	-	-	-	-
Temp. (°C)	Burnt	29.00^{ab}	29.80^{a}	29.80^{a}	29.40^{ab}	0.31	-	-	-	<0.0001	0.0004	<.0001
	Green	29.40^{ab}	26.00^{c}	28.9^{ab}	28.10^{b}		-	-	-	-	-	-

$^{a\text{-}c}$Means with different superscript within treatment and SCT type in the same row differ ($P < 0.05$); pH*i*= pH before ensiling; TDML = total DM loss; Mol = molasses; Temp. = temperature; d= day; SEM = standard error of the mean.

especially for green SCT above the recommended pH 4.5, indicating that urea might have reduced fermentation and acid production during ensiling. During ensilage, the ammonia released from urea is slightly basic, causing delay in pH drop and DM loss in grass silage (Kung and Shaver, 2001). Molasses when used in combination with urea failed to significantly counter-act the effect of urea alone to reduce silage pH both in green and in burnt SCT silages.

However, Khanal et al. (1995) reported a significantly reduced pH of green SCT silage treated with urea and molasses combination when compared with urea only treated with green SCT silage. Generally the application of silage additives used in the current study had no beneficial effect in reducing total dry matter loss. Similar to the result of the current study, increased pH were observed in green SCT (Khanal et al., 1995) and Napier grass (Samanta et al., 2001) ensiled with urea and urea-molasses as additive, leading to poor fermentation of silage.

Total dry matter loss was lower (P<0.05) in green SCT ensiled with molasses alone than the other additive containing treatments. Paderoso et al. (2011) reported 31% reduction in dry matter loss of sugarcane silage when ensiled with urea at lower dose (0.5%) than the present dose. Treating green SCT with urea alone resulted in three-fold TDML over molasses alone in silages (2.31 vs. 8.19), implying that undesirable microbes might have been favored by urea than molasses addition.

The temperature of silages measured upon opening the silos, ranged from 26 to 29.8°C. Value were similar among treatments for the burnt SCT, while for green SCT, the temperature of molasses alone treated silage was lower than the silage treated with combination of molasses and urea. The present silage temperatures of SCT ensiled without additive which exceed the value of 26°C as reported by Akinbode et al (2017) after 42 days of ensiling. Temperature range from 27 to 32°C is often acceptable as indicator of good fermentation status of silage. Kung (2011) suggested that, silage temperature of small silos similar to the ambient temperature or just a few degrees warmer is normal. Thus, the result of this study showed that the generated heat was small, indicating the occurrence of minimal aerobic deterioration. Excessive heat production due to aerobic oxidation leads to browning (Millard) reaction, forming protein and carbohydrate complex that inhibits protein and fiber digestion (Bolsen et al., 1996).

There was no significant interaction between treatment and SCT forages, except for texture and pH, on the average score values of silages (Table 4). The average score value for smell increased (P<0.001) for molasses containing additives when compared to the control, and was higher (P<0.0025) in burnt than the green SCT silage. The score for color was lower in silages treated with molasses + urea than with molasses alone. Score for texture was higher (P=0.0047) in molasses containing treatments of the green SCT than burnt SCT silages, and among the treatments differences were observed between control and molasses+urea containing treatments

Table 4. Average score values (*scale: 1-4) for physical properties and pH of SCT ensiled with or without urea, molasses and their combination.

		Treatment (T)					SCT type			Effect (P-value)		
Parameter	**SCT type**	**Control**	**Mol-4%**	**Urea-1%**	**Urea-1% +Mol4%**	**SEM**	**Burnt**	**Green**	**SEM**	**SCT type**	**T**	**SCT type x T**
Smell	-	3.23^{b}	3.81^{a}	3.48^{ab}	3.63^{a}	0.09	3.65^{a}	3.42^{b}	0.06	0.0161	0.0010	0.1427
Color	-	3.53^{ab}	3.63^{a}	3.59^{ab}	3.24^{b}	0.10	3.42	3.57	0.07	0.1304	0.0335	0.5066
Texture	Burnt	3.79^{ab}	3.51^{bc}	3.63^{abc}	3.37^{c}	0.06	-	-	-	<0.0001	0.0047	0.0031
	Green	3.82^{a}	3.91^{a}	3.64^{abc}	3.76^{ab}	-	-	-	-	-	-	-
Moldiness	-	3.09^{b}	3.67^{a}	3.08^{b}	3.16^{ab}	0.13	3.45^{a}	3.05^{b}	0.09	0.0049	0.0110	0.1874
pH	Burnt	3.20^{a}	3.20^{a}	1.80^{b}	3.20^{a}	0.25	-	-	-	0.0092	<.0001	0.0003
	Green	3.60^{a}	3.00^{a}	1.60^{b}	1.20^{b}	-	-	-	-	-	-	-
Average	-	3.41^{ab}	3.58^{a}	3.1^{c}	3.16^{bc}	0.07	3.39^{a}	3.23^{b}	0.05	0.0328	<.0001	0.2594

$^{a-c}$Means with different superscript within treatment and SCT type in the same row differ ($P< 0.05$); *(1- bad; 2-moderate;3-good; 4- excellent); Mol = molasses; SEM = standard error of the mean.

for the burnt SCT. Moldiness score increased in molasses based additives, and was higher in burnt than green SCT silages. Generally, a slight mold was observed on top of all silos, which could be due to air trapped while sealing. The score of pH was lower for urea treated silages than other treatments.

Accordingly to the scale used in this study, the average score values of the silages indicated that the best physical attributes and pH values were attained when SCT was ensiled without additive or with 4% molasses alone. Akinbode et al. (2017) reported that green SCT ensiled without additive which had a greenish yellow color, pleasant smell and slightly moldy.

Change in dry matter and nutrient composition

There was a significant interaction between treatments and sugarcane top types ($P<0.05$) on chemical composition of silages except for ether extract (Table 5). For burnt SCT molasses + urea, additive treatment was higher than the other treatments, while for green SCT molasses + urea additive treatment had the highest and the control had the lowest DM content of pre-ensiled forages. Addition of molasses increased ($P<0.05$) DM content of fermented green SCT silages as compared with control silage, or that treated with urea alone. Generally there was a reduction of less than 4.6% in DM content of the ensiled material as compared to pre-ensiled SCT, presumably due to loss of soluble nutrients during fermentation. McDonald (2010) reported that up to 5% DM loss occurring during ensiling process is considered as normal.

Addition of molasses alone do not increase ($P>0.05$) CP content when compared with control silages. However, SCT ensiled with urea based additives had significantly higher ($P<0.05$) CP content than the treatments without. These results are in agreement with reports of Pedroso et al. (2011), where urea addition increased CP content of sugarcane silage. In contrary, Khanal et al. (1995) reported that no difference in CP content between control and urea treated green SCT silages, but increased when molasses was included at 3 to 12% DM. The NDF content increased with urea based additives, while ADF decreased with molasses based additives in green SCT. For burnt SCT, NDF and ADF values for molasses + urea additive silage was lower than urea alone additive silage. This could be possibly due to low acid condition of urea treated silages, resulting in reduced NDF solubility and/or increased loss of soluble nutrients. With increase in silage acidy a decrease in NDF content was reported (McDonald et al., 1991). The increase in fiber components of SCT silages associated with urea based treatments could be due to loss of some fermentable carbohydrates, leading to rise in the concentration of NDF in DM.

The application of molasses alone lowered NDF in green than burnt SCT silage, while the reverse is true with urea and molasses combination. This

Table 5. Chemical composition of SCT silage untreated or treated with urea, molasses and their combination.

	Bunt SCT silage				Green SCT silage					Effect (P-value)		
Parameter	**Control**	**Mol- 4%**	**Urea- 1%**	**Urea-1% +Mol -4%**	**Control**	**Mol-4%**	**Urea- 1%**	**Urea-1% +Mol- 4%**	**SEM**	**SCT type**	**T**	**SCT*T**
DM*i*	34.97^{e}	35.57^{ced}	35.48^{ed}	36.24^{bc}	35.12^{e}	36.55^{b}	36.16^{bcd}	37.42^{a}	0.15	<.0001	<.0001	0.0164
DM	34.45^{ab}	34.09^{b}	33.94^{b}	34.9^{ab}	33.50^{b}	36.26^{a}	34.03^{b}	35.22^{ab}	0.41	0.1673	0.0051	0.0059
Ash	11.90^{dc}	11.50^{de}	11.92^{dc}	10.97^{e}	13.76^{b}	12.30^{c}	14.17^{ab}	14.76^{a}	0.17	<.0001	<.0001	<.0001
CP	2.75^{c}	2.82^{c}	3.91^{ab}	4.00^{ab}	3.15^{c}	2.80^{c}	3.67^{b}	4.09^{a}	0.09	0.3892	<.0001	0.0096
EE	1.443	1.464	1.437	1.467	1.592	1.466	1.427	1.702	0.084	0.1241	0.3065	0.4080
NDF	68.20^{cd}	70.20^{bc}	70.80^{bc}	67.40^{d}	66.20^{d}	67.00^{d}	72.40^{b}	77.80^{a}	0.59	0.0003	<.0001	<.0001
ADF	40.80^{bc}	39.40^{bc}	41.40^{b}	35.60^{c}	46.00^{a}	38.80^{c}	44.80^{a}	41.60^{b}	0.52	<.0001	<.0001	<.0001
ADL	7.55^{ab}	6.69^{bcd}	7.05^{abc}	7.87^{a}	6.12^{de}	5.59^{e}	6.77^{bcd}	6.55^{dc}	0.20	<.0001	<.0001	0.0306
Hemi	27.40^{d}	30.80^{bc}	29.40^{bcd}	31.80^{b}	20.20^{e}	28.20^{dc}	27.60^{dc}	36.20^{a}	0.73	0.0015	<.0001	<.0001
IVDMD	52.81^{ab}	51.30^{bc}	50.60^{c}	53.68^{a}	48.23^{d}	50.81^{bc}	45.31^{e}	50.17^{dc}	0.45	<.0001	<.0001	<.0001
IVOMD	45.95^{b}	45.05^{b}	$44.61b^{c}$	48.34^{a}	42.84^{c}	44.25^{bc}	40.20^{d}	44.21^{bc}	0.42	<.0001	<.0001	0.0009
ME	7.35^{b}	7.21^{b}	7.14^{bc}	7.74^{a}	6.85^{c}	7.08^{bc}	6.43^{d}	7.07^{bc}	0.07	<.0001	<.0001	0.0009
NFC	15.70^{a}	14.01^{ab}	11.93^{b}	16.17^{a}	15.29^{a}	16.43^{a}	8.34^{c}	1.65^{d}	0.60	<.0001	<.0001	<.0001
Ca	0.40^{d}	1.44^{a}	0.91^{bc}	1.32^{a}	0.43^{d}	0.65^{d}	0.59^{cd}	1.16^{ab}	0.08	<.0001	<.0001	0.0002
P	0.30^{cd}	0.51^{ab}	0.64^{a}	0.13^{e}	0.27^{d}	0.59^{a}	0.43^{bc}	0.38^{bcd}	0.03	0.3178	<.0001	<.0001

Within treatment and SCT type in the same row, means with different superscript differ ($P<0.05$); DM*i* - Dry matter of pre-ensiled forage; DM- dry matter of silage; IVDMD- *In-vitro* dry matter digestibility; IVOMD- *In-vitro* organic matter digestibility; NFC- non-fibrous carbohydrate; Mol-molasses; T- treatment; SEM- standard error of mean.

can be explained from reduction in non-fiber carbohydrate (NFC) for green SCT silages treated with urea or, urea + molasses than the corresponding burnt SCT silages. The loss in soluble sugar arises from microbial fermentation which occurs during ensiling (McDonald et al., 1991).

The *in vitro* dry matter digestibility (IVDMD) and organic matter digestibility (IVOMD) were lowest ($P<0.0001$) in green SCT ensiled with urea alone. Except for molasses treated silages, higher digestibility coefficients were obtained in burnt than green sugarcane top silages. The highest IVDMD ($P<0.0001$) and IVOMD values were obtained in burnt SCT ensiled with urea+molasses, which could be related to lower fiber contents in this treatment (NDF, ADF and hemicelluloses). In agreement with the present finding, Khanal et al. (1995) reported increased IVDMD and IVOMD of green SCT silage ensiled with urea + molasses when compared to silage without additive, but addition of urea had no effect over control.

The highest ME value was noted in the burnt SCT silage treated with urea + molasses, and the lowest was in green SCT ensiled solely with urea. The ME value of intact SCT was reported to be 7.0 MJ/kg DM (McKenzie and Griffiths, 2007). Higher NFC value was obtained in green SCT ensiled without additive, or with molasses alone compared with urea based treatments. In green SCT silage, this value was low when ensiled with urea and largely depleted with urea + molasses treatment. Akinbode et al. (2017) reported that, green SCT ensiled without additive had 13.9% NFC after 42 days of ensiling, which approached the green SCT (15.3%) in the present study.

The higher value of NFC indicated that the silages were well fermented and preserved. Moreover, Ferreira et al (2014) reported that, fermentation characteristics of elephant grass low in NFC (3.2%) was greatly improved by addition of cashew bagasse rich in NFC (11.9%). Ether extract values of the silages were not affected by SCT types and treatment ($P>0.05$).

Conclusion

Ensiling SCT with urea and molasses had beneficial effect on the fermentative quality and nutritive value of SCT silage. In terms of digestibility, green SCT was best fermented and preserved when ensiled without additive or treated with 4% molasses, while the burnt SCT was best preserved with 1% urea and 4% molasses combination.

It can however be established that, both burnt and green SCT can be adequately fermented and preserved as silage without additive like urea and molasses and their combination.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

Getahun Kebede would like to thank Ethiopian Institute of Agricultural Research for financing this study, and the technical and research staff in the Department of Livestock Research and Nutrition Laboratory of Debre-Zeit Agricultural Research Center for their support in implementing the experiment. The author also acknowledged Wonji- shoa sugar factory for permitting access to cane plantation and SCT sampling.

REFERENCES

Australian Fodder Industry Association (AFIA) (2011). Laboratory Methods Manual. Version 7:80-81.

Akinbode RM, Isah OA, Oni AO, Arigbede OM, Ojo VOA (2017). Nutritional evaluation of sugarcane top ensiled with varying proportion of broiler litter. Livest. Res. Rural Dev. 29:6.

Anteneh W (2014). Effect of Different Levels of Dried Sugar Cane Tops Inclusion on the Performance of Washera Sheep Fed a Basal Diet of Grass Hay. A Thesis Submitted to the School of Graduate Studies (School of Animal and Range Sciences), Hramaya University, Ethiopia.

Association of Official Analytical Chemists (AOAC) (1990). Official Methods of Analysis. 15th Edition. Arlington, Verginia, USA. pp. 12-98.

Bolsen KK, Ashbell G, Weinberg ZG (1996). Silage fermentation and silage additives. Rev. Asian-Aust. J. Anim. Sci. 9:483-493.

Bureau of Animal Production and Health (BAPH) (1996). Criteria for evaluation of maize stover silage. BAPH, Ministry of Agriculture, Bejing, China. FAO publication.

Central Statistics Agency (CSA) (2017). Agricultural sample survey, Area and production of major crops: private peasant holdings. Ethiopia: Stat. Bull. 1:584.

Tena E, Mekbib F, Shimelis H, Mwadzingeni L (2016). Sugarcane production under smallholder farming systems: Farmers preferred traits, constraints and genetic resources. Cogent Food Agric. 2:1191323.

Gendley MK, Singh P, Garg AK (2002). Performance of Crossbred Cattle Fed Chopped Green Sugarcane top and Supplemented with Wheat Bran or Lentil Chuni Concentrates. Asian-Aust. J. Anim. Sci. 15(10):1422-1427.

Hall MB (2000). Neutral detergent-soluble carbohydrates. Nutritional and relevance analysis. Florida: University of Florida. Bulletin P. 339.

Heikkilä T, Saarisalo E, Taimisto AM, Jaakkola S (2010). Effects of dry matter and additive on wilted bale silage quality and milk production. Grassland Sci. Eur. 15:500-502.

Kaensombath L, Lindberg JE (2013). Effect of additives on ensiling of taro (*Colocasia esculenta* (L.) Schott) leaves and Stylo CIAT 184 (Stylosanthes guianensis (Aubl.) Sw. var. guianensis) forage. Livest. Res. Rural Dev. 25:69.

Khanal RC, Perera ANF, Perer ERK (1995). Ensiling characterstics and nutritive value of sugarcane top. Trop. Agric. Res. 7:177-185.

Kung L (2011). Silage Temperatures: How Hot is Too Hot? Dept. of Animal & Food Sciences. 531 South College Avenue, Newark, DE 19717-1303.

Kung L, Shaver R (2001). Interpretation and use of silage fermentation analysis reports. Focus on Forage 3(13):1-5.

