OPEN ACCESS

September 2020
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 a double blind peer reviewed journal. AJAR publishes articles in all areas of agriculture such as arid soil research and rehabilitation, agricultural genomics, stored products research, tree fruit production, pesticide science, post-harvest biology and technology, seed science research, irrigation, agricultural engineering, water resources management, agronomy, animal science, physiology and morphology, aquaculture, crop science, dairy science, forestry, freshwater science, horticulture, soil science, weed biology, agricultural economics and agribusiness.

Indexing

Science Citation Index Expanded (ISI), CAB Abstracts, CABI's Global Health Database
Chemical Abstracts (CAS Source Index), Dimensions Database, Google Scholar
Matrix of Information for The Analysis of Journals (MIAR) Microsoft Academic
ResearchGate, The Essential Electronic Agricultural Library (TEEAL)

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Agricultural Research is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

Article Copyright

When an article is published by in the African Journal of Agricultural Research the author(s) of the article retain the copyright of article. Author(s) may republish the article as part of a book or other materials. When reusing a published article, author(s) should;

Cite the original source of the publication when reusing the article. i.e. cite that the article was originally published in the African Journal of Agricultural Research. Include the article DOI

Accept that the article remains published by the African Journal of Agricultural Research (except in occasion of a retraction of the article)

The article is licensed under the Creative Commons Attribution 4.0 International License.

A copyright statement is stated in the abstract page of each article. The following statement is an example of a copyright statement on an abstract page.

Copyright ©2016 Author(s) retains the copyright of this article..

Self-Archiving Policy

The African Journal of Agricultural Research is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.

Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Agricultural Research is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.

https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Agricultural Research encourages metadata harvesting of all its content. The journal fully supports and implements the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

OPEN ACCESS

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

creative commons

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

<idpf>

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajar@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJAR

Submit manuscript online http://ms.academicjournals.org

Academic Journals

73023 Victoria Island, Lagos, Nigeria

ICEA Building, 17th Floor, Kenyatta Avenue, Nairobi, Kenya

Editors

Editorial Board Members

Table of Content

Depletion of phosphate rock reserves and world food crisis: Reality or hoax?
Kisinyo Peter Oloo and Opala Peter Asbon 1223

Growth performance of royal purple and white guinea fowl varieties and their crosses under an intensive management system
Patrick Kgwatalala, Freddy Manyeula and Candy Sefemo 1228

Pastoral farming system and its temporal shift: A case of Borana zone, Oromia National Regional State, Ethiopia
Dirriba Mengistu, Simbone Tefera and Bely Biru 1233

Evaluation of blended fertilizer on growth performance and yield of onion (Allium cepa L.) at irrigated conditions Tselemti District North Western Tigray, Ethiopia 1239
Solomon Mebrahtom, Kinfe Tekulu, Tewolde Berhe, Tsadik Tadele, Weldegebreal Gebrehiwot, Gebresemaeti Kahsu, Samrawit Mebrahtu and Goitom Aregawi

Household determinants of food security in rural Central Uganda
John Baptist Semazzi and Moses Kakungulu
1245

Banana pest risk assessment along banana trade axes running from low to high altitude sites, in the Eastern DR Congo and in Burundi 1253
Guy Blomme, Walter Ocimati, Serge Amato, Alexandra zum Felde, Muller Kamira, Mariam Bumba, Liliane Bahati, Daniel Amini and Jules Ntamwira

Enhancing maize production in a Striga infested environment through weed management practices, sowing date and improved crop varieties
Aliyu Baba Mohammed, Emmanuel Daniya and Musa Gimba Matthew Kolo 1270

Floral activity of Apis mellifera (Hymenoptera: Apidae) on Bidens steppia (Asteraceae), Cordia africana (Boraginaceae), Pittosporum viridiflorum (Pittosporaceae) and Psychotria mahonii (Rubiaceae) in Nyambaka (Adamawa, Cameroon) 1278
Nentcherse Mbere, Michelson Azo'o Ela, Tchobsala and Fernand-Nestor Tchuenguem Fohouo