Leng RA, Preston TR (1985). Constraints to the efficient utilization of sugarcane and its by-products as diets for production of large ruminants. In: R M Dixon (ed.), Ruminant feeding systems utilizing fibrous agricultural residues. International Development Program of the Australian Universities and Colleges, Canberra, Australia pp. 27-48.

Magaña R, Aguirre J, Aguirre A, Gómez A, Martínez S, Lemus C, Ulloa R, Ly J (2009). Entire sugar cane or sugar cane residues for feeding sheep. Performance traits of hairless sheep. Livest. Res. Rural Dev. 21:24.

McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA, Sinclair LA, Wilkinson RG (2010). Animal Nutrition. 7th Ed. Ashford Color Press Ltd., Gosport, England.

McDonald P, Henderson AR, Heron SJE (1991). The Biochemistry of Silage. 2nd Ed. Chalcombe publications, Marlow, Bucks, UK.

McKenzie J, Griffiths C (2007). Cane tops as cattle fodder. New South Wales Department of Primary Industries, Primefacts, N°314.

Ososanya TO, Olorunnisomo OA (2015). Silage characteristics and preference of sheep for wet brewer's grain ensiled with maize cob. Livest. Res. Rural Dev. 27:12.

Pedroso AF, Rodrigues AA, Júnior WB, Souza GB (2011). Fermentation parameters, quality and losses in sugarcane silages treated with chemical additives and bacterial inoculants. R. Bras. Zootec. 40(11):2318-2322.

Pedroso AF, Nussio LG, Loures DRS (2008). Fermentation, losses, and aerobic stability of sugarcane silages treated with chemical and bacterial additives. Sci. Agric. 65:567-691.

Ramírez-Cathí H, Aida C, Salcedo C, Briones F, Lucero FA, Cárdenas A, Marcof C, Martínez JC (2014). Bromatological and morphological characterization and yield of sugar cane top in Huasteca Potosina, Mexico. Cuban J. Agric. Sci. 48:4.

Samanta AK, Singh KK, Verma NC, Misra AK (2001). Effect of additives on silage quality of Napier ensiled in plastic bag. Indian J. Anim. Sci. 71(9):881-882.

Statistical Analysis System (SAS) (2004). Version 9.1. SAS Institute. Inc., Cary, NC, USA.

Sharma VK, Tomar SK, Kundu SS, Pankaj J, Pankaj J, Muneendra K, Manju L (2012). Chemical Composition and Effect of Feeding Different Levels of Sugarcane top with Concentrate Mixture/Mustard Cake on Digestibility in Buffalo Calves Indian J. Dairy Sci. 65:5.

Suárez R, Mejía J, González M, García DE, Perdomo DA (2011). Evaluation of mixed silages of Saccharum officinarum and Gliricidia sepium using additives. Pastos Forrajes 34(1):69-86.

Suttie JM (2000). Hay and straw conservation for small-scale farming and pastoral conditions. FAO Plant Production and Protection Series No. 29, FAO, Rome.

Tadesse A, Fulpagare YG, Gangwar SK (2014). Effect of urea treatment on chemical composition and oxalate content of sugarcane top. Int. J. Sci. Nature 5(1):15-18.

Tilley J, Terry RA (1963). A two stage technique for the in-vitro digestion of forage crops. J. Brit. Grassland Soc. 18:104–111.

Van Soest P, Robertson JB (1985)s. analyses of forage and fibrous foods. A laboratory manual for Animal Science 613. Cornell University, Ithaca, New York, USA.

Vol. 13(20), pp. 1018-1025, 17 May, 2018
DOI: 10.5897/AJAR2018.13157
Article Number: 399330857133
ISSN 1991-637X
Copyright©2018
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Correlation of climatic factors between the development of tomato cultivars (*Solanum lycopersicum* L., Solanaceae) with adults of two key pests

Isabelle Cristina Santos Magalhães[1*], Rubens Pessoa de Barros[2], Ligia Sampaio Reis[3], Jhonatan David Santos das Neves[4], Claudio Galdino da Silva[5], Diego Jorge da Silva[6], Alverlan da Silva Araujo[6], Adriely Vital de Souza[6], Aleyres Bispo Chagas[6], Tamara Taís dos Santos[6], Joice Kessia Barbosa dos Santos[6] and Eliane dos Santos[6]

[1]Stricto Sensu in Plant Protection at the Center of Agricultural Sciences, Federal University of Alagoas (UFAL), Brazil.
[2]Center of Agricultural Sciences, Federal University of Alagoas, Brazil.
[3]Agro-Food Technological Pole of Arapiraca / Universidade Estadual de Alagoas (UNEAL), Brazil.
[4]Group of Environmental and Ethnobiological Studies, Universidade Estadual de Alagoas (UNEAL), Brazil.
[5]Biological Sciences, State University of Alagoas, Brazil.
[6]Department of Biological Sciences, State University of Alagoas, Brazil.

Received 29 March, 2018; Accepted 24 April, 2018

The tomato (Solanum lycopersicum L., Solanaceae) is a crop has suffered from insect attacks and environmental factors. The objective of this work was to evaluate the correlations of climatic factors and two key pests at the development of cultivars. The study was conducted in Alagoas, Northeastern Brazil, monitored from September 2016 to August 2017. The experimental randomized with five treatments and twelve replicates. Collection of adult insects was performed with Delta® traps with Tuta absoluta pheromone and Bemisia tabaci Genn. through manual harvesting. Data were analyzed by Pearson correlation and climatic factors. Data were subjected to analysis of variance, and the means were compared by the Tukey test at the 5%. probability. In numbers of flower buds, the cultivars Santa Cruz and Rio Grande gave the highest values, 9.65 and 13.6, respectively. In numbers of fruits, the cultivar Cereja gave higher yields, with a mean value of 6.91. For fruit diameter, the cultivars Santa Clara, Caline IPA 6 and Santa Cruz produced fruits whose diameter was 2.93 cm, 2.95 cm and 3.22 cm, respectively. In of fruit weight, the cultivars Caline IPA 6 and Santa Cruz gave averages of 29.14 g and 38.9 g, respectively, both superior to those of the other cultivars studied. The correlations precipitation, radiation, temperature and wind were climatic factors contributing to the development of tomato varieties in protected crops and caused damage to the physiology of the plant, and acted as environmental indicators for the planning of integrated pest management.

Keywords: vegetable production, productivity, agriculture, abiotic factors.

INTRODUCTION

Tomato *Solanum lycopersicum* L., is one of the most cultivated vegetables in the world. It is cultivated in fields, in protected environments with or without soil, with various levels of cultural management and with several climatic variations (Dorais et al., 2011).

The growth and development of the tomato plant depends on environmental variables and appropriate management for the crop integrity; the fruits produced are used in agroindustries that depend on its production in the field (Horowitz et al., 2005; Silva et al., 2007).

The whitefly (*Bemisia tabaci* Genn. [Hemiptera: Aleyrodidae]) is capable of causing both direct and indirect damage to the tomato crop. It causes direct damage by sucking plant sap, and indirect damage from toxins excreted in its saliva during feeding. The management of *B. tabaci* has been a challenge for farmers (Baldin et al., 2005; Silva et al., 2009).

The moth *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae), is a key pest causing damage and low yield in tomatoes, both in the field and in closed crops (Bacci, 2006; Desneux et al., 2010; Guedes and Picanço, 2012).

Climatic factors including radiation, relative humidity, temperature, precipitation and wind interfere in tomato development and productivity. Increased radiation increases the production of photoassimilates that can contribute to the growth of the tomato, while excess hinders stomatal conductance and photosynthesis (Andriolo, 2000).

Relative humidity exerts an effect on tomato development, in which high humidity allows for emergence of diseases, and low rates cause evapotranspiration, favoring water deficiency, reducing the photosynthetic rate and consequently decreasing crop production (Kalungu, 2008).

Temperature has a strong influence on the adaptation of the tomato crop; low temperatures slow down growth, while high temperatures affect flowering, fruiting and fruit development, giving rise to deformed fruits that do not have nutrients when climatic conditions are not adequate (Silva et al., 2006).

Rainfall is important during the phenological cycle, participating in vital plant processes, including germination and flowering. However, water availability limits growth and alters productivity as well as promoting the emergence of diseases (Farias, 2007).

Wind indirectly affects crop development, renewing the CO_2 supply for photosynthesis and maintaining transpiration. Excess wind inhibits plant development via mechanical damage (e.g., falling leaves and branches) (Pereira et al., 2002).

An association of climatic variables in the development of tomato cultivars with the presence of two key pests was proposed in the study. The objective of this study was to evaluate the correlation of climatic factors on development of five tomato cultivars (Santa Clara, Caline IPA 6, Santa Cruz, Rio Grande, Cereja) in a protected environment, to assist with the planning of integrated pest management.

MATERIALS AND METHODS

The study was conducted in a greenhouse with a 50% shaded environment, located in the municipality of Arapiraca, Alagoas, Northeast Brazil, at geographic coordinates: 9° 75’ 25” S latitude 36° 60’ 11” W longitude. The municipality gave edaphic conditions as follows: Temperature 28°C; average annual rainfall 550 mm (Alagoas-Semarh-dmet, 2017); the climate of the region is As' type, that is, a tropical and hot climate according to the classification of Köppen and Geiger.

The study was carried out with five tomato (*S. lycopersicum)* varieties, cultivated from September 2016 to August 2017. The design was completely randomized with five treatments (Santa Clara, Caline IPA 6, Rio Grande, Santa Cruz and Cereja cultivars) and twelve replicates.

The data were recorded weekly in a spreadsheet with the evaluated varieties from the phases of post-transplant and opening of the flower bud until fruit formation. The following parameters were recorded: Height (cm), branches (U), flower buds (U), number of fruits (U), fruit diameter (cm) and fruit weight (g).

Climatic evaluations were recorded using monthly data for precipitation (mm), relative humidity (%), temperature (ºC), wind and solar radiation, provided by the National Institute of Meteorology (INMET), for the periods 2016 to 2017.

The insects were collected using the Delta® trapping strategy with IscalureTuta® pheromone, for moth (*T. absoluta*) and for whitefly (*B. tabaci*), using a paintbrush on each plant in the pot. Insects were taken to the laboratory for classification verification with the aid of identification keys. For insect analysis, the design was completely randomized with two treatments and fifteen replicates. For the Pearson correlation coefficient (r) of the phenological variables with climactic factors, *Action Stat* software, a statistical system developed by the Estatcamp Team (2014) was used. Data were subjected to analysis of variance and the means were compared by the Tukey test at the 5% probability level, using the statistics package, Assistat - Statistical Analysis System (Silva et al., 2016).

RESULTS AND DISCUSSION

Evaluation of tomato cultivar development

The variables height (H), branches (B), flower buds (FB), fruit number (FN), fruit diameter (FD) and fruit weight (FW) analyzed among the cultivars (Santa Clara, Caline Ipa 6, Santa Cruz, Rio Grande and Cereja), differed significantly from one another (Table 1). Gracia (2016) studied fruit production of the Salada group in planting season, giving significant values for numbers of fruit. Shirahige (2010) found significant differences among cultivars such as Santa Cruz and Italiano in terms

*Corresponding author. E-mail: smagalhaes.isabelle@gmail.com.

Table 1. Average data and standard deviation of the development of *Solanum lycopersicum* L with *Tuta absoluta* and *Bemisia tabaci.*

Mean and standard deviation of insects and phenological variables of tomato plants								
Cultivar	***Tuta absoluta***	***Bemisia tabaci***	**Height (cm)**	**Branches (U)**	**FB(U)**	**NF(U)**	**DF(cm)**	**WF(g)**
Santa Clara	67±7.8^a	56±3.4^a	77.49±3.44^a	18.74±1.32^a	7.27±1.1^b	3.16±0.93^c	2.93±0.59^a	20.68±3.95^b
Caline Ipa 6	47±3.2^b	39±1.8^b	64.92±5.30^a	10.39±0.56^b	5.2±0.99^b	2.12±0.50^c	2.95±0.38^a	29.14±4.41^a
Santa Cruz	54±2.3^a	41±2.1^b	77.01±1.85^a	13.23±0.51^b	9.65±0.87^a	3.54±0.39^b	3.22±0.31^a	38.9±4.97^a
Rio Grande	55±1.4^a	52±2.5^a	60.44±1.40^b	11.32±0.31^b	13.6±0.73^a	4.41±1.41^b	2.03±0.48^b	2.03±0.48^c
Cereja	14±0.8^c	13±0.5^c	72.51±1.54^a	22.74±1.16^a	7.22±0.70^b	6.91±2.62^a	1.45±0.24^b	5.4±1.10^c

Means followed by the same letter in the column and in the row did not differ significantly by the Tukey test at 5% probability. A = height; B = branches; FB = flower buds; NF = number of fruits; DF = fruit diameter; PF = fruit weight.

of productivity and quality of these tomato hybrids, as well as data on yield, number of fruits per plant, fruit number per flower head, length and width of the fruit.

Due to the significant differences identified for tomato height, it was observed that only the Rio Grande cultivar showed less development (mean and standard deviation 60.44 ± 1.40). Soares (2011), in a study of tomato growth rates, observed significant differences between the phenological phases, with higher rates of relative and absolute growth in diameters in stressed plants in the reproductive phase, but they did not verify differences in growth rates related to height.

The Santa Clara and Cereja cultivars showed higher values for branches than Caline Ipa 6, Santa Cruz and Rio Grande. Silva (2008) studied hybrid tomato cultivation in two different environments and found that the number of lateral branches emitted per plant did not differ in terms of dry mass. The comparison of the means of the flower buds variable of the cultivars showed that the cultivar Santa Cruz and Rio Grande gave the highest values, with means of 9.65 and 13.6 flower buds per plant, respectively.

The cultivar Cereja showed higher production in terms of characteristic number of fruits (6.91 ± 2.62) than did the other cultivars. Among the analyzed cultivars, the cultivars Santa Clara and Caline Ipa 6 gave lower performance, with fruit numbers 3.16 ± 0.93 and 2.12 ± 0.50, respectively. Melo et al. (2009) evaluated the performance of tomato cultivars in an organic system under protected cultivation and reported a number of fruits between 32.2 and 68.9 fruits per plant. Similar results were found by Silva et al. (2013), who reported an average of 37.4 fruits per plant in protected environment cultivation.

The cultivars Santa Clara, Caline Ipa 6 and Santa Cruz gave fruits with greater diameter than did the other cultivars. Shirahige (2009) found greater fruit diameters in the Santa Cruz hybrids THX-02 and THX-03, 6.1 and 6.6 cm, respectively, in plants grown in experimentally protected environments.

The cultivars Caline, Ipa 6 and Santa Cruz showed higher average fruit weights than did the other cultivars. In a similar study by Libânio (2010), the cultivar Santa Clara showed the higher average fruit weights than did other cultivars, with 21.33 g.

Among the cultivars, the differences in attacks by key pests (*Tuta absoluta* and *Bemisia tabaci*) were significant among the five tomato varieties. Santa Clara was the most susceptible and Cereja was least susceptible, or most resistant, to attacks by two key pests.

Baldin et al. (2007) and Togni et al. (2009) obtained similar results, in controlled studies using extracts of plants in a greenhouse. Oliveira et al. (2008), in a study of *T. absoluta*, obtained significant results, corroborating this study in terms of climatic variables.

Analysis of climatic factors

There were no variations among the average values of the climatic variables, relative humidity, temperature, wind and radiation. However, there was variation in terms of rainfall, with the months of March to July 2017 being having with the highest rainfall (Figure 1).

Various climatic conditions are determinant factors for the productivity of the tomato crop, with precipitation, relative humidity, temperature, wind and radiation modulating crop performance.

Wind, rainfall and relative humidity were the climatic factors that most modified the performance of tomato plants, since wind assists in the growth of tomatoes, contributing to photosynthesis by increasing concentrations of CO_2. This process produces biochemical energy to perform physiological activities, in addition to participating in the transpiration processes, allowing water present in the tomato plants to escape through the stomata, regulating plant temperature, and inhibiting wilting (Gravena and Benvenga, 2003).

Rainfall participates in several physiological and biochemical processes in tomato plants, allowing the absorption and transport of nutrients throughout the plant. Relative humidity prevents the absorption of nutrients, in addition to keeping the leaves of the tomato moist for long periods, favoring the appearance of diseases caused mainly by fungi and bacteria (Barbosa et al., 2016).

In onion production, wind had a strong influence on

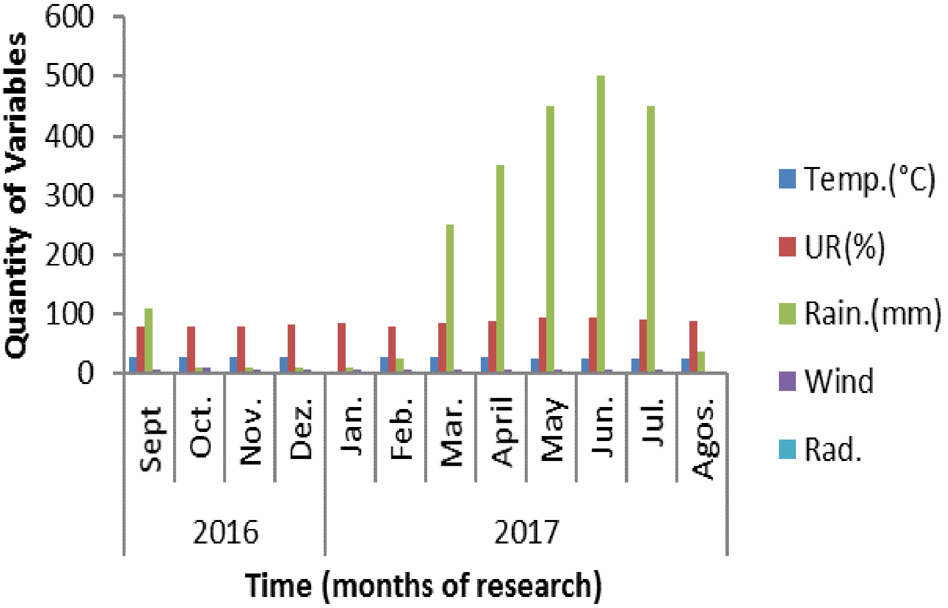


Figure 1. Climatic variables of the rural region of Alagoas, Northeast Brazil, during the period of the research (2016~2017).
Source. Research Data.

plant growth, contributing to transpiration, increasing CO_2 absorption and consequently increasing the photosynthetic rate, as well as exerting substantial mechanical effects on onion leaves (Oliveira et al., 2014). In beet cultivation, high rainfall favored infestation of invasive plants, limited the development of the crop, increased the occurrence of diseases causing physiological disturbances and reduced productivity (Costa, 2014).

Evaluation of the correlations of adult key pests and explanatory variables

Tables 2 to 6 display the Pearson correlation coefficients of the phenological variables of the cultivars (Santa Clara, Caline Ipa 6, Santa Cruz, Rio Grande and Cereja) with climatic variables (precipitation, relative humidity, temperature, wind and radiation). There were positive and negative correlations for the climatic variables and the phenological variables of the tomato plants with the monitoring of the adult pest insects. Correlations between *T. absoluta* and *B. tabaci* were negative for each cultivar. The populations of these insects were inversely proportional, that is, while one grows the other one diminishes during the culture cycle.

Fernandes et al. (2009), in a study of *Leucoptera coffeella* (Guérin-Mèneville, 1842) (Lepidoptera: Lyonetiidae) in coffee plants, observed that in correlation studies and trail analysis, the environmental variables that most influenced the intensity of the attack of this pest were rainfall (r = 0.69), air temperature (r = -0.40) and solar radiation (r = -0.44).

According to Oliveira et al. (2011), the principal meteorological elements that provided energy for evaporation and removal of water vapor from evaporating surfaces were solar radiation, air temperature, relative humidity, wind speed and vapor pressure deficit. In this study, solar radiation was the most important element for the evaporative demand of the atmosphere (Tables 1 and 2).

The study of simple correlations between the variables allowed only measurement of association to verify their magnitude, direction and intensity (Coimbra et al., 2005; Vieira et al., 2007)

The data collected from the cultivars and the climatic dynamics in the tomato growing region correlated with explanatory variables, following the hypothesis raised for the association of the endemic presence of the key pests *T. absoluta* and *B. tabaci*. These environmental indicators could aid the planning of integrated pest management - IPM.

Evaluation of correlations of phenological variables with climatic factors

The pest insects studied cause damage to the crop and damage is associated with presence during seasonality and climatic variables. In the case of rainy days, the application of chemical control is not effective (Guimarães et al., 2007). The data presented on the correlations were significant at $p < 0.01$ level of

Table 2. Pearson's correlation coefficient between the agronomic performance variables of the Santa Clara cultivar with the climatic variables and the pest insects.

	Cultivar Santa Clara												
	T. absoluta	***B. tabaci***	**Heig.**	**Bran.**	**FB**	**NF**	**DF**	**WF**	**Rain.**	**UR**	**Temp.**	**Win.**	**Rad.**
T. absoluta	-	-0.25	-										
B. tabaci	-0.25	-											
Heig.	0.74	0.67	-										
Bran.	0.67	0.63	0.11	-									
FB	0.55	0.73	-0.06	-0.59	-								
NF	0.57	0.74	-0.58	-0.13	0.12	-							
DF	0.33	0.47	-0.15	-0.33	0.85	0.30	-						
WF	0.35	0.36	-0.24	-0.25	0.53	0.46	0.77	-					
Rain.	0.82	0.56	-0.06	-0.04	-0.32	-0.50	-0.54	-0.44	-				
UR	0.53	0.46	-0.11	0.30	-0.69	-0.02	-0.74	-0.55	0.46	-			
Temp.	-0.19	-0.17	0.04	-0.36	0.49	0.12	0.53	0.35	-0.29	-0.59	-		
Wind	-0.42	-0.38	-0.29	-0.25	0.37	0.49	0.64	0.53	-0.42	-0.42	0.72	-	
Rad.	0.44	0.46	0.07	-0.43	0.19	-0.42	-0.08	-0.23	0.37	-0.03	0.55	0.06	-

Heig. = Height; Branc. = Branches; FB = Flower buds; NF = Number of fruits; DF = Fruit diameter; WF = Fruit weight; Rain. = Rainfall U.R = Relative humidity; Temp = Temperature; Wind = Winds; Rad. = Sun radiation.

significance. These positive (+) and or negative (-) correlations are important because they are directly proportional or inversely proportional, in intensity and direction in relation to explanatory variables. Magnitudes were defined as follows: Weak (0.20 < | r | < 0.40), moderate (0.40 < | r | < 0.60), strong (0.60 < | r | < 0.80) and very strong (| r | > 0.80); these parameters are corroborated by the publication of Franzblau (1958).

Flower buds of the tomato cultivars had positive and negative correlations, depending on the cultivar, with a greater number of climatic variables. Under the conditions studied, precipitation, temperature, relative humidity, wind and radiation modulated the performance of tomato plants (Table 2).

In cultivar Santa Clara, the correlations between fruit diameter and temperature (r = 0.53), and fruit diameter (r = 0.64), fruit weight (r = 0.53) with wind, were positive at a level of p < 0.01. In this cultivar there was also a negative correlation between precipitation and fruit diameter (r = -0.54), as well as between relative humidity with flower buds (r = -0.69), fruit diameter (r = -0.74) and fruit weight (r = -0.55). These results show that flowering and fruit quality increased when there was a lower level of precipitation and relative humidity (Table 2).

These data suggest that fruit quality was associated with climatic variables when the crop was in the field. Carmo et al. (2010) found that temperature directly participated in growth phases, limiting cultivation, becoming the climatic factor of greatest importance for the tomato crop. Guimarães et al. (2007) found that high humidity levels interfered with pollination of the flowers and caused abortion, as well as reducing the transpiration process of the plant because it interfered with the absorption of nutrients.

In cultivar Caline Ipa 6, there was a significant positive correlation between flower buds and rainfall (r = 0.51), suggesting that increased rainfall correlated with greater flowering of the tomato in the field. The negative correlation (r = -0.76) between flower buds and wind was desirable because lower air velocity contributes to flower bud performance, increasing tomato production in crops without control of the variables (Table 3).

Although tomato is a demanding species in terms of water requirements, excess rainfall limited cultivation, favored disease occurrence, and impaired fruit quality, causing a reduction in soluble solids content (ºBrix) (Silva et al., 2006).

For Santa Cruz there was a positive correlation between precipitation and flower buds (r = 0.70), suggesting that higher rainfall gives rise to greater development of flower buds. Solar radiation positively correlated with flower buds (r = 0.65), directly contributing to increased tomato productivity (Table 4).

In the tomatoes used in the study of Fabbri (2009) on radiation, they observed that tomatoes exposure to radiation for over fifteen days caused a delay in fruit ripening, with fruits remaining greenish in color. Holcman (2009), in a study of Cereja tomato fruits, found large fruit numbers were obtained with larger amounts of solar radiation.

In cultivar Rio Grande, there was a negative correlation between flower buds and relative humidity (r = -0.65). This result demonstrates that at lower relative humidity there was a greater emission of flower buds. The other phenological variables did not show significant correlations (Table 5).

High rates of relative humidity modulate the development of lettuce, leading to the emergence of

Table 3. Pearson's correlation coefficient between the agronomic performance variables of the Caline Ipa 6 cultivar with the climatic variables and the pest insects.

	Caline Ipa 6												
	T. absoluta	***B. tabaci***	**Heig.**	**Bran.**	**FB**	**NF**	**DF**	**WF**	**Rain.**	**UR**	**Temp.**	**Win.**	**Rad.**
T. absoluta	-	-0.21	-										
B. tabaci	-0.21	-											
Heig.	0.77	0.67	-										
Bran.	0.66	0.63	0.09	-									
FB	0.58	0.70	-0.14	-0.06	-								
NF	0.56	0.71	0.46	-0.01	-0.43	-							
DF	0.34	0.44	0.58	0.40	-0.37	-0.02	-						
WF	0.33	0.36	0.55	0.44	-0.31	-0.06	0.96	-					
Rain.	0.81	0.55	0.19	-0.45	0.51	-0.08	-0.06	0.02	-				
UR	0.53	0.44	0.02	-0.36	0.36	0.13	-0.27	-0.21	0.46	-			
Temp.	-0.18	-0.19	0.12	0.23	-0.36	0.12	0.12	0.12	-0.29	-0.59	-		
Wind	-0.42	-0.37	-0.06	-0.05	-0.76	0.34	0.08	-0.01	-0.42	-0.42	0.72	-	
Rad.	0.43	0.44	0.35	0.02	0.14	0.17	0.06	0.19	0.37	-0.03	0.55	0.06	-

Heig. = Height; Branc. = Branches; FB = Flower buds; NF = Number of fruits; DF = Fruit diameter; WF = Fruit weight; Rain. = Rainfall U.R = Relative humidity; Temp = Temperature; Wind = Winds; Rad. = Sun radiation.

Table 4. Pearson's correlation coefficient between the agronomic performance variables of the Santa Cruz cultivar with the climatic variables and the pest insects.

	Santa Cruz												
	T. absoluta	***B. tabaci***	**Heig.**	**Bran.**	**FB**	**NF**	**DF**	**WF**	**Rain.**	**UR**	**Temp.**	**Win.**	**Rad.**
T. absoluta	-	-0.24	-										
B. tabaci	-0.24	-											
Heig.	0.75	0.67	-										
Bran.	0.66	0.64	-0.18	-									
FB	0.56	0.69	-0.30	0.54	-								
NF	0.54	0.72	-0.09	0.33	-0.01	-							
DF	0.33	0.45	0.08	-0.08	0.16	0.24	-						
WF	0.35	0.36	0.23	-0.32	-0.01	0.17	0.95	-					
Rain.	0.81	0.57	-0.39	0.41	0.70	0.18	-0.01	-0,21	-				
UR	0.51	0.47	0.22	0.04	0.24	0.11	-0.36	-0.32	0.46	-			
Temp.	-0.18	-0.16	-0.36	0.01	0.03	0.07	0.30	0.34	-0.29	-0.59	-		
Wind	-0.42	*-0.39*	-0.37	-0.38	-0.29	-0.19	0.18	0.26	-0.42	-0.42	0.72	-	
Rad.	0.46	0.48	-0.47	0.39	0.65	0.36	0.09	0.02	0.37	-0.03	0.55	0.06	-

Heig. = Height; Branc. = Branches; FB = Flower buds; NF = Number of fruits; DF = Fruit diameter; WF = Fruit weight; Rain. = Rainfall U.R = Relative humidity; Temp = Temperature; Wind = Winds; Rad. = Sun radiation.

diseases, and low indices of relative humidity facilitated dehydration of the plant more frequently (Tibiriçá et al., 2004).

Cultivar Cereja did not present significant correlations at the level of $p < 0.01$ between climatic and phenological variables. It was observed that this cultivar grew without regard to climatic variations in the study area. In this study, the plants irrigated daily in a protected environment with 50% shade, these factors aided in the phenology of tomato plants (Table 6).

Conclusion

Tomato cultivation in protected environments was influenced by climatic variables in terms of the phenological development of the cultivars used and was correlated with the presence of two key pests. The correlations of phenological and climatic variables were significant for the presence of *T. absoluta* and *B. tabaci* in cultivars of tomatoes cultivated in pots, establishing the endemism of these two key pests in the tomato growing

Table 5. Pearson's correlation coefficient between the agronomic performance variables of the Rio Grande cultivar with the climatic variables and the pest insects.

	Rio Grande												
	T. absoluta	***B. tabaci***	**Heig.**	**Bran.**	**FB**	**NF**	**DF**	**WF**	**Rain**	**UR**	**Temp.**	**Win.**	**Rad.**
T. absoluta	-	-0.22	-										
B. tabaci	-0.22	-											
Heig.	0.75	0.68	-										
Bran.	0.64	0.63	0.51	-									
FB	0.55	0.70	0.11	0.65	-								
NF	0.53	0.71	0.58	-0.03	0.06	-							
DF	0.32	0.44	0.41	-0.09	0.02	0.60	-						
WF	0.33	0.35	0.41	-0.09	0.02	0.60	0.99	-					
Rain.	0.81	0.55	-0.44	-0.30	-0.34	0.05	-0.37	-0.37	-				
UR	0.55	0.42	-0.01	-0.36	-0.65	-0.01	-0.15	-0.15	0.46	-			
Temp.	-0.17	-0.16	0.40	0.35	0.17	0.29	0.33	0.33	-0.29	-0.59	-		
Wind	-0.41	-0.35	0.34	0.48	0.43	0.14	0.47	0.47	-0.42	-0.42	0.72	-	
Rad.	0.44	0.43	0.28	0.24	-0.25	0.16	-0.28	-0.28	0.37	-0.03	0.55	0.06	-

Heig. = Height; Branc. = Branches; FB = Flower buds; NF = Number of fruits; DF = Fruit diameter; WF = Fruit weight; Rain = Rainfall U.R = Relative humidity; Temp = Temperature; Wind = Winds; Rad. = Sun radiation.

Table 6. Pearson's correlation coefficient between the agronomic performance variables of the Cereja cultivar with the climatic variables and the pest insects.

	Cereja												
	T. absoluta	***B. tabaci***	**Heig.**	**Bran**	**FB**	**NF**	**DF**	**WF**	**Rain**	**UR**	**Temp**	**Win.**	**Rad**
T. absoluta	-	-0.23	-										
B. tabaci	-0.23	-											
Heig.	0.76	0.69	-										
Bran.	0.67	0.65	0.62	-									
FB	0.57	0.71	0.69	0.47	-								
NF	0.55	0.73	0.14	0.12	0.57	-							
DF	0.34	0.45	0.40	0.41	0.69	0.37	-						
WF	0.34	0.37	0.42	0.37	0.69	0.36	0.99	-					
Rain.	0.83	0.56	0.10	-0.39	-0.07	-0.44	-0.07	0.01	-				
UR	0.52	0.45	-0.04	-0.04	-0.22	-0.46	0.13	0.20	0.46	-			
Temp.	-0.19	-0.17	-0.17	-0.04	0.03	0.29	-0.15	-0.19	-0.29	-0.59	-		
Wind	-0.43	-0.39	0.06	0.45	0.23	0.42	-0.01	-0.06	-0.42	-0.42	0.72	-	
Rad.	0.45	0.47	-0.02	-0.27	-0.13	-0.13	-0.09	-0.06	0.37	-0.03	0.55	0.06	-

Heig. = Height; Branc. = Branches; FB = Flower buds; NF = Number of fruits; DF = Fruit diameter; WF = Fruit weight; Rain = Rainfall U.R = Relative humidity; Temp = Temperature; Wind = Winds; Rad. = Sun radiation.

regions, although no economic damage was done. It was observed that climatic factors including precipitation, radiation, temperature and wind were environmental factors that contributed to the development of tomatoes cultivated in fields or protected environments, and to the monitoring of pests for planning integrated pest management – IPM.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Andriolo JL (2000). Fisiologia da produção de hortaliças em ambiente protegido. Hortic. Bras. Bras. 18:26-33.

Alagoas Brazil (2007). Secretaria de Estado do Meio Ambiente e dos Recursos Hídricos – AL. Diretoria de Meteorologia. Boletim anual de dados climatológicos 35p.

Bacci L (2006). Fatores determinantes do ataque de *Tuta absoluta* ao tomateiro. Tese de Doutorado. Universidade Federal de Viçosa.

Baldin ELL, Vendramim JD, Lourenção AL (2005). Resistência de genótipos de tomateiro à mosca-branca *Bemisia tabaci* (Gennadius) biótipo B (Hemiptera: Aleyrodidae). Neotrop. Entomol. 34:435-441.