Spatiotemporal hotspot patterns of wheat rust incidence and severity in Ethiopia
Abu Tolcha, Olika Dessalegn, Almaz Nigussie and Degefie Tibebe 1289

Table of Content

Impact of native arbuscular mycorrhizal fungi based fertilizers on to increase maize productivity in North Benin 1298
Abdel D. KODA, Gustave DAGBENONBAKIN, Françoise ASSOGBA, Nadège A. AGBODJATO, Christine N'TCHA, Sylvestre ASSOGBA, Ricardos M. AGUEGUE, Aude E. KELOMEY, Adolphe ADJANOHOUN and Lamine BABA-MOUSSA

Effect of potassium on yield and growth of Enset (Ensete ventricosum (Welw.) Cheesman) in Dale District, Sidama Region, Ethiopia 1307
Kibreselassie Daniel and Suh-Yong Chung

Field evaluation of introduced and local cowpea genotypes performance in Botswana 1317
Odireleng O. Molosiwa and Bose C. Makwala

Effect of different planting techniques and sowing density rates on the development of quinoa 1325
Abdalla Dao, Jorge Alvar-Beltrán, Abdou Gnanda, Amidou Guira, Louis Nebie and Jacob Sanou

Vol. 16(9), pp. 1223-1227, September, 2020
DOI: 10.5897/AJAR2020.14892
Article Number: 411FD9464714
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Review

Depletion of phosphate rock reserves and world food crisis: Reality or hoax?

Kisinyo Peter Oloo[1]* and Opala Peter Asbon[2]

[1]Department of Agronomy and Environmental Science, School of Agriculture, Natural Resources and Environmental Studies, Rongo University, P. O. Box 103-40404, Rongo, Kenya.
[2]Department of Applied Plant Sciences, School of Agriculture and Food security,Maseno University, Private Bag, Maseno, Kenya.

Received 4 April, 2020; Accepted 23 June, 2020

Phosphate rock (PR) deposits are the major source of phosphate (P) fertilizers for soil fertility replenishment. The demand for P fertilizers in the year 2014 was 42,706,000 tons and was expected to reach 46,648,000 tons in 2018. Majority of PR deposits are found in only a few countries including Morocco, USA and China. There is however conflicting information on the extent of world PR reserves, therefore, complicating the ability to accurately determine their lifespan. Consequently, proper planning on the utilization of this resource is hampered. Two schools of thought have emerged in regard to the longevity of the PR reserves. Some argue that there is imminent depletion of this resource and the world should therefore be prepared for a looming food crisis. However, based on the most recent estimates of 290 billion tons of PR reserves, some scientists have predicted that the PR reserves will be depleted between the years 2311 and 2411 and therefore conclude that there is no immediate course of alarm. What is not in doubt, however, is the finiteness of PR reserves. Therefore, an approach that encourages society to adopt a sustainable utilization of this phosphate resource should be advocated as an insurance against food insecurity.

Key words: Food security, phosphate rock depletion, sustainable agriculture.

INTRODUCTION

Soil degradation and infertility are major constraints to sustainable agricultural production in many parts of the world. Phosphorus deficiencies in particular are widespread with P being second only to N in terms of deficient nutrients in most soils (Syers et al., 2011). Phosphorus rarely occurs in highly concentrated forms in the earth's crust. Therefore, P is a limiting nutrient to growth and production in marine, freshwater, and terrestrial ecosystems (Elser et al., 2007). Phosphorus is an essential element in plant nutrition and plays several essential roles. It is important for photosynthesis, seed and fruit formation, root growth and development (Mengel and Kirkby, 2001; Marschner, 2012). Therefore, P deficiency interferes with photosynthesis, protein synthesis, respiration and biomass production in plants and adversely affects crop productivity in large areas of the world (Plenet et al., 2000).

The green revolution and the related increases in crop

*Corresponding author. E-mail: kisinyopeter65@gmail.com, pkisinyo@rongovarsity.ac.ke.