Baldin ELL, Souza DR, Souza ES, Beneduzzi RA (2007). Controle de mosca-branca com extratos vegetais, em tomateiro cultivado em casa-de-vegetação. Horticultura Brasileira, 25:602-606.

Barbosa BC, Paschoalini M, Maciel TT, Prezoto F (2016). Visitantes florais e seus padrões temporais de atividade em flores de Dombeya wallichii (Lindl.) K. Schum (Malvaceae). Entomotropica 31:131-136.

Costa MEB (2014). Cultivo de Beterraba em Sistema de Plantio Direto de Hortaliças. Universidade Federal de Santa Catarina. Florianópolis 34p.

Carmo CAS, Caliman LF (2010). Clima, época de plantio e cultivar. In: Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão RuraL Tomate. Vitória: INCAPER 67p.

Coimbra JLM, Benin G, Vieira EA (2005). Conseqüências da multicolinearidade sobre a análise de trilha em canola. Ciência Rural, Santa Maria 35(2):347-352.

Desneux N, Wajnberg E, Wyckhuys KAG, Burgio G, Arpaia S, Narvéz-Vasquez CA, Gonzáles-Cabrera J, Ruescas DC, Tabone E, Frandon J, Pizzo J, Poncet C, Cabello T, Urbaneja A. (2010). Biological invasion of European tomato crops by *Tuta absoluta:* ecology, geographic expansion and prospects for biological control. Journal of Pest Science, 83:197-215.

Dorais M, Gosselin A, Papadopoulos AP (2001). Greenhouse tomate fruit quality. Hortic. Reviewes, New York, 26:239-306.

Fabbri ADT (2009). Estudo da radiação ionizante em tomates in natura (*Lycopersicum esculentum* Mill) e no teor de licopeno do molho. Tese (Mestrado em Ciências) - Universidade de São Paulo. São Paulo-SP.

Farias JRB, Nepomuceno AE, Neumaier N (2007). Ecofisiologia da soja. Londrina: Embrapa Soja, 10p (Embrapa Soja. Circular Técnica, 48).

Fernandes FL, Mantovani EC, Bonfim Neto H, Nunes VV (2009). Efeitos de variáveis ambientais, irrigação e vespas predadoras sobre *Leucoptera coffeella* (Guérin-Méneville) (Lepidoptera: Lyonetiidae) no cafeeiro. Neotropical Entomology, *38*(3):410-417.

Franzblau AN (1958). A primer of statistics for non-statisticians. Harcourt Brace & Compant, New York.

Gracia NAO (2016). Produção e qualidade de tomates oriundos da polinização natural e mecânica. Universidade Federal de Viçosa 73p.

Gravena S, Benvenga SR (2003). Manual Prático para Manejo Ecológico de Pragas do Tomate. Gravena, Jaboticabal.

Guedes RNC, Picanço MC (2012). The tomato borer *Tuta absoluta* in South America: pest status, management and insecticide resistance. Bulletin OEPP/EPPO Bulletin 42:211-216.

Guimarães MA, Caliman FRB, Silva DJH, Flores MP, Elsayed AYAM (2007). Exigências climáticas da cultura do tomateiro. In: SILVA, D.J.H.; VALE, F.X. R (ed). Tomate: Tecnologia de produção. pp. 85-99.

Holcman E (2009). Microclima e produção de tomate tipo cereja em ambientes protegidos com diferentes coberturas plásticas. Tese (Mestrado em Ciências) – Universidade de São Paulo. Piracicaba.

Horowitz AR, Kontsedalov S, Khasdan V, Ishaaya I (2005) Biotypes B and Q of Bemisia tabaci and their relevance to neonicotinoid and pyriproxyfen resistance. Archives of Insect Biochemistry and Physiology, 58:216-225.

Kalungu JW (2008). Respostas do tomateiro a diferentes lâminas de irrigação, doses de potássio e cobertura do solo em ambiente protegido. 2008. 80p. Dissertação (Mestrado em Irrigação e Drenagem) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba.

Libânio RA (2010). Cultivares e densidades de plantio em cultivo orgânico de tomate. 66f. Tese – Universidade Federal de Lavras. Minas Gerais.

Melo PCT, Tamiso LG, Ambrosano EJ, Schammass EA, Inomoto MM, Sasaki MEM, Rossi F (2009). Desempenho de cultivares de tomateiro sem sistema orgânico sob cultivo protegido. Horticultura Brasileira, Brasília, DF, 27(4):553-539.

Oliveira ACR, Veloso VRS, Barros RG, Fernandes PM, Souza ERB (2008). Captura de *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) com armadilha luminosa na cultura do tomateiro tutorado. Pesquisa Agropecuária Tropical, 38(3):153-157.

Oliveira EM, Oliveira RA, Sediyama GC, Cecon PR, Drumond L.D (2011). Análise do coeficiente e o desempenho do Irrigâmetro e a influência dos elementos do clima na estimativa da evapotranspiração. Engenharia na Agricultura, Viçosa, MG 19(4):348-360.

Oliveira VR, Marouelli WA, Madeira NR. (2014). Influência de fatores climáticos na produção de cebola. Embrapa Hortaliças – Nosso Alho 24p.

Pereira AR, Angelocci LR, Sentelhas PC (2002). Agrometeorologia: Fundamentos e aplicações práticas. Guaíba: Agropecuária 478p.

Silva LD, Omoto C, Bleicher E, Dourado PM (2009). Monitoramento da Suscetibilidade a Inseticidas em Populações de Bemisia tabaci (Gennadius) (Hemiptera: Aleyrodidae) no Brasil. Neotropical Entomology, 38(1):116-125.

Silva RC, Martini R (2006). Tomate mergulha na tecnologia. HortifrutiBrasil, São Paulo: Cepea, Ano 5(47):6-14.

Silva DJH, Vale FXR. (2007). Tomate: Tecnologia e Produção. Viçosa: UFV 355p.

Silva FAZ, Azevedo CAV (2016). The Assistat Software Version 7.7 and its use in the analysis of experimental data. African Journal of Agricultural Research, 11(39):3733-3740.

Silva KS (2008). Uso de paclobutrazol em tomateiro cultivado em dois ambientes. Tese (doutorado) - Universidade Estadual Paulista. Faculdade de Engenharia de Ilha Solteira. Especialidade: Sistemas de Produção 124p.

Silva-Neto C, Lima FG, Gonçalves BB, Bergamini LL, Bergamini BAR, Elias MAS, Franceschinelli EV (2013). Native bees pollinate tomato flowers and increase fruit production. Journal of Pollination Ecology, Guelph 11(6):41-45.

Silva JBC, Giordano LB, Furumoto O, Boiteux LS, França FH, Bôas GLV (2006). Cultivo de tomate para industrialização. Anápolis/GO: Embrapa Hortaliças.

Shirahige FH, Melo AMT, Purquerio LFV, Carvalho CRL, Melo PCT (2010). Produtividade e qualidade de tomates Santa Cruz e Italiano em função do raleio de frutos. Horticultura Brasileira, 28:292-298.

Togni PHB, Frizzas MR, Medeiros MA, Nakasu EYT, Pirescss; Sujii ER (2009). Dinâmica populacional de *Bemisia tabaci* biótipo B em tomate monocultivo e consorciado com coentro sob cultivo orgânico e convencional. Horticultura Brasileira,27:183-188.

Tibiriçá ACG, BRITO AAA, Baêta FC (2004). Produção de alface no verão: estufas como ambiente de cultivo. Florianópolis, SC, Brasil.

Vieira EA, Carvalho FIF, Oliveira AC, Martins LF, Benin G, Silva JAG, Coimbra J, Martins AF, Carvalho MF, Ribeiro G (2007). Análise de trilha entre os componentes primários e secundários do rendimento de grãos em trigo. Rev. Bras. de Agrociência, Pelotas 13(2):169-174.

Vol. 13(20), pp. 1026-1032, 17 May, 2018
DOI: 10.5897/AJAR2018.13161
Article Number: DF9C23657135
ISSN 1991-637X
Copyright©2018
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Cowpea nutrient responses for Malawi and Tanzania

Moses W. Munthali[1], Catherine Senkoro[2], Patson Nalivata[3], Wilkson I. Makumba[4], Muhamad Mzimbiri[5] and Charles Wortmann[6*]

[1]Chitedze Agricultural Research Station, P. O. Box 158, Lilongwe, Malawi.
[2]Agricultural Research Institute Mlingano, P. O. Box 5088, Tanga, Tanzania.
[3]Lilongwe University of Agriculture and Natural Resources, Bunda Campus, P. O. Box 219, Lilongwe, Malawi.
[4]Department of Agricultural Research Services, P.O. Box 30, Lilongwe, Malawi.
[5]Uyole Agricultural Research Institute, P. O. Box 400, Mbeya, Tanzania.
[6]369 Keim Hall, Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln,
NE 68583-0915, USA.

Received 29 March, 2018; Accepted 26 April, 2018

Research was conducted in Malawi and Tanzania to determine cowpea (*Vigna unguiculata* L. Walp) grain yield responses to applied P and K, the agronomic and economic efficiency of nutrient application, and the importance of other nutrient deficiencies. Nine site-years of research were conducted. Cowpea did not respond to fertilizer P and K in Malawi. In Tanzania, the yield response to applied P was linear with 21 kg of grain yield increase per kg of P applied. Overall, the effect of P applied at the economically optimal rate (EOR) were mean cowpea grain yield increases and profit to cost ratios (PCR), respectively, of 0.47 Mg ha^{-1} and 3.2 in Tanzania. Similar effects for K application in Tanzania with an EOR of 17 kg ha^{-1} were 0.264 Mg ha^{-1} yield gain and a PCR of 2.3. There were no responses to application of Mg, S, Zn and B. Financially constrained farmers are often not able to apply fertilizer at EOR for all of their cropland. The mean effect of applying K in Tanzania at 50% compared with 100% of EOR to twice as much land was 35% more production increase and 52% more PCR. The results indicate the importance of adequate availability to farmers of straight P and K fertilizers for farmer profitability. Use of multi-nutrient fertilizers implies paying for nutrients that will not give a yield response, thereby reducing the profit potential.

Key words: Economically optimal rate, net return to fertilizer, optimization, phosphorus, potassium, response functions.

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) is important in sub-Saharan Africa (SSA) as a crop rotated or intercropped with non-legumes for food protein and micro-nutrients (Gibson and Ferguson, 2008) and income earnings. The average 2012 and 2013 annual production (Mg yr^{-1}) and grain yield (Mg ha^{-1}) for cowpea, respectively, were:

---

*Corresponding author. Email: cwortmann2@unl.edu Tel: 402 472 2909.

Table 1. Characteristics of sites for determination of cowpea response to applied nutrients in Malawi (MW) and Tanzania (TZ) during 2014 and 2015.

Country	Site	Mean yield (mg ha^{-1})	Lat‡	Long	Ele m asl	Variety	Planting date	Harvest date
			WGS 84					
MW	DeF	0.83	-14.31	34.41	1601	IT116	8/Jan/15	27/Apr/15
MW	DeS	0.74	-14.33	34.44	1601	IT116	8/Jan/15	27/Apr/15
MW	LiF†	1.64	-14.19	33.77	1180	IT116	5/Jan/15	25/Apr/15
MW	LiS	2.18	-14.18	33.79	1180	IT116	5/Jan/15	25/Apr15
MW	SaF	1.35						
MW	SaS	0.71	-13.68	34.27	615	IT116	25/Jan/15	12/May15
TZ	Mavamizi	2.64	-5.14	38.85	190	Vuli 1	7/Apr/14	21/Jul/14
TZ	Mlingano	3.48	-5.14	38.85	80	Vuli 1	5/Apr/14	17/Jul/14
TZ	Ilonga	1.78	-6.78	37.04	490	Vuli 1	13/Mar/14	10/Jul/14

†The sites in Malawi were in Lilongwe (Li), Salima (Sa) and Dedza (Dz) districts and included on-farm (F) and on-station (S) trials. ‡Lat, Long and Alt refer to latitude, longitude and altitude, respectively.

118,300 and 0.54 for Kenya; 33,400 and 0.46 for Malawi; 82,800 and 1.15 for Uganda; and 182,300 and 0.82 for Tanzania (Food and Agriculture Organization Statistics (FAOSTAT), 2016). Cowpea is primarily a crop of smallholder farmers grown with little control of biotic and abiotic production constraints. Yield is often constrained by inadequate nutrient availability (Osodeke, 2005; Woomer et al., 2012; Olaleye et al., 2012) but numerous other abiotic and biotic constraints and inadequate management also contribute to low yields and to low responses to applied inputs as was determined for bean (*Phaseolus vulgaris* L.) (Wortmann et al., 1998). Little fertilizer is applied for cowpea production (Chianu et al., 2011) while mean fertilizer use across all crops is only about 27 kg ha^{-1} in Malawi and 8 kg ha^{-1} in Tanzania (Walters, 2007).

Cowpea is an especially important pulse in semi-arid regions of Sub-Saharan Africa (Ajeigbe et al., 2012; Dube and Fanadzo, 2013; Maman et al., 2017). The leaves and grain are important foods with protein contents of 27-43% in leaves and 21-33% in grain (Ddamulira et al., 2015; Abudulai et al., 2016). It is also used as a livestock fodder in West Africa and can account for more than 40% of the value of the crop in the Sahel (Kamara et al., 2012; Maman et al., 2017). Cowpea can have high levels of biological N fixation and is relatively tolerant of soil water deficits with wide adaptation (Bisikwa et al., 2014; Ddamulira et al., 2015).

Great profitability from fertilizer use decisions based on robust response functions is likely to be essential for great increases in fertilizer use (Kaizzi et al., 2017; Nalivata et al., 2017; Senkoro et al., 2017). Applying nutrients at the steep part of response functions can offer great profit opportunity in situations of financially constrained fertilizer use while application at the economically optimal rate (EOR) to maximize net returns ha^{-1} from fertilizer use is important when fertilizer use is adequately financed (Jansen et al., 2013). Some information from past research can be considered along with current results in determination of nutrient response functions (http://agronomy.unl.edu/OFRA). Cowpea responses to applied nutrients have included mean cowpea grain yield increases of 0 and 0.24 Mg ha^{-1} due to 10 kg ha^{-1} N without and with P uniformly applied, respectively (Agboola, 1978; Buerkert et al., 1997), and 0.19 Mg ha^{-1} mean increase due to 10 kg ha^{-1} P alone applied (Magani and Kuchinda, 1997; Ndor et al., 2012: Nyoki and Ndakidemi, 2013). Maman et al. (2017) found that cowpea response to P added greatly to fertilizer use profitability for pearl millet-cowpea intercropping. They also established a basis for determining intercrop response functions from pearl millet sole crop information.

Determination of robust crop nutrient response functions is important to improving the profitability of fertilizer use for cowpea sole crop production in SSA. The objectives of this research were to determine for cowpea production areas of Malawi and Tanzania the grain yield responses to applied P and K, the agronomy and economic efficiency of applied P and K, and the importance of applied Mg, S, Zn and B to yield.

MATERIALS AND METHODS

Study field trial sites

Nine site-yr of research for cowpea were conducted across diverse growing conditions for determination of response to applied nutrients (Tables 1 and 2). The spans of coverage included 9° latitude, 1500 m elevation, 5.6 to 6.7 soil pH, 10 to 16 g kg^{-1} soil organic C, 7 to 26 mg kg^{-1} Mehlich 3 P, and 86 to 390 mg kg^{-1} K. This research was conducted as part of an alliance of 13 nations in SSA under the Optimization of Fertilizer Recommendations in Africa (OFRA) project (Kaizzi et al., 2017).

In central Malawi, trials were conducted in the Salima, Lilongwe and Dedza areas (Tables 1 and 2). The Dedza trials had Hapic Lixisol soils and a sub-humid climate with mean monthly minimum

Table 2. Soil test properties of sites used to evaluate cowpea response to applied nutrients in Malawi (MW) and Tanzania (TZ) during 2014 and 2015.

Country†	Site	TC‡	pH	SOC‡	P	K	Mg	S	Zn	B
				g kg^{-1}	mg kg^{-1}					
MW_CP	LiF	SCL	5.58	10.5	8.7	90	188	10.7	2.02	0.12
MW_CP	LiS	SCL	5.63	11.2	6.7	86	172	10.6	2.08	0.12
MW_CP	SaS	SCL	6.21	11.1	26.1	179	244	8.6	2.09	0.11
MW_CP	SaF	SCL	6.31	10.0	10.3	160	318	9.3	1.77	0.14
TZ_CP	Mavamizi	C	6.24	14.5	7.9	392	264	10.3	3.58	0.51
TZ_CP	Ilonga	C	6.68	11.2	15.2	367	259	7.6	1.84	0.27
TZ_CP	Mlingano	C	5.89	16.4	7.0	337	239	12.6	3.84	0.52

†The sites in Malawi were in Lilongwe (Li), Salima (Sa) and Dedza (Dz) districts and included on-farm (F) and on-station (S) trials. ‡ TC: soil texture class with C = clay, SCL = sandy clay loam, and SC = sandy clay. SOC: soil organic C.

Table 3. Nutrient rate treatments (T) for determination of cowpea response to applied nutrients in Malawi (MW) and Tanzania (TZ) during 2014 and 2015.

T	P	K
	(kg ha^{-1})	
1	0	0
2	7.5	0
3	15	0
4	22.5	0
5	0	20
6	7.5	20
7	15	20
8	22.5	20
9	15	10
10	15	30
11	Diagnostic†	

†The diagnostic treatment applied rates of 15 P, 20 K, 15 S, 2.5 Zn, 10 Mg, and 0.5 B kg ha^{-1} for comparison with treatment 7.

and maximum temperatures of 9 to 16 and 20 to 26°C. The Lilongwe trials had Hapic Lixisol soil and a sub-humid climate with mean monthly minimum and maximum temperatures of 8 to 17 and 24 to 30°C, respectively. The Salima on-farm trials had Lithic Leptosol soil and the on-station trials had Eutric Fluvisol soil with a semi-arid climate with respective mean monthly minimum and maximum temperatures of 16 to 22 and 26 to 33°C. The rainfall distribution for each area was uni-modal with 94, 90 and 90% of the rainfall for Salima, Lilongwe and Dedza, respectively, occurring during December to June. Soil properties ranged from 5.4 to 6.4 pH, 9 to 17 g kg^{-1} soil organic C, and 7 to 26 mg kg^{-1} Mehlich 3 P.

In eastern Tanzania, cowpea trials were conducted on clay soils at Ilonga with a Eutric Fluvisol, Mavamizi with a Ferralitic Cambisol, and Mlingano with a Ferralitic Cambisol (Tables 1 and 2). Mavamizi and Mlingano have a mean of about 1280 mm yr^{-1} precipitation with 46 and 38% occurring during March to June and September to December. Rainfall for Ilonga was about 975 mm yr^{-1} precipitation with 90% occurring during November to May. The mean monthly minimum and maximum temperatures (°C) range respectively from approximately: 15 to 21 and 28 to 32 for Ilonga; and 18 to 22 and 27 to 33 for Mavimizi and Mlingano. Soil properties for the Tanzania sites ranged from 5.9 to 7.7 pH, 11 to 17 g kg^{-1} soil organic C, and 7 to 20 mg kg^{-1} Mehlich 3 P.

Experimental design and agronomic practice

There were 11 nutrient rate treatments with 4 P levels in 7.5 kg ha^{-1} increments evaluated with 0 and 20 kg ha^{-1} K uniformly applied, and four K levels in 10 kg ha^{-1} increments evaluated with 15 kg ha^{-1} P uniformly applied (Table 3). The trials in Tanzania also had a diagnostic treatment to test for yield response to Mg, S, Zn, and B. The on-station trials had three replications. The on-farm trials had at least six replications with each replication in the field of another farm. Trials had a randomized complete block design. Plot size was six rows wide and 6 m long.

The nutrient sources were triple super phosphate for P, KCl for K, magnesium sulfate for Mg and S, zinc sulfate for Zn and S, and borax for B. All of the P, K, and the diagnostic package were applied at planting time. The land for all sites was tilled before planting but the tillage practice varied. Ridges were formed in Malawi and seed was planting into the top of the ridge but planting was on flat soil in Tanzania. The cowpea varieties were IT116 of 68 days to maturity in Malawi and Vuli 1 in Tanzania of 65 days to maturity (Table 1).

Row spacing was 0.5 m. The intended plant spacing was 15 cm. Weed control was by hand hoeing. In Malawi and Tanzania, insect pest control involved spraying the crops with cypermethrine ([cyano-(3-phenoxyphenyl)methyl] 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate). Copper oxychloride ($Cl_2Cu_2H_3O_3^-$) fungicide was applied to control fungal diseases.

Data collection and analysis

Soil samples composed of soil from at least eight sampling points per replication were collected before tillage. The samples were air-dried, sieved through a 2-mm sieve and analyzed for particle size distribution, pH, organic C (OC), and exchangeable K, Ca, Mg, Zn, S and B were analyzed at the World Agroforestry Centre in Nairobi Kenya. Upper fully expanded leaves of an N-P-K treatment were sampled at flowering in Tanzania and analyzed for N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B, and M at the same laboratory. Analyses were with a combination of wet chemistry and mid-infrared scanning methods (Shepherd and Walsh, 2007; Terhoeven-Urselmans et al., 2010; Towett et al.. 2015; https://www.worldagroforestry.org/sd/landhealth/soil-plant-spectral-

Table 4. Cowpea grain yield response to applied P and K in Malawi and Tanzania.

Parameter	**Grain Yield (mg ha^{-1})**							
					Tanzania			
P (kg ha^{-1})	**0**	**7.5**	**15**	**22.5**	***a*†**	***b***	***c***	**Adj. R^2**
Mavamizi	2.52	2.46	2.60	2.90	2.427	0.017		0.60
Ilonga	3.32	3.68	3.37	3.58	Ns			
Mlingano	1.21	1.82	1.78	2.25	1.302	0.041		0.80
Mean	2.35	2.66	2.58	2.91	2.384	0.021		0.81
K (kg ha^{-1})	**0**	**10**	**20**	**30**				
Mean	2.43	2.62	2.73	2.73	2.765	0.334	0.911	0.99
					Malawi			
P (kg ha^{-1})	**0**	**10**	**20**	**30**				
Mean	1.32	1.32	1.26	1.21	ns			
K (kg ha^{-1})	**0**	**10**	**20**	**30**				
Mean	1.25	1.23	1.16	1.13	ns			

†Coefficients *a, b* and *c* are for response functions. If the values reported are *a* and *b* only, the response is linear. If *c* is included, the response is curvilinear to plateau according to Y = $a - bc^r$ where r is the nutrient rate (kg ha^{-1}).

diagnostics-laboratory/sops).

Harvest for yield determination was by uprooting the plants from the two inner rows, removing the pods and air-drying before shelling. The harvested grain was weighed and air-dried grain yield calculated. To determine grain water content, grain was tested with a Dickey-John Tester in Tanzania. In Malawi, 100 kernels were dried in an oven at 70 – 80°C for 24 h for water content determination. The collected data were used to calculate: grain yield at 850 g kg^{-1} moisture; agronomic efficiency (AE), or the gain in grain yield per kg of P and K (kg kg^{-1}); and economically optimum rates (EOR), that is, the rate to maximize net returns per ha. The profit to cost ratio (PCR) was calculated as the ratio of the net returns due to the nutrient application relative to the cost of that nutrient application. Economic calculations were done with differing fertilizer use costs relative to grain value. These ratios of nutrient application cost to grain value (CP) ranged from 3 to 7 kg kg^{-1}.

Analysis of variance (ANOVA) combined across site-yr (SY) within countries were conducted to determine treatment and interaction effects on grain yield. The P × K interaction was evaluated by conducting ANOVA on the sub-set of eight treatments when treatment effects were significant. The K rate and diagnostic treatment effects were tested using orthogonal contrasts. Effects were considered significant when $P \leq 0.05$. Asymptotic regression was fitted to the data for yield response to applied nutrients. The asymptotic function was given as yield (Mg ha^{-1}) $y = a - bc^r$, where *a* was yield at the plateau due to application of that nutrient, *b* was the maximum gain in yield due to application of that nutrient, *c* was a curvature coefficient, and *r* was the nutrient rate. When the asymptotic function failed to give a realistic convergence, linear functions were attempted.

RESULTS

The mean cowpea grain yield was 2.63 Mg ha^{-1} in Tanzania and 1.29 Mg ha^{-1} in Malawi (Table 1). Grain yield was on average 0.15 Mg ha^{-1} less with the diagnostic treatment compared with the similar P-K treatment in Tanzania, but the diagnostic treatment effect was not significant in the overall analysis or for any location. The diagnostic treatment was not included for the Malawi trials.

In Tanzania, grain yield was not affected by the P × K interaction but P effects differed by location with no P effect at Ilonga and with linear P effects of differing slopes at Mavamizi and Mlingano, along with a linear effect overall (Table 4). The application of K had a curvilinear to plateau effect on grain yield overall in Tanzania. The overall EOR for P due to linear effect of P was inferred to be 22.5 kg ha^{-1} as the highest rate evaluated (Figure 1), with the AE of P use equal to 21 kg kg^{-1} and the PCR with CP = 5 equal to 3.2 kg kg^{-1}. The EOR of K ranged from 14 to 20 kg ha^{-1} for CP 7 to 3. With CP of 5, the EOR of K was 16 kg ha^{-1} with a yield gain of 0.263 Mg ha^{-1}, an AE of 16.5 kg kg^{-1}, and a PCR of 2.30 kg kg^{-1}. The equation for Tanzania to calculate EOR of K from CP was EOR = 29.0 – 3.6CP + 0.21CP^2. In Malawi, the only treatment effect on grain yield was negative for K application with the on-station trial at Dedza according to Yield = 1.10 – 0.021K, R^2 = 0.92.

DISCUSSION

Diagnosis of nutrient deficiencies requires consideration of information from multiple sources but crop response to applied nutrients is the strongest indicator of deficiency. Grain yield was not increased by the diagnostic treatment containing Mg, S, Zn and B for the six trials that included the diagnostic treatment. Soil test results indicated adequate availability of Mg, S, Zn and B for all trial sites. For foliar samples collected in Tanzania, the minimum, maximum and median foliar nutrient concentrations were:

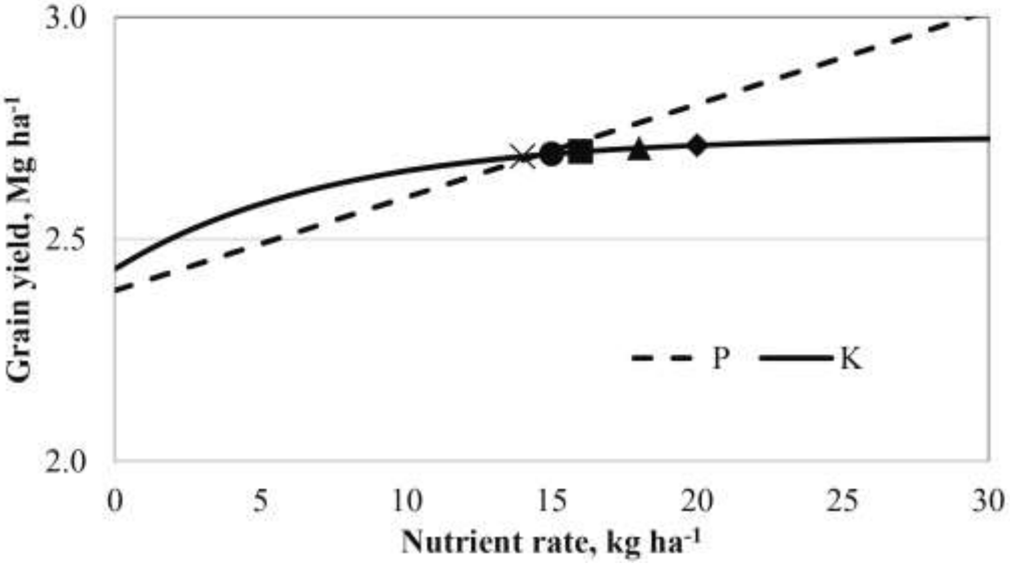


Figure 1. Cowpea response to applied P and K in Tanzania. The economically optimal K rates determined for cost of nutrient use expressed relative to grain value (kg kg^{-1}) of 3, 4, 5, 6 and 7 are symbolized, respectively, by the diamond, triangle, square, circle and X.

3.2, 3.5 and 3.3 g kg^{-1} for Mg; 2.6, 3.3 and 2.7 g kg^{-1} for S; 35, 51 and 36 mg kg^{-1} for Zn; and 19, 36 and 33 mg kg^{-1} for B, respectively. The critical levels for deficiency used by OFRA in interpretation of cowpea foliar test results have been 2.5 and 2.0 g kg^{-1} for Mg and S, and 20 and 15 mg kg^{-1} for Zn and B, respectively. According to these critical levels, the foliar results indicate that the plants were not deficient for Mg, S, Zn and B.

Cowpea yield responses to applied P in Malawi and Tanzania were not related to Mehlich 3 P even though it was < 15 mg kg^{-1} in five of seven cases (Tables 2, 3, 4). There was a positive yield response to K in Tanzania but not in Malawi even though soil test values were overall higher in Tanzania.

The results demonstrate good profit potential for P and K applied at EOR to cowpea in Tanzania but not in Malawi (Figure 1). However, financially constrained smallholders are seldom able to buy enough fertilizer to apply at EOR to all of their cropland and expect higher PCR by applying at less than EOR without great losses in production potential. An exception is for the linear response to P in Tanzania where PCR was constant across P rates to the maximum applied rate of 22.5 kg ha^{-1} P. Estimated yield gains and PCR with 100 and 50% of EOR were: 0.264 and 0.198 Mg ha^{-1} and 2.3 and 3.9 \$ \$$^{-1}$ for K in Tanzania. These comparisons indicate that, with curvilinear to plateau responses, the effect of nutrients applied at 50% compared with 100% EOR were about 22% less yield gain but 88% more PCR. Therefore, the greatly improved PCR with 50% compared with 100% EOR while applying the affordable amount of fertilizer to twice as much cropland presents an opportunity for smallholders to improve their total production and profit, and eventually gain the financial ability to apply fertilizer at EOR to cropland.

Maximizing profit potential of fertilizer use is relatively easy for situations where fertilizer use is not financially constrained as farmers apply at EOR to all crops in consideration of the current CP for each crop-nutrient combination. However, the resource poor farmer needs to consider more than the profit potential of a single nutrient applied to a single crop. For example, P compared with K applied to cowpea in Tanzania has higher PCR. The PCR is generally greater with rates of less than 100% of EOR. Other crops in the system also have PCR associated with the diverse feasible crop-nutrient-rate combinations. Profit maximization is expected with the affordable fertilizer allocated to the highest PCR opportunities. Consideration of all potential permutations, especially with more than three crops in the system requires advanced calculations such was through use of linear optimization (Jansen et al., 2013; Kaizzi et al., 2017). Under OFRA, a dataset of >5950 geo-referenced nutrient functions was developed from results of past and OFRA-supported field research. Using the OFRA Inference Tool (Wortmann et al., 2017) for spatial transfer of results, fertilizer use optimization tools were developed for 67 recommendation zones, each able to consider the nutrient needs of up to nine crops or intercrops. These and other OFRA resources are freely available at http://agronomy.unl.edu/OFRA.

Conclusion

Fertilizer P and K can be profitably applied at EOR for cowpea production in Tanzania but not in Malawi. The available information from crop response, soil test, and available foliar test results indicate that deficiencies of Mg, S, Zn and B are not of concern for cowpea production in Malawi and Tanzania. Farmers whose fertilizer use is financially constrained can greatly improve net returns on their investment by applying fertilizer at less than EOR but over more land. The mean effects of applying the same amount of fertilizer nutrients at 50% compared with 100% EOR include 56% more production and 88% more PCR. Farmers are likely to have more profit potential from use of straight fertilizers such as triple super phosphate by avoiding the cost of nutrients in fertilizer mixes for which there is no response.

Abbreviations

CP, the cost of one kg of nutrient applied relative to grain value, kg kg^{-1}; EOR, the economically optimal rate of nutrient application or the rate expected to maximize net return to nutrient application; OFRA, optimizing fertilizer recommendations in Africa; PCR, the ratio of net returns to cost for application of nutrient.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are thankful to the Alliance for Green Revolution in Africa (AGRA), CABI, the University of Nebraska-Lincoln, and the Governments of Malawi, Kenya and Tanzania for supporting the research work. The contributions of research support staff, research center management, and cooperating farmers were essential to the success of this research.

REFERENCES

Abudulai M, Seini SS, Haruna M, Mohammed AM, Asante SK (2016). Farmer participatory pest management evaluations and variety selection in diagnostic farmer field Fora in cowpea in Ghana. African Journal of Agricultural Research, 11:1765-1771.

Ajeigbe HA, Saidou AK, Singh BB, Hide O, Satoshi T (2012). Potentials for cowpea (*Vigna unguiculata*) for dry season grain and fodder production in the Sudan and Sahel zones of West Africa. In: Boukar O, Coulibaly O, Fatokun CA, Lopez K, Tamo M editors. Innovative Research Along the Cowpea Value Chain. Proc. 5th World Cowpea Conf., Saly, Senegal. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, pp. 189-202.

Bisikwa J, Kawooya R, Ssebuliba JM, Ddungu SP, Biruma M, Okello DK (2014). Effects of plant density on the performance of local and elite cowpea varieties in Eastern Uganda. African Journal of Applied Agricultural Sciences and Technologies, 1:28-41.