Table 1. World population forecast.

Year	Population	Yearly % change	Fertility rate	Population density (persons/km²)
2017	7,515,284,153	1.11	2.50	58
2020	7,758,156,792	1.09	2.47	60
2025	8,141,661,007	0.97	2.43	63
2030	8,500,766,052	0.87	2.38	65
2035	8,838,907,877	0.78	2.35	68
2040	9,157,233,976	0.71	2.31	70
2045	9,453,891,780	0.64	2.28	73
2050	9,725,147,994	0.57	2.25	75

Source: World Population Forecast (2017).

production largely required a concurrent increase in the use of inorganic fertilizers of which P was a major component (Scholz and Wellmer, 2013). Phosphate rock (PR) is the main raw material for the production of commercial P fertilizers such as diammonium phosphate, triple superphosphate, monoammonium phosphate, and complex fertilizers including their mixes thereof (Khabarov and Obersteiner, 2018; Hellal et al., 2019). Minor sources of P are of organic origins such as manures, guano and human excreta. Modern agriculture also relies heavily on P addition to animal feeds (Cordell et al., 2009). Moreover, the production of biomass for biofuels also relies on P application, and thereby also tends to increase the global demand for P (Vos et al., 2011).

Phosphate rocks are finite, therefore none renewable through biological processes as in the case of nitrogen (Edixhoven et al., 2014). The major challenge facing humankind is therefore utilizing this limited resource in a way that promotes sustainable development to include intra- and intergenerational fairness (Mew et al., 2018). The likely depletion of PR is a serious matter, because the PR deposits took millions of years to form (Edixhove et al., 2014). Although the current geological P resources are still sufficient to meet the growing demand of the near future (Vos et al., 2011), just how much of the PR reserves are available for future use remains contentious (Baveye, 2015). In recent years, many researchers have claimed that world reserves of PR were getting depleted at an alarming rate while others have claimed that such apocalyptic forecasts were frequent in the past but have always been proven unfounded, making it likely that the same will be true in the future (Baveye, 2015). This paper reviews these contrasting viewpoints and the implications on the world's food security status.

WORLD PHOSPHATE FERTILIZER USAGE

Due to increase in world human population over the years, the demand for more food to feed this population has continued to increase. Between the years 2017 and 2050, world human population is expected to increase by about 29% (Table 1). In the year 2017, the world population was about 7.5 billion and is expected to rise to about 9.7 billion in the year 2050. However, the overall rate of growth will decline due to decrease in human fertility over the years to 2050 (World Population Forecast, 2017). To feed this population, increased fertilizer use by farmers will be needed to enhance food production. Up to 90% of worldwide phosphate production is utilized in agriculture in the form of feed and food additives, but mainly as phosphate fertilizers (Heckenmüller et al., 2014). The global use of fertilizers that contain N, P and K increased by 600% between the years 1950 and 2000 (International Fertilizer Industry Association, 2006). The world demand for P fertilizer is projected to increase from 41 151 000 to 45 858 000 tons between the years 2015 and 2020 (Table 2) (FAO, 2017). Demand for P fertilizer over the same period is expected to grow annually by 2.44% (FAO, 2017). Currently, a total of 200 to 265 million metric tons of marketable PR concentrate is mined (Geissle et al., 2018) and further processed to produce phosphorus fertilizer (83%) or industrial P (17%) (Prud'homme, 2016).

Africa has continued to lag behind in fertilizer use compared to other parts of the world. Its fertilizer use is about 17 kg/ha/year, compared to 85 kg/ha/year in North America, 96 kg/ha/year in Latin America and 196 kg/ha/year in Asia (International Fertilizer Industry Association, 2009). It is estimated that P fertilizer use in Africa is only about 5.1 kg/ha/year (Africa Fertilizer Summit, 2006). The low fertilizer use in Africa compared to other parts of the world is attributed to their high costs, lack of credit for many farmers, poor transport and lack of local production or distribution capacity (Africa Fertilizer Summit, 2006).