Chianu JN, Nkonya EM, Mairura FS, Chianu JN, Akinnifesi FK (2011). Biological nitrogen fixation and socioeconomic factors for legume production in sub-Saharan Africa: a review. Agronomy for Sustainable Development, 31: 139–154.

Ddamulira G, Santos CAF, Obuo P, Alanyo M, Lwanga CK (2015). Grain yield and protein content of Brazilian cowpea genotypes under diverse Ugandan environments. American Journal of Plant Sciences, 6:2074-2084.

Dube E, Fanadzo M (2013). Maximizing yield benefits from dual-purpose cowpea. Food security, 5:769-779.

Food and Agriculture Organization Corporate Statistical Database FAOSTAT (2016). Food and Agriculture Organization of the United Nations Statistics Division Available at: http://faostat3.fao.org/download/Q/QC/E. Accessed March 2018.

Gibson R, Ferguson E (2008). An interactive 24-hour recall for assessing the adequacy of iron and zinc intakes of developing countries. Tech. Monog. 8. HarvestPlus, Washington DC, USA.

Jansen JA, Wortmann CS, Stockton MA, Kaizzi KC (2013). Maximizing net returns to financially constrained fertilizer use. Agronomy Journal, 105:573-578.

Kamara AY, Ewansiha SU, Ajeigbe HA, Okechukwu R, Tefera H, Boukar O, Omoigui LO (2012). Improvement in grain and fodder yield of cowpea (*Vigna unguiculata*) varieties in the Sudan savannas of Nigeria over the past four decades. In: Boukar O, Coulibaly O, Fatokun CA, Lopez K, Tamo M editors. Innovative Research Along the Cowpepa Value Chain. Proc. 5th World Cowpea Conf., Saly, Senegal. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Crop Science, pp. 179-188.

Kaizzi CK, Mohammed MB, Maman N (2017). Fertilizer use optimization: principles and approach. In: Wortmann CS, Sones K. Editors. Fertilizer Use Optimization in Sub-Saharan Africa. CABI, London, UK pp. 9-19.

Magani IE, Kuchinda CM (1997). Effect of phosphorus fertilizer on growth, yield and crude protein content of cowpea (*Vigna unguiculata* [L.] Walp) in Nigeria. Journal of Applied Biosciences, 23:1387-139.

Maman N, Garba M, Wortmann CS (2017). Optimizing fertilizer use within the context of integrated soil fertility management in Niger. In: Wortmann CS, Sones K. Editors. Fertilizer Use Optimization in Sub-Saharan Africa. CABI, London, UK. pp 136-147.

Nalivata PC, Munthali Mw, Makumba WI, Mbewe E, Manase H (2017). Optimizing fertilizer use within the context of integrated soil fertility management in Malawi. In: Wortmann CS, Sones K. Editors. Fertilizer Use Optimization in Sub-Saharan Africa. CABI, London, UK pp. 113-124.

Ndor E, Dauda NS, Abimuku EO, Azagaku DE, Anzaku H (2012). Effect of phosphorus fertilizer and spacing on growth, nodulation count and yield of cowpea (*Vigna unguiculata* (L) Walp) in Southern Guinea Savanna agroecological zone. Nigeria. Asian Journal of Agricultural Sciences, 4:254-257.

Nyoki D, Ndakidemi PA (2013). Economic benefits of Bradyrhizobium japonicum inoculation and phosphorus supplementation in cowpea (*Vigna unguiculata* (L) Walp) grown in northern Tanzania. American Journal of Research Communication, 1:173-189.

Olaleye O, Fagbola O, Abaidoo RC, Ikeorah N (2012). Phosphorus response efficiency in cowpea genotypes. American Journal of Research Communication, 4:1:81-90.

Osodeke VE (2005). Determination of phosphorus requirements of cowpea (*Vigna unguiculata*) in the acid soils of south-eastern Nigeria using sorption isotherms. Global Journal of Agricultural Sciences, 4:135-138.

Senkoro CJ, Ley GJ, Marandu AE, Wortmann C, Mzimbiri M, Msaky J, Umbwe R, Lyimo SD (2017). Optimizing fertilizer use within the context of integrated soil fertility management in Tanzania. In: Wortmann CS, Sones K. Editors. Fertilizer Use Optimization in Sub-Saharan Africa. CABI, London, UK. pp. 176-192.

Shepherd KD, Walsh MG (2007). Infrared spectroscopy—enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. JNIRS 15:1-19.

Terhoeven-Urselmans T, Vagen TG, Spaargaren O, Shepherd KD (2010). Prediction of soil fertility properties from a globally distributed soil mid-infrared spectral library. Soil Science Society of America Journal, 74:1792-1799.

Towett EK, Shepherd KD, Sila A, Aynekulu E, Cadisch G (2015). Mid-infrared and total x-ray fluorescence spectroscopy complementarity for assessment of soil properties. Soil Science Society of America Journal, 79: 1375-1385.

Walters D (2007). Tanzania: The challenge of moving from subsistence to profit. Busi. Develop. OECD Journal, 8:79-102.

Woomer PL, Baijukya F, Turner A (2012). Progress towards achieving the vision of success of N2Africa. www.N2Africa.org. P 23.

Wortmann CS, Kirkby RA, Eledu CA, Allen DJ (1998). An Atlas of Common Bean (*Phaseolus vulgaris* L.) Production in Africa. Cali, Colombia: Centro Internacional de Agricultura Tropical. http://www.ciat.cgiar.org/africa/pdf/atlas_bean_africa/contents.pdf.

Wortmann CS, Milner M, Kaizzi KC, Maman N, Cyamweshi RA, Dicko MK, Kibunja C, Macharia M, Maria R, Nalivata P, Negash D, Nkonde D, Ouattara K, Senkoro CJ, Tarfa BD, Tetteh FM (2017). Maize-nutrient response information applied across Sub-Saharan Africa. Nutrient Cycling in Agroecosystems, 107:175-186.

Vol. 13(20), pp. 1033-1041, 17 May, 2018
DOI: 10.5897/AJAR2018.13160
Article Number: F2A669E57137
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Rainfed rice response to fertilizer in the Sudan Savanna of West Africa

Idriss Serme[1*], Mohamed Dicko[2], Korodjouma Ouattara[1], Baba Sidibe[2] and Charles Wortmann[3]

[1]Institut de l'Environnement et de Recherches Agricoles (INERA), O4 BP 8645 Ouagadougou, Burkina Faso.
[2]Institut d'Economie Rurale (IER), Mali.
[3]Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln NE, USA.

Received 29 March, 2018; Accepted 17 April, 2018

In West Africa, rice (*Oryza sativa* L. and *Oryza glaberrimal* Steud) production is not meeting current demand. Low yields are attributed to diverse biotic and abiotic constraints including nutrient deficiencies, inadequate agronomic practices, and socio-economic constraints. This study quantified yield and profit responses of rainfed rice produced in the Sudan Savanna of Burkina Faso and Mali to fertilizer N, P, K, and Mg-S-Zn-B treatment. The mean yields were 2.2 and 2.4 Mg ha^{-1} for upland rice in Finkolo and for lowland rice in Longorola in Mali, respectively, and 1.5 and 2.2 Mg ha^{-1} for upland rice at Boni and Karaba in Burkina Faso. Lowland rice grain yield was not affected by nutrient application at Longorola. The grain yield increases with 30 and 60 kg ha^{-1} N were, respectively, 0.30 and 0.48 Mg ha^{-1} at Karaba, 0.21 and 0.34 Mg ha^{-1} at Boni, and 0.32 and 0.41 Mg ha^{-1} at Finkolo indicating similarity in response. Grain yield response to P was observed only at Karaba. If fertilizer were applied at 50% rather than 100% of the economically optimum rate, as might be the case for financially constrained farmers, the mean yield increase was 36% less but agronomic efficiency was 23% higher and the profit cost ratio was 66% higher. There was no response to K or to Mg-S-Zn-B. The results, therefore, indicate high potential for profitable response of rainfed upland rice production for Sudan Savanna to fertilizer N but little potential for other fertilizer nutrients. These results should, however, be considered together with other field research results in making fertilizer use decisions.

Key words: Agronomic efficiency, economically optimal rate, response function, yield.

INTRODUCTION

Rice (*Oryza sativa* and *O. glaberrima*) production in West Africa has increased by > 2% year^{-1} recently but demand has a higher rate of increase (WARDA, 2005; CROPSTAT, 2013; Muthayya et al., 2014). Inadequate production practices, financial limitations, and various biotic and abiotic constraints contribute to declining or stagnant yields (Fosu et al., 2016). Mean rainfed rice grain yield has been estimated to be about 2 Mg ha^{-1}

*Corresponding author. E-mail: sermeidriss@yahoo.fr.

across several African countries (Aune and Bationo, 2008; Apaseku et al., 2013) and approximately one-third of the rainfed potential (GYGA, 2017). The Sudan Savanna covers about 350,000 km^2 in Burkina Faso and Mali and is very important for crop production in these countries.

Rainfed rice can be very responsive to fertilizer application; highly profitable curvilinear to plateau responses of upland rice grain yield to applied N occurred in Uganda and for the Northern Guinea Savanna of Nigeria (Kamara et al., 2010; Okonji et al., 2012; Kaizzi et al., 2014). Curvilinear to plateau response to applied P has also been reported (Bationo, 2008; Okonji et al., 2012; Kaizzi et al., 2014). Rainfed rice yield in Burkina Faso and Mali was often increased by more than 100% with the application of N and P (Bado, 2002).

Current blanket fertilizer recommendations in Mali and Burkina Faso do not consider local conditions and farmer's financial capacity, and are not well based on field research results. Such results were few and mostly from trials conducted on land of the research stations that may not represent the farmers' situations. Optimization of fertilizer use may improve yields and profitability from rainfed rice production in West Africa. This requires determination of robust crop-nutrient response functions specific to recommendation domains. It was hypthesized that rainfed rice produced in the Sudan Savanna will be responsive to N, P and K but that the responses will vary with nutrient, production conditions and location, and that yield is affected by deficiencies of other nutrients. The objectives of this research were to: (i) Quantify the yield response of rainfed rice to N, P and K; (ii) Determine the profit opportunities of fertilizer use for rainfed rice production; and (iii) Diagnose other nutrient deficiencies.

MATERIALS AND METHODS

Study sites

Trials were conducted in Burkina Faso and Mali during the 2014 and 2015 rainy seasons to determine the responses of rainfed upland and lowland rice to applied nutrients. All research sites were in the Sudan Savanna with unimodal rainfall falling mostly from May to October. The sites were selected to represent rainfed rice production in the respective areas and to avoid soils with atypical edaphic constraints that might prevent response to applied nutrients.

In Mali, trials were conducted for upland rice near Finkolo and for lowland rainfed rice near Longorola with 1200 to 1400 mm of seasonal rainfall (Table 1 and Figure 1). The trials in Mali were on farmers' fields with farmers managing land preparation and weed control and researchers managing treatment application, sowing and harvesting. In Burkina Faso, upland rice trials were conducted on land of a research station at Boni about 20 km northeast of Houndé and on-farm at Karaba about 7 km north of Houndé. The rainfall distribution was unimodal with seasonal precipitation of 800 and 950 mm year^{-1}. The trials sites were within 0.5° latitude band but separated by 2.3° longitude

Composite soil samples for the 0-0.2 m depth were collected for each replicate before fertilizer application, dried, sieved to 2-mm, and sent to the World Agroforestry Center Soil-Plant Spectral Diagnostic Laboratory in Nairobi, Kenya for analysis (https://www.worldagroforestry.org/sd/landhealth/soil-plant-spectral-diagnostics-laboratory/sops) (Table 1). The analysis was with mid-infrared spectral analysis. About 10% of the samples, with at least one sample per site, were analyzed by wet chemistry for calibration of the spectral analysis (Shepherd and Walsh, 2007; Terhoeven-Urselmans et al., 2010; Towett et al., 2015). Organic C and N were determined with a Thermal Scientific Flash 2000. Soil pH was measured in a 1:2.5 soil:water slurry. The nutrient extraction was by Mehlich-3 (Mehlich, 1984). A Horiba LA 950 Laser Scattering Particle Size Distribution Analyzer was used for the determination of particle size distribution.

In Mali, the soil organic C was 5 and 13 g kg^{-1} at Finkolo and Longorola, respectively, with soil pH 5.2 at both sites. The sites in Burkina Faso had 1% slope, 5.2-5.5 pH, <10 g kg^{-1} soil organic C, and low base availability.

Experimental design and agronomic practices

The treatments for all trials included five rates of N and four rates of P and K (Table 2). The N rate effect was evaluated with 0 and 15 (22.5 in Burkina Faso for 2014) kg ha^{-1} P uniformly applied. The N rate increments were 30 kg ha^{-1} with the exception of 25 kg ha^{-1} at Finkolo. The P and K rate increments were 7.5 and 10 kg ha^{-1}, respectively. A diagnostic treatment (Mg-S-Zn-B) containing NPK plus 15 kg ha^{-1} S, 2.5 kg ha^{-1} Zn, 10 kg ha^{-1} Mg, and 0.5 kg ha^{-1} B was included and compared to the treatment with the same NPK rates.

The experimental design was a randomized complete block design with three replicates. The plots were 6 × 3 m with 30 rows of 3-m length. In Burkina Faso, four adjacent trials were conducted with different varieties, and with and without 5 Mg ha^{-1} of manure applied and incorporated. The mean manure values were pH 7.8 and C:N ratio 17.0 kg kg^{-1} with contents of 206, 12, 4, and 21 g kg^{-1}, respectively, for C, N, P and K. The manure was broadcasted and incorporated before sowing. The trials in Mali were shifted to nearby sites for the 2015 trials but the 2015 trials in Burkina Faso used the same experimental units for study of the residual effect of manure.

The land was plowed to 0.2-m depth and harrowed except for Longorola where the land was plowed and plots were enclosed with bunds when the soil was well drained. The rice varieties used in Burkina Faso were FKR 45N, with 95 days to maturity, and WAB C165, with 90 days to maturity, for which nutrient responses were evaluated in adjacent trials. In Mali, 3- to 4-weeks old seedlings of SIK350-A15, with 120 days to maturity, were transplanted at Longorola. At Finkolo, NERICA4 with 105 days to maturity was directly sown. All varieties were *O. sativa* except for NERICA4 which was derived from hybridization of *O. sativa* and *O. glaberrima.* Sowing and harvest dates were reported in Table 1. Direct sowing was performed manually at 0.05-m depth. The sowing or transplanting points were spaced at 0.2 by 0.2 m for all trials. Weeds were controlled with manual hoeing at 3 and 6 week after sowing. In both countries, fertilizers were band applied 2 week after sowing of upland rice at least 5 cm from the rows and covered, but broadcast were applied and incorporated prior to transplanting of lowland rice. Nitrogen was split applied with 50% applied at panicle initiation. The nutrient sources were urea, triple super phosphate, potassium chloride, magnesium sulfate, zinc sulfate and borax.

Rice was harvested from a distance of 13 m^2 after excluding two borders rows at maturity in each plot. The harvest was dried, threshed, and milled to remove the grain hull. Grain yields were determined at 140 g kg^{-1} water content.

Data analysis

The analysis of variance to assess treatment effects and their

Table 1. Site and soil test properties for the 0 to 0.2 m depth, and sowing and harvest dates, for two sites each in Burkina Faso and Mali.

Properties[†]	Burkina Faso		Mali	
	Boni	**Karaba**	**Finkolo**	**Longorola**
Latitude, N	11.542	11.535	11.274	11.384
Longitude, W	3.346	3.543	5.304	5.662
Elevation, m	325	335	450	340
Mean monthly temperatures for August to December (°C)				
Maximum	32		32	
Minimum	19		15	
Soil properties				
Soil class	Luvisol	Luvisol	Lixosol	Fluvisol
pH, water†	5.2	5.5	5.2	5.2
OC, g kg^{-1}	3.8	6.0	5.4	13
Total N, g kg^{-1}	0.3	0.4	0.3	0.8
Mehlich3 P, mg kg^{-1}	19.7	13.8	31.0	6.9
S, mg kg^{-1}	11.7	10.8	11.7	16.7
K, cmol kg^{-1}	0.18	0.18	0.17	0.37
Ca, cmol kg^{-1}	1.45	2.78	1.9	3.9
Mg, cmol kg^{-1}	0.56	0.74	0.54	1.88
Na, cmol kg^{-1}	0.15	0.13	0.1	0.2
B, mg kg^{-1}	0.16	0.08	0.07	0.13
Mn, mg kg^{-1}	57.19	58.39	93.4	134.9
Zn, mg kg^{-1}	2.23	4.08	3.86	2.09
Clay, g kg^{-1}	310	373	292	786
Silt, g kg^{-1}	324	298	263	146
Textural class	Clay and loam	Clay and loam	Clay and loam	Clay
Sowing and harvest dates				
2014 sowing	30 July		14 July	17 July[‡]
2014 harvest	6 Nov		30 Oct	4 Dec
2015 sowing	22 July		13 July	26 July
2015 harvest	30 Oct		26 Oct	30 Nov

[†] Soil test values were means of composite soil samples taken by block. Nutrient extraction was by Mehlich-3. ‡Dates of transplanting for Longorola.

interactions was conducted by location across years for Mali, but by year and across varieties and manure rates in Burkina Faso due to differing P rate increments in 2014 and 2015. The N rate main and interaction effects were further analyzed for the sub-set of 10 N rate treatments. The effects of P and K rate and of Mg-S-Zn-B were evaluated using linear contrast tests.

When nutrient rate effects were signficant, fitting of curvilinear to plateau response functions was attempted, with yield (Mg ha^{-1}) = $a - bc^r$, where a was the yield at the plateau for that nutrient, b was the maximum gain in yield due to application of the nutrient, c was a curvature coefficient, and r was the nutrient rate. When the response was not curvilinear, a linear fitting was attempted with yield (Mg ha^{-1}) = $a + br$, where a was the yield at 0 kg ha^{-1}, b was the yield increase per kg ha^{-1} of nutrient applied, and r was the nutrient rate.

Data analyses were done using Statistix 10 (Analytical Software, Tallahassee, FL). Results were considered significant when $P \leq 0.05$.

The agronomic efficiency of nutrient use was calculated as the gain in crop yield per unit of nutrient applied (kg kg^{-1}). The economically optimal rate (EOR; kg ha^{-1}) of nutrient application was determined as the rate of maximum net return of fertilizer use or the rate where the value of yield gain due to a one kilogram increment in nutrient rate equals the cost per kilogram of nutrient use. The EOR were determined for nutrient use costs relative to on-farm grain value ratios equal to 3, 6, 9 and 12 (kg kg^{-1}). The profit:cost ratio (PCR) was calculated as the value of increased crop yield minus the cost of fertilizer nutrient use difference divided by the cost of fertilizer nutrient use.

RESULTS

In Mali, the mean 2014 and 2015 yields were, respectively, 2.4 and 1.9 Mg ha^{-1} for upland rice at

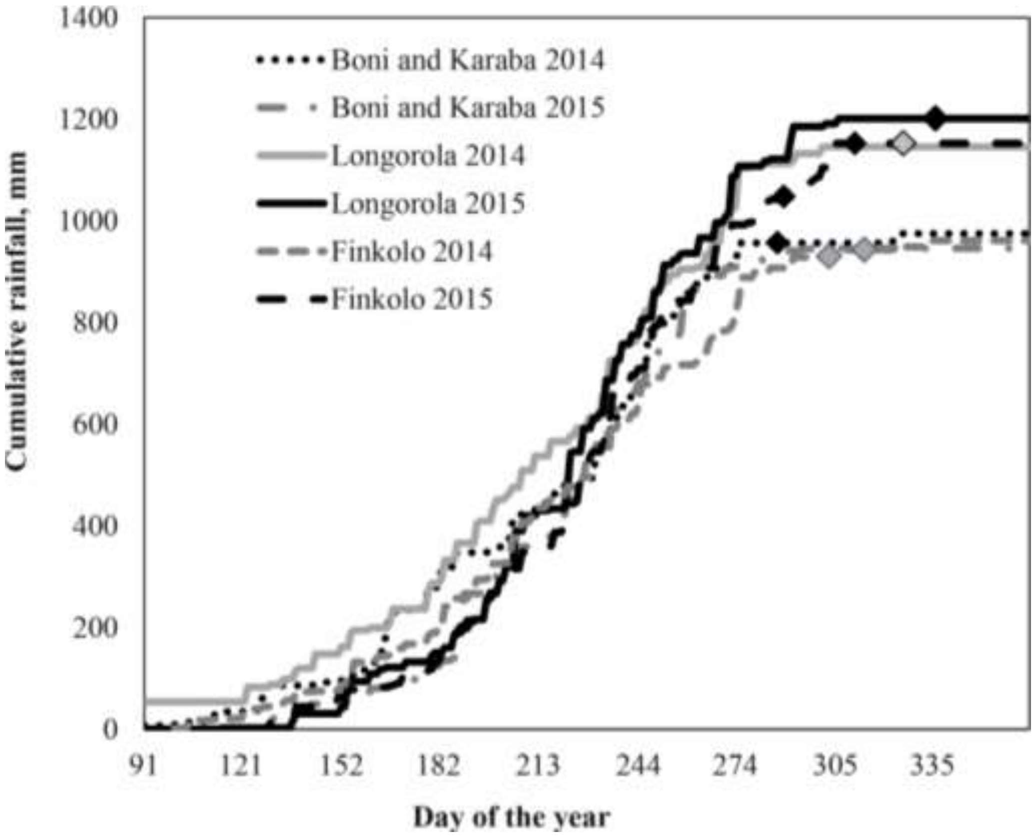


Figure 1. Cumulative rainfall for rainfed rice research site-years in Mali and Burkina Faso. The diamond symbols indicate the harvest dates.

Table 2. Treatment structure for rainfed rice nutrient response trials conducted in Burkina Faso and Mali.

Burkina Faso		Mali	
Boni	**Karaba**	**Longorola**	**Finkolo**
2014	**2015**	**2014-5**	**2014-5**
0-0-0	0-0-0	0-0-0	0-0-0
30-0-0	30-0-0	30-0-0	25-0-0
60-0-0	60-0-0	60-0-0	50-0-0
90-0-0	90-0-0	90-0-0	75-0-0
120-0-0	120-0-0	120-0-0	100-0-0
0-22.5-0	0-15-0	0-15-0	0-15-0
30-22.5-0	30-15-0	30-15-0	25-15-0
60-22.5-0	60-15-0	60-15-0	50-15-0
90-22.5-0	90-15-0	90-15-0	75-15-0
120-22.5-0	120-15-0	120-15-0	100-15-0
90-7.5-0	90-7.5-0	90-7.5-0	75-7.5-0
90-15-0	90-22.5-0	90-22.5-0	75-22.5-0
90-30-0	90-15-10	90-15-10	75-15-10
90-22.5-10	90-15-20	90-15-20	75-15-20
90-22.5-20	90-15-30	90-15-30	75-15-30
90-22.5-30	90-15-20-D	90-15-20-D	75-15-20-D
90-22.5-20-D			

The trials in Burkina Faso were with and without 5 Mg ha^{-1} of manure applied. The nutrient rate treatments refer to: N-P-K with D as the diagnostic treatment with N-P-K-S-Zn-Mg-B.

Table 3. The N rate effects on rainfed rice grain yield (Mg ha^{-1}) for two locations in Burkina Faso and in Finkolo, Mali.

N rate (kg ha^{-1})	**Finkolo**		**N rate (kg ha^{-1})**	**Boni**			**Karaba**[†]	
	2015	**Mean**		**2014**	**2015**	**Mean**	**2015**	**Mean**
0	0.92	1.69	0	1.52	0.79	1.16	1.18	1.60
25	1.25	1.92	30	1.90	0.87	1.39	1.43	1.86
50	1.81	2.09	60	2.09	1.07	1.58	1.46	2.00
75	2.16	2.21	90	1.96	0.95	1.46	1.70	2.15
100	2.37	2.35	120	2.06	1.28	1.67	1.71	2.01
‡	***	*		*	*	*	***	*
a§	2.454	2.406	*a*	2.041	1.570	1.756	2.000	2.053
b	1.534	0.716	*b*	0.523	0.00585	0.601	0.809	0.453
c	0.982	0.982	*c*	0.951		0.986	0.991	0.961

The N x P rate interactions were not significant. In Burkina Faso, the N rate interactions with manure and variety and of NxP were not significant. [†]Yield was not affected by N rates at Karaba and Finkolo in 2014 and at Longorola in both years. ‡* and *** are significant at P ≤0.05 and 0.001, respectively. §Grain yield responses to nutrient rate were curvilinear to plateau if coefficients *a, b, c* are present ($Y = a - bc^r$ with r = rate) or linear if only *a* and *b* are present.

Table 4. The P rate (kg ha^{-1}) effects on rainfed rice grain yield (Mg ha^{-1}) in Karaba, Burkina Faso†.

P rate (kg ha^{-1})	**Karaba**	
	2015	**Mean**
0	1.52	2.04
7.5	1.84	2.16
15	1.88	2.22
22.5	1.90	2.26
	*‡	ns
a	1.893	2.276
b	0.371	0.236
c	0.765	0.905

†Yield was not affected by P rates at Karaba in 2014 and at Boni, Finkolo, and Longorola in both years. ‡: ns and * are not significant and significant at P ≤0.05, respectively. §: The *a, b, c* coefficients for the yield response to P functions $Y = a - bc^r$ with r = P rate.

Finkolo, and 2.8 and 1.9 Mg ha^{-1} for lowland rice at Longorola. In Burkina Faso, the mean 2014 and 2015 rice yields were, respectively, 2.0 and 1.0 Mg ha^{-1} at Boni, and 2.6 and 1.7 Mg ha^{-1} at Karaba.

The treatment x year interaction was significant at Finkolo due to no treatment effects in 2014 while there was a weakly curvilinear response to N in 2015 and across years (Table 3). Rice yield was not affected by P or K rate, or by Mg-S-Zn-B. In Longorola, fertilizer treatments did not affect lowland rice grain yield in either years.

At Boni, the N x P interactions were not significant (Table 3). There were no interactions of treatment with manure rate or variety. The P and K rate effects and the Mg-S-Zn-B effect were not significant for grain yield. The response to N was curvilinear in 2014, linear in 2015, and curvilinear for the means of 2014 and 2015 combined.

Rice yield at Karaba was not affected by treatments in 2014 but was affected by N and P rate in 2015 (Tables 3 and 4). The effects of K rate, Mg-S-Zn-B and interactions were not significant. The grain yield response to N rate was near linear in 2015 but curvilinear for the mean response across years. The P rate effect was curvilinear to plateau (Figure 2).

Depending on the cost of N use relative to grain value, the mean EOR for N ranged from 9 to 81 kg ha^{-1} for Finkolo, 10 to 45 kg ha^{-1} for Karaba, and 24 to 74 kg ha^{-1} for Boni (Figure 2). For Boni, N application was not profitable when the cost of N use per kilogram was equal to the value of 9 or more kilogram grain. Depending on the cost of P use relative to grain value, the mean EOR for P ranged from 6 to 20 kg ha^{-1} for Karaba.

The yield gains at EOR for N ranged from 0.11 to 0.55 Mg ha^{-1} with the greatest N cost effect at Finkolo (Table 5). The yield gains at EOR for P ranged from 0.11 to 0.21 Mg ha^{-1} at Karaba. The agronomic efficiency at EOR

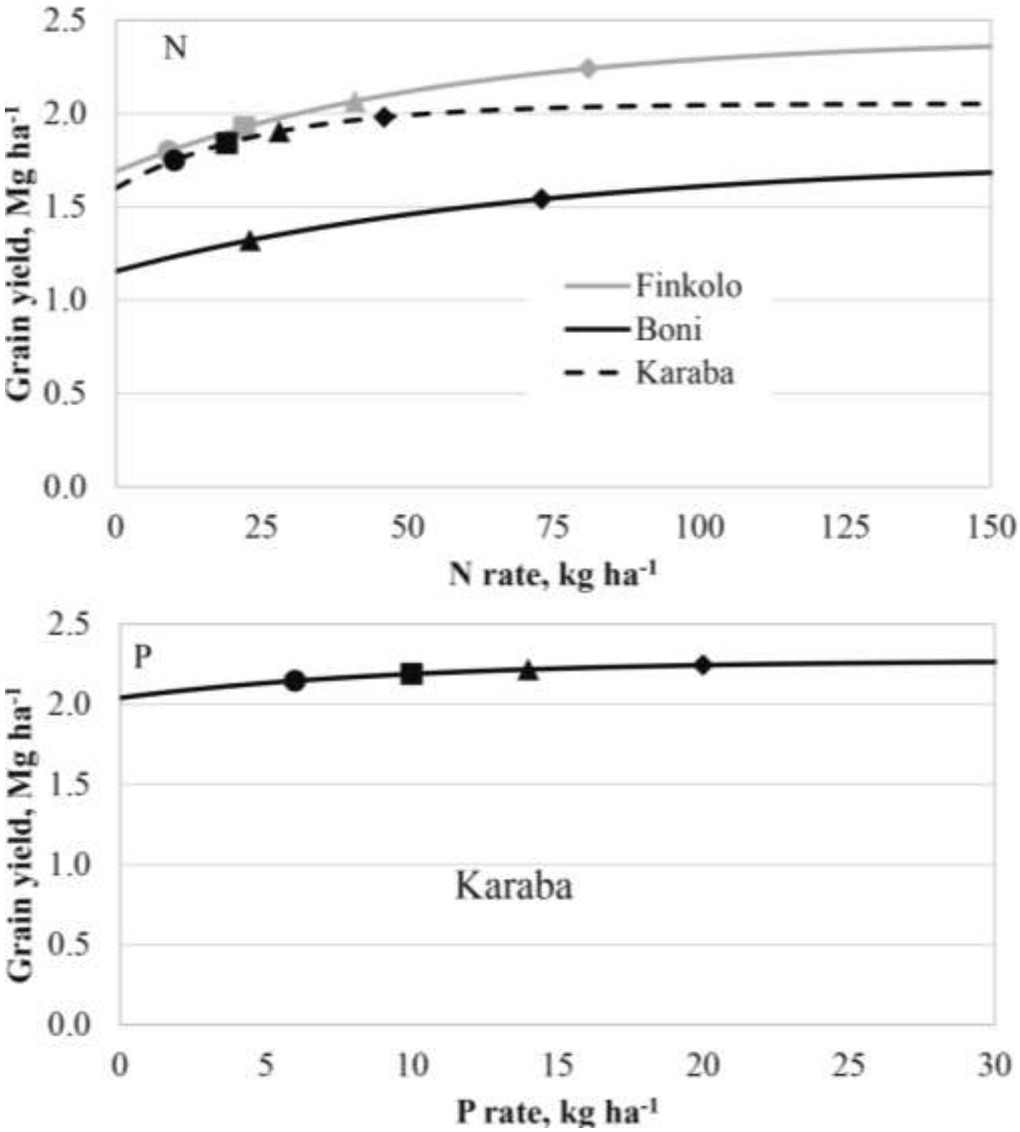


Figure 2. Rice grain yield responses to applied N at Boni and Karaba in Burkina Faso and Finkolo in Mali and to applied P at Karaba in Burkina Faso when the cost of nutrient use is equal to the value of 3 (♦), 6 (■), 9 (■), or 12 (●) kg of rice grain.

ranged from 4.6 to 14.9 kg kg^{-1} for N and from 10.4 to 16.0 kg kg^{-1} for P. The PCR at EOR in cases of significant response functions ranged from 0.00 to 1.79 \$ \$$^{-1}$ for N, and from 0.33 to 2.45 \$ \$$^{-1}$ for P at Karaba. If fertilizers were applied at 50% rather than 100% EOR, as might be the case for financially constrained farmers, the mean yield gain was reduced by 36% but for means AE it was increased by 23% and for mean PCR by 66%.

DISCUSSION

Crop-nutrient response data is required for profit optimization from fertilizer use. The on-station and on-farm research sites for the 20 trials of this study differed for soil properties and included Fluvisols, Luvisols and Lixisols with ranges of pH 5.2 to 5.5, Mehlich-3 P 6.9 to 31.0 mg kg^{-1} and Mehlich-3 K 0.18 to 0.37 cmol kg^{-1} (Table 1). The SOC was <10 g kg^{-1}, except at Longorola, and probably had little new organic material input to the soil in recent years due to crop residue harvest, grazing, or burning. Low soil pH may have constrained yield and response to nutrient application and the range of inference for the results should be limited to soil pH of <5.6. There were no yield responses to Mg-S-Zn-B indicating that deficiencies of these nutrients are not of concern for current rainfed rice production in Sudan Savanna. With irrigated lowland rice in Mali, but not in Niger, there were yield responses to Mg-S-Zn-B (Garba et al., 2018a) and there were occasional responses to Zn

Table 5. The effect of nutrient application at 100% compared with 50% of the economically optimal rate (EOR) on rice yield increase (Yield□), agronomy efficiency of nutrient use (AE), and profit to cost ratio (PCR) for rainfed rice at Finkolo in Mali and at Boni and Karaba in Burkina Faso.