WORLD PHOSPHATE RESERVES

Scientists have, over the years, endeavoured to estimate the actual amounts of the world's PR reserves. Majority of PR reserves are found in Morocco, the USA and China

Table 2. World demand for P (P_2O_5) fertilizer nutrients years 2015-2020 in thousand tons.

Variable	Year					
	2015	2016	2017	2018	2019	2020
World	41 151	41 945	43 195	44 120	45 013	45 858
Africa	3 573	3 641	3 788	3 964	4 126	4 302
Americas	22 506	23 030	23 379	23 768	24 169	24 564
Asia	66 294	67 082	68 446	69 493	70 525	71 476
Europe	15 874	16 016	16 161	16 290	16 407	16 504
Oceania	1 779	1 806	1 833	1 861	1 888	1 917

Source: FAO (2017).

with very little in other countries (Table 3). The world PRs reserves were estimated to be 16 billion tons by van Kauwenbergh (2010) but this was deemed as an underestimation since not all deposits in the world were included. These estimates were revised upwards by the International Fertilizer Development Centre (IFDC) to about 60 to160 billion tons (van Kauwenbergh, 2010) and are similar to those reported by the United States Geological Survey report (Jasinski, 2011). Morocco has the biggest phosphate resource with an estimated reserve of 50 billion tons. China, Morocco, the United States and Russia are the leading countries in phosphate production accounting for 79% of all the production. Other countries including Brazil, Jordan, Egypt and Saudi Arabia take up the rest of the production.

Recent estimates of global PR reserves as reported by the US Geological Survey (USGS) have increased from 16 000 Mega tons PR in 2010 to 65 000 Mt PR in 2011 and further to 67 000 Mega tons PR in 2014 (Edixhoven et al., 2014). Despite this upward trend, it is likely that the PR reserves are still underestimated since deposits with small quantities are not listed (Jama and van Straaten, 2006).

PREDICTED LIFESPAN OF THE EXISTING WORLD PHOSPHATE ROCKS RESERVES

Mineable reserves of PR ore are dynamic and future availability depends on prices, supply-demand functions, exploration, technology development and other factors (Scholz and Wellmer, 2013). The fact that there is no accurate information on the total amount of the existing PR reserves makes it difficult to predict how long they will last. Some in fact argue that it is impossible to predict future reserves of P or any other resource for that matter (Baveye, 2015). Nevertheless, this has not deterred other scientists from making predictions to determine their lifespan. The predictions made so far took into account the existing global reserves, quality, rate at which they are mined and demand by the users (Cordell et al., 2009; FAO, 2015). Numerous recent studies discuss phosphate rock extraction, and some even propose that a peak in production could be reached in coming decades (Cordell et al., 2009; van Vuuren et al., 2010). Some of these studies have suggested an impending peak of PR production by use of curve fitting models where mathematical functions are fitted to historical world production data but studies using other methods reach completely different results (Walan et al., 2014). Also, a sudden increase in global reserve estimates is commonly used to dismiss these warnings, and has somewhat altered the debate.

The recent multiplication of estimated reserves is mostly based on an increase of the Moroccan reserve estimate which has resulted to Morocco currently making up most of the global reserves (Walan et al., 2014). This seems to be the basis of a recent report by IFDC that indicates that the deposits are likely to be depleted between the years 2311 and 2411 based on reserves of 60 to 160 billion tons of PR at the current rate of mining 160 to 170 million per annum and not soon as earlier thought (Edixhoven et al., 2014). Thus some like Ulrich and Frossard (2014) argue that this is a clear demonstration that we should not unduly worry about P depletion, nor think about modifying agricultural practices too drastically in anticipation of a possible scarcity of that nutrient in the future. It is unlikely however that the rate of PR mining will remain constant given the continuous increase in demand of P fertilizers over the years according to FAO (2015). As a result, some think the PRs are likely to be depleted sooner than expected (Cordell et al., 2009) with devastating consequences since PR-based fertilizers are irreplaceable in modern agriculture.

The depletion of PR reserves can however be delayed by increasing the efficiency along the value chain along mining, processing and utilization of the PR. Measures to improve sustainable P use will in addition require recycling of P in order to reduce the current P losses, minimize environmental impacts and conserve the finite resource (Schroder et al., 2010). In particular, greater recycling efforts are required on the farm through measures such as control of soil erosion, use of manures and crop residues because P recycling from urban wastes, such as for example struvite production from urban waste waters is too costly (Weikard, 2016).

Table 3. World phosphate reserves.

Country	Morocco	China	USA	Jordan	Russia	Brazil	Syria	Israel	South Africa	Tunisia	Australia	Egypt	Senegal	Togo	Canada	Other Countries
Billion tons	51000	3700	1800	900	500	400	250	230	230	85	82	51	50	34	50	600

Source: van Kauwenbergh (2010).

CONCLUSION

The major source of phosphorus for world food production is phosphate rocks. The demand for more food to feed the ever increasing human population has necessitated the use of more P fertilizers mainly the inorganic sources over the years. This has exerted increased pressure on the mining of PR deposits which are unfortunately finite. To facilitate proper planning of the utilization of PR sources, many attempts have been made to predict the quantities of existing PR deposits. However, these estimates are fraught with uncertainty as more deposits continue to be discovered. As a consequence, two diametrically opposed viewpoints on whether there is a looming crisis due to imminent PR depletion have emerged. The pessimists predict that the PR deposits will be depleted in the next few decades and that unless serious efforts are invested in the efficient utilization of the current deposits, the world could be faced with serious food and political crisis. There are others however who view such predictions as scaremongering with an aim of arm-twisting the donors to invest more in phosphorus research. They argue that the existing PR deposits can last for several hundreds of years. However, what is not in doubt among these view point is the finiteness of PR reserves. An approach that encourages society to adopt a sustainable utilization of phosphate resources should therefore be advocated.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Africa Fertilizer Summit (2006). Africa Fertilizer Summit Proceedings. International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, USA

Baveye PC (2015). Looming Scarcity of Phosphate Rock and Intensification of Soil Phosphorus Research. Revista Brasileira de Ciência do Solo 39(3):637-642.

Cordell D, Drangert JO, White S (2009). The Story of Phosphorus: Global food security and food for thought. Global Environmental Change 19(2):292-305.

Edixhoven JD, Gupta J, Savenije HG (2014). Recent revisions of phosphate rock reserves and resources: A critique. Earth System Dynamics 5(2):491-507.

Elser JJ, Bracken MES., Cleland EE, Gruner, DS, Harpole, WS. Hillebrand H, Ngai JT, Seabloom EW, Shurin JB, Smith JE (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine, and terrestrial ecosystems. Ecology Letters 10(12):1135-1142.

FAO (2017). World fertilizer trends and outlook to 2020. FAO, Rome.

FAO (2015). World fertilizer trends and outlook to 2018. FAO, Rome.

Heckenmüller M, Narita D, Klepper G (2014). Global Availability of Phosphorus and Its Implications for Global Food Supply: An Economic Overview. Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany. Kiel Working Paper No. 1897

Hellal F, El-Sayed S, Zewainy R (2019). Importance of phosphate pock application for sustaining agricultural production in Egypt. Bulletin of the National Research Centre 43(1):11. https://doi.org/10.1186/s42269-019-0050-9.

International Fertilizer Industry Association (2009). Annual Phosphate Rock Statistics. International Fertilizer Industry Association, Paris.

International Fertilizer Industry Association (2006). Production and International Trade Statistics. International Fertilizer Industry Association, Paris.

Jama B, Van Straaten P (2006). Potential of East African phosphate rock deposits in integrated nutrient management strategies. Annals of Brazilian Academy of Sciences 78(4):781-790.

Jasinski SM (2011). Phosphate Rock. In: Mineral Commodity Summaries. United States Geological Survey. United States Government Printing Office, Washington, D.C.