CP	**Application at 100% EOR**				**Application at 50% EOR**			
	EOR	**Yield△**	**AE**	**PCR**	**EOR**	**Yield△**	**AE**	**PCR**
kg kg^{-1}	**kg ha^{-1}**	**kg ha^{-1}**	**kg kg^{-1}**	**\$ \$$^{-1}$**	**kg ha^{-1}**	**kg ha^{-1}**	**kg kg^{-1}**	**\$ \$$^{-1}$**
Nitrogen								
Finkolo								
3	81	552	6.8	1.27	40.5	373	9.2	2.07
6	43	388	9.0	0.50	21.5	231	10.7	0.79
9	20	218	10.9	0.21	10	119	11.9	0.32
12	9	108	12.0	0.00	4.5	56	12.4	0.04
Boni								
3	74	339	4.6	0.53	37	244	6.6	1.20
6	24	172	7.2	0.19	12	93	7.8	0.29
9	0				0			
12	0				0			
Karaba								
3	45	377	8.4	1.79	22.5	268	11.9	2.97
6	28	304	10.9	0.81	14	193	13.8	1.30
9	17	223	13.1	0.46	8.5	130	15.3	0.70
12	10	149	14.9	0.24	5	82	16.4	0.37
Phosphorus								
Karaba								
3	20	207	10.4	2.45	10	149	14.9	3.97
6	14	178	12.7	1.12	7	119	17.0	1.83
9	10	149	14.9	0.66	5	93	18.6	1.07
12	7	112	16.0	0.33	3.5	70	20.0	0.67

The results are in consideration of the cost of nutrient use per kg relative to the value of one kg of rice grain (CP).

and B in Nigeria (Daudu et al., 2017).

The rice grain yield was higher with lowland production at Longorola compared to the other sites but below the country mean yield for rainfed rice of 2.9 Mg ha^{-1} and far below the estimated potential yield of 6.1 Mg ha^{-1} (GYGA, 2017). The site captures runoff from the watershed that is retained within bunds. This water capture, together with high SOC and clay content compared with the upland sites, likely resulted in few or no occurrences of early and mid-season soil water deficits. However, rainfall ceased 50 to 60 days before harvest in both years and it is likely that yield was constrained by soil water deficit during grain filling (Figure 1). Rice is most sensitive to stress during the early reproductive stages but stress during grain filling is also important (O'Toole, 1982). The lack of more response to fertilizer at Longorola may also be due to the delivery of nutrients in the runoff captured from other parts of the watershed.

Nutrient response information suitable for estimation of response functions is scarce for rainfed lowland rice in Western Africa. However, irrigated lowland rice mean yield increases due to 80 kg ha^{-1} N were estimated to be: 2.34 Mg ha^{-1} and 105% for four trials in Burkina Faso (Segda et al., 2005; Segda et al., 2014); 1.37 Mg ha^{-1} and 40% for four trials in Nigeria (Daudu et al., 2017); 0.58 Mg ha^{-1} and 25% for three trials in Niger (Garba et al., 2018a); and 1.56 Mg ha^{-1} and 52% for two trials in Mali (Garba et al., 2018a). For the same irrigated lowland trials, the mean responses to 15 kg ha^{-1} P were estimated to be: 0.74 Mg ha^{-1} and 20% in Burkina Faso; 0 Mg ha^{-1} in Nigeria; 0.53 Mg ha^{-1} and 19% in Niger; and 0.92 Mg ha^{-1} and 20% in Mali. Similarly, the mean responses to 20 kg ha^{-1} K were estimated to be: 0.15 Mg ha^{-1} and 3% in Burkina Faso; 0.82 Mg ha^{-1} and 19% in Nigeria with much inconsistency; 0.00 Mg ha^{-1} in Niger; and 0.80 Mg ha^{-1} and 15% in Mali. The yields in these trials were much higher compared with Longorola. Alleviation of constraints to higher yield, other than nutrient deficiencies, is likely to increase response to applied nutrients at Longorola.

Rice responded to N at the three upland rice locations agreeing with other results indicating that N deficiency is a common constraint to upland rice yield (Okonji et al., 2012; Haefele et al., 2014; Kaizzi et al., 2014; Niang et al., 2017) (Table 3). The mean responses for each location fitted the curvilinear to plateau function. The yield responses to N were greater at Finkolo and Karaba compared with Boni where the yield with no fertilizer applied was relatively low (Table 5 and Figure 2). Therefore, the history of upland rice yield for a location may be an indicator of the potential response to N. For example, if yield without N applied is typically less than 1.5 Mg ha^{-1}, the potential for profitable response to N may be small.

A curvilinear to plateau response to P occurred at Karaba with about 60% of the potential response occurring with 10 kg ha^{-1} P applied and generally agreeing with results of Okonji et al. (2012) and Kaizzi et al. (2014) (Table 4). There was no response to P at Boni and Finkolo which had higher Mehlich-3 P compared with Karaba (Table 1). The response to 10 kg ha^{-1} P at Karaba was 0.15 kg ha^{-1} more grain yield (Table 5) compared with an average paddy yield response of 0.54 Mg ha^{-1} in Uganda where Mehlich-3 P mean was on average lower compared with Karaba.

The lack of response to K is consistent with upland rice results from Uganda (Kaizzi et al., 2014) and with results for other upland crops in Sudan and Sahel Savanna (Garba et al., 2017a; Garba et al., 2017b; Tarfa et al., 2017). With sufficient mitigation of other constraints to growth and much increased yield, response to applied K may occur as Mehlich-3 K was low for the upland rice sites.

Manure application and rice variety did not affect upland rice response to nutrients in Burkina Faso. Therefore, application of manure may increase yield with or without fertilizer application, but this would be an additive rather than a synergistic effect. Garba et al. (2018b) found additive effects of manure and fertilizer P application for Sudan Savanna but synergistic effects for Sahel Savanna. Kaizzi et al. (2014) also found that well-adapted upland rice varieties responded consistently to applied nutrients with no significant variety x treatment interaction.

The agronomic efficiency of nutrient use was low to moderate because of small yield responses to applied nutrients and, as expected, declined with increased nutrient rates (Table 5). For comparison, the agronomic efficiencies for N reported by Kaizzi et al. (2014) were determined to be 18 and 26 kg kg^{-1} for application of 60 and 30 kg ha^{-1} N, although this was for paddy yield. Fageria et al. (2014) also reported relatively higher agronomic efficiency for upland rice.

Profit considerations are very important to farmer decision making and especially for smallholders who are very constrained financially but account for most agricultural production in Sudan Savanna. Such farmers need profit to cost ratios >1 for an investment to compete with other uses of available finance (CIMMYT, 1988). Application of nutrients at 50% of EOR greatly improves the PCR but the PCR is still generally <1 if fertilizer use cost relative to grain value is relatively high. The results indicate that financially constrained farmers need to consider fertilizer use for rainfed rice production very carefully relative to alternative uses of available finance such as fertilizer use for other crops. Given the low EOR for N, application of all N at panicle initiation may reduce N losses and improve recovery and agronomic efficiency of fertilizer N. The farmer may also make the in-season N application conditional on observed crop performance until that time.

The results from this and other studies were used to develop a decision tool for Sudan Savanna that considers the farmer's land allocation to different crops and the amount of finance available for fertilizer use, the fertilizer use costs, and the grain values (http://agronomy.unl.edu/OFRA). The tool then gives the crop-nutrient-rate choices expected to maximize profit from fertilizer use.

Conclusions

The results indicate that K, Mg, S, Zn and B deficiencies are not constraining rainfed rice yield in the Sudan Savanna. Nutrient response functions for rainfed rice indicated profit potential from applied N for rainfed upland rice production in the Sudan Savanna but the results do not support N application for lowland production where stress due to soil water deficits during grain fill are likely to occur. However, the indicated profit potential is not great enough to be attractive to financially constrained farmers unless fertilizer N costs are uncommonly low relative to on-farm rice grain value and if applied at less than EOR. The profit potential for N application appears to be greater for fields if mean past yields were more compared with less than 1.5 Mg ha^{-1} unless other constraints to productivity are mitigated. Fertilizer P application resulted in increased grain yield for upland rice at only one of three locations and there were no responses to K suggesting that, unless other research results indicate otherwise, fertilizer P and K use does not have much profit potential for rainfed rice in Sudan Savanna. The results of this study do not justify fertilizer application for rainfed lowland rice production in the Sudan Savanna but are from a single location with two years of results with drought stress during grain fill. These results are from two years of research at one location and need to be considered with other nutrient response results in making fertilizer use decisions. Based on the results of this study, fertilizer N application for upland rice in the Sudan Savanna should be applied only if the yield history for the field indicates a high probability of >1.5 Mg ha^{-1} yield but should be limited to 25 kg ha^{-1} N unless fertilizer N use relative to grain value is uncommonly inexpensive. This N application should be at panicle initiation with no pre-plant application to minimize the risk of nitrate-N leaching loss. The in-season N application decision may also be in consideration of the observed yield potential of the crop. The results indicate that fertilizer P, K, Mg, S, Zn, and B should not be applied for upland rice in the Sudan Savanna if farm profits are of major concern. Even though the upland rice results are from 18 trials conducted at 3 locations, fertilizer use decisions for upland rice should consider not only these results, but also other results of other well-conducted field research, especially if soil pH is >5.5. Some investigation of the effect of lime application where soil pH is 5.2 may be justified, especially if pulses are in the crop rotation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the Alliance for Green Revolution in Africa (AGRA) for funding, to CAB International for managing the implementation, and to the University of Nebraska-Lincoln for scientific backstopping of the project “Optimizing Fertilizer Recommendations in Africa”

ABBREVIATIONS

EOR, Economically optimal rate of nutrient application or the rate expected to maximize net return per hectare to nutrient application; **Mg-S-Zn-B,** a diagnostic treatment containing NPK plus 15 kg ha^{-1} S, 2.5 kg ha^{-1} Zn, 10 kg ha^{-1} Mg, and 0.5 kg ha^{-1} B; **PCR,** profit to cost ratio, or the net return divided by the cost of fertilizer nutrient use.

REFERENCES

Apaseku JA, Mbatchou VC, Dogbe W, Dawda S (2013). Lowland NERICA and some sativa line rice lowland responses to nitrogen and phosphorus in Guinea Savanna agroecoystem. Int. J. Res. Chem. Environ. 3:295-307.

Aune JB, Bationo A (2008). Agricultural intensification in the Sahel-the ladder approach. Agric. Syst. 98:119-125.

Bado BV (2002). Rôle des légumineuses sur la fertilité des sols ferrugineux tropicaux des zones guinéenne et soudanienne du Burkina Faso (Doctoral dissertation, Université Laval).

CIMMYT Economics Program (1988). From agronomic data to farmer recommendations: an economics training manual (No. 27), CIMMYT.

CROPSTAT (2013). FAOSTAT. www.fao.org/faostat. Accessed May 2017.

Garba M, Dicko M, Abdou G, Wortmann C (2017a). Sorghum and groundnut sole and intercrop nutrient response in semi-arid West Africa. Agron. J. 109:1-11.

Garba M, Dicko M, Abdou G, Kouyaté Z, Wortmann C (2017b). Pearl millet and cowpea intercrop response to applied nutrients in West Africa. Agron. J. 109:2333-2342.

Garba M, Dicko M, Kamissoko N, Garba N, Wortmann C (2018a). Fertilizer use efficiency and profitability of irrigated rice in Mali and Niger. Agron. J. submitted.

Garba M, Serme I, Garba N, Korodjouma O, Gonda A, Wortmann C, Mason S (2018b). Crop response to manure plus fertilizer in Burkina Faso and Niger. Nutr. Cycl. Agroecosyst. pp. 1-14. Doi.org/10.1007/s10705-018-9921-y

Daudu CK, Ugbaje EM, Oyinlola EY, Tarfa BD, Alhaji YA, Amapu IY, Wortmann C (2017). Lowland rice nutrient response functions for Nigeria. Agron. J. 110:1079-1088.

Fageria NK, Moreira A, Moraes LAC, Moraes MF (2014). Nitrogen uptaken and use efficiency in upland rice under two nitrogen sources. Commun. Soil Sci. Plan. 45(4):461-469.

Fosu MZ, Zida Z, Bidjakin J, Atakora W, Dogbe W, Ouédraogo A, Dicko M, Basso A, Semoka J (2016). Cross-country approaches to scaling out rice production in West Africa. In: Alliance for a Green Revolution in Africa, Going Beyond Demos to Transform African Agriculture: The AGRA Soil Health Prog., Nairobi, Kenya pp. 66-74.

Global Yield Gap Atlas (GYGA) (2017). Global Yield Gap Atlas. http://www.yieldgap.org/web/guest/download_data. Accessed 7 July 2017.

Haefele SM, Bhattachan BK, Adhikari BB, Abon Jr. CC, Shresta SM (2014). Spatial variability of fertilizer management and response in rainfed rice of Nepal. Agric. Ecosyst. Environ. 189:190-198.

Kaizzi CK, Byalebeka J, Semalulu O, Alou I, Zimwanguyizza W, Nansamba A, Odama E, Wortmann CS (2014). Upland rice response to fertilizer in Uganda. Afr. J. Plant Sci. 8:416-425.

Kamara AY, Ekeleme F, Omoigui LO, Oikeh SO, Chikoye D, Tegbaru A (2010). Response of upland rice cultivars to nitrogen fertilizer in the savannas of Nigeria. Agron. J. 102:333-339.

Mehlich A (1984). Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. Commun. Soil. Sci. Plant Anal. 15:1409-1416.

Muthayya S, Sugimoto JD, Montgomery S, Maberly GF (2014). An overview of global rice production, supply, trade, and consumption. Ann. New York Acad. Sci. 1324:7-14.

Niang A, Becker M, Ewert F, Dieng I, Gaiser T, Tanaka A, Segda Z (2017). Variability and determinants of yields in rice production systems of West Africa. Field Crops Res. 207:1-12.

O’Toole JC (1982). Adaptation of rice to drought prone environments. In Drought Resistance in Crops With Emphasis on Rice. pp. 195-213. International Rice Research Institute, Manila, Philippines.

Okonji CJ, Okeleye AK, Oikeh SO, Aderibigbe SG, Nwilene FE, Ajayi O, Oyekanmi AA (2012) Rice yield and yield components as influenced by phosphorus and nitrogen application rates in the moist savanna of West Africa. J. Agric. Sci. Tech. 2:1214-1223.

Segda Z, Yameogo LP, Sie M, Bado VB, Mando A (2014) Nitrogen use efficiency by selected NERICA varieties in Burkina Faso. Afr. J. Agric. Res. 9:1172-1179.

Segda Z, Haefele SM, Wopereis MCS, Sedogo MP, Guinko S (2005). Combining field and simulation studies to improve fertilizer recommendations for irrigated rice in Burkina Faso. Agron. J. 97:1429-1437.

Shepherd KD, Walsh MG (2007). Infrared spectroscopy - enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. J. Near Infrared Spectrosc. 15:1-19.

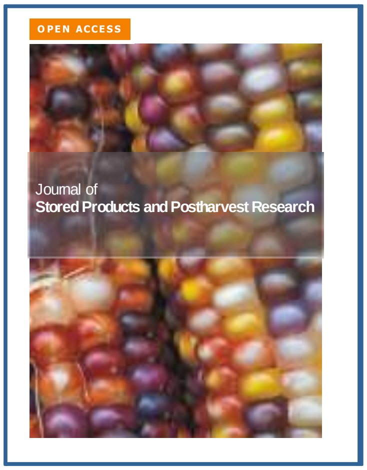
Tarfa BD, Garba N, Ouattara K, Serme I, Wortmann C (2017). Groundnut and soybean response to nutrient application in West Africa. Agron. J. 109:2323-2332

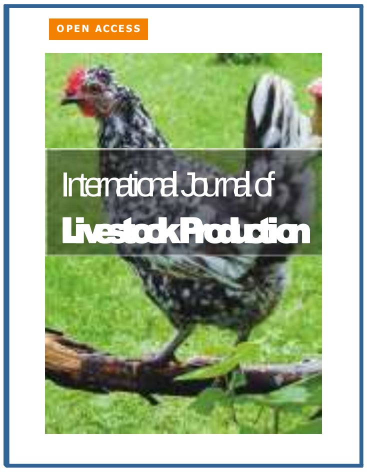
Terhoeven-Urselmans T, Vagen TG, Spaargaren O, Shepherd KD (2010). Prediction of soil fertility properties from a globally distributed soil mid-infrared spectral library. Soil Sci. Soc. Am. J. 74:1792-1799.

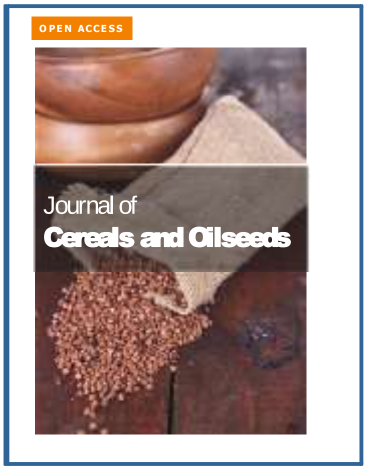
Towett EK, Shepherd KD, Sila A, Aynekulu E, Cadisch G (2015). Mid-infrared and total x-ray fluorescence spectroscopy complementarity for assessment of soil properties. Soil Sci. Soc. Am. J. 79:1375-1385.

WARDA (2005) West Africa Rice Development Association Annual Report. P 15.

Related Journals:







www.academicjournals.org