Khabarov N, Obersteiner M (2018). Modeling Global Trade in Phosphate Rock within a Partial Equilibrium Framework. Sustainability 10(5):1550. doi:10.3390/su10051550 1-15.

Marschner H (2012). Mineral Nutrition of Higher. Third edition. Academic Publishers.

Mengel K, Kirkby EA (2001). Principles of Plant Nutrition. Kluwer Academic Publishers.

Mew MC, Steiner G, Geissler B (2018). Phosphorus Supply Chain, Scientific, Technical, and Economic Foundations: A Transdisciplinary Orientation. Sustainability 10(4):1087.

Plenet D, Mollier A, Pellerin S (2000). Growth analysis of maize field crop under phosphorus deficiency II. Radiation use efficiency, biomass accumulation and yield components. Plant and Soil 224(2):259-272.

Prud'homme M (2016). Trends in Global Phosphate Supply. In Proceedings of the 5th Sustainable Phosphate Summit, Kuming, China 20-22.

Scholz RW, Wellmer F (2013). Approaching a dynamic view on the availability of mineral resources: What we may learn from the case of phosphorus? Global Environmental Change 23(1):11-27.

Schroder SS, Cordell D, Smit AL, Rosemarin A (2010). Plant Research International, Report No. 357. Wageningen UR.

Syers JK, Bekunda M, Cordell D, Corman J, Johnston J, Rosemarin A, Salcedo I (2011). Phosphorus and Food Production. In Goverse, T., & Bech, S. (Eds.), UNEP Yearbook 2011: Emerging Issues in Our Global Environment (pp. 34-45). Nairobi: United Nations Environment Programme (UNEP) – Division of Early Warning and Assessment.

van Kauwenbergh S (2010). World Phosphate Rock Reserves and Resources, IFDC Technical Bulletin 75. International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, USA.

Van Vuuren DP, Bouwman, AF, Beusen, AHW (2010). Phosphorus demand for the 1970–2100 period: A scenario analysis of resource depletion. Global Environmental Change 20(3):428-439.

Vos G, Schenk SJ, Scheele H (2011). The phosphate balance:

Current developments and future outlook. Report Number 10.2.232E, Utrecht, the Netherlands, February.
Walan P, Davidssona S, Johansson S, Hööka M (2014). Phosphate rock production and depletion: Regional disaggregated modelling and global implications. Resources Conservation and Recycling 93:178-187.
Weikard H (2016). Phosphorus recycling and food security in the long run: A conceptual modelling approach. Food Security 8(2):405-414. https://doi.org/10.1007/s12571-016-0551-4
World Population Forecast (2017). Retrieved 10th February, 2017. Available at www.worldometers.info.
Ulrich AE, Frossard E (2014). On the history of a reoccurring concept: Phosphorus scarcity. Science of the Total Environment 490:694-707.

Vol. 16(9), pp. 1228-1232, September, 2020
DOI: 10.5897/AJAR2020.14804
Article Number: E87A44164717
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Growth performance of royal purple and white guinea fowl varieties and their crosses under an intensive management system

Patrick Kgwatalala*, Freddy Manyeula and Candy Sefemo

Department of Animal Science and Production, Faculty of Animal and Veterinary Sciences, Botswana University of Agriculture and Natural Resources, P/Bag 0027, Sebele, Gaborone, Botswana.

Received 24 February, 2020; Accepted 13 May, 2020

Commercialization of guinea fowl production in many countries is growing and the demand for their meat is high. The study evaluated the growth of crossbred royal purple x white variety relative to purebred royal purple and white varieties. Twenty pure-bred white, 20 purebred royal purple and 20 cross-bred keets were housed together in 4 houses resulting in 4 replications. The keets were fed broiler starter crumbs from day old to 4 weeks of age and thereafter broiler grower pellets for 16 weeks. Body weights of individual keets were measured fortnightly from 4 to 16 weeks of age. There were no significant differences between body weights of males and females of the three varieties at all ages. There were also no significant differences in body weights among females of the three varieties from 4 to 16 weeks of age. Males of the three varieties displayed non-significant differences in body weights from 4 to 10 weeks of age. Royal purple males were significantly heavier than their white counterparts from 12 to 16 weeks of age. There were, however, no significant differences in body weights between crossbred males and royal purple males at all ages. Crossbreeding was thus effective in improving growth performance of the white variety of guinea fowl.

Key words: Growth, cross breeding, royal purple guinea fowls, white guinea fowls.

INTRODUCTION

The guinea fowl are a group of birds that make up both domestic and wild birds, and are known to be native to the African continent (Adjetey et al., 2014). The helmeted guinea fowl (*Numidia meagris*) has been commercially widely used, with common varieties that include the pearl gray, lavender, royal purple and white helmeted guinea fowl. There are a major source of animal protein in resource-poor communities and thus play a critical role in ensuring food and nutrition security (Ebegbulem and Asuquo, 2018). However, there are known for their hardiness, low production costs, greater capacity to utilize green feeds, and are generally resistant to most endemic poultry diseases (Moreki and Seabo, 2012).

Strategies that enhance productivity of guinea fowls include improving their nutrition and cross breeding. Cross breeding combine different characteristics of different breeds (Getu and Birhan, 2014). In poultry, the hybrid fowl have been observed to be more uniform than

*Corresponding author. E-mail: pkgwatal@buan.ac.bw.

Table 1. Nutritional composition of feeds given to guinea fowl in g/kg.

Composition	Chicks starter	Grower pellets
Protein	200	180
Moisture	120	120
Fibre	50	60
Calcium	8	7
Fat	25	25
Phosphorus	6	5.5
Lysine	12	10

most standard breeds, except for colour in some crosses, while the vigor and productivity of the hybrid were superior to original breeds or breeds of origin (Egahi et al., 2013). Mohammed and Abdalsalam (2005) showed that cross breeding also improve body weight gain in poultry species. On other hand, Ebegbulem and Asuquo (2018) found no significant difference in growth performance and carcass characteristics between pure and crossbred guinea fowls. These conflicting reports suggest that further studies are necessary to determine growth performance of different guinea fowl varieties and their crosses.

In Botswana the amount of meat produced by guinea fowls is unknown as the production of birds is unregulated and unstructured (Moreki and Seabo, 2012). Enhancing the productivity of these birds is, therefore, imperative if food and nutrition security in Botswana communities are to be guaranteed. However, there is currently limited information on the growth performance of royal purple and white guinea fowl varieties and their crosses under an intensive management system in Botswana. This study was, therefore, conducted to evaluate growth performance of crossbred royal purple x white guinea fowl relative to the purebred royal purple and white varieties under an intensive management system.

MATERIALS AND METHODS

Description of the study site

This study was conducted from October to December 2017 at the Botswana University of Agriculture and Natural Resources (BUAN) Content Farm, Sebele, Gaborone. BUAN is located at 25.94°S, 24.58°E at altitude of 991 m. During this time, the mean ambient temperature was 35°C.

Experimental animals and feeding

Five royal purple guinea fowl (RPGF) males were housed together with 30 White guinea fowl (WGF) females in one deep litter house to produce fertile eggs. Another five royal purple males were housed together with 30 pure-bred royal purple females and five white males were housed together with 30 pure-bred white females in three separate houses to produce fertile eggs. Hundred and fifty eggs were collected from each of the three guinea fowl houses and incubated in an automatic egg incubator at 37.5°C and 65% relative humidity for 28 days to produce cross-bred and pure-bred keets. Upon hatching pure-bred and cross-bred (CBGF) keets were housed separately in brooding units until 3 weeks of age. At four weeks of age, the guinea fowls were individually identified using leg bands. Twenty pure-bred white, 20 pure-bred royal purple and 20 cross-bred guinea fowls were housed together in a guinea fowl house for a total of 4 houses, resulting in 4 replications. The guinea fowls were fed commercial broiler starter crumbs from day old to 4 weeks of age, and thereafter fed commercial broiler grower pellets until the end of the study. Both commercial feeds (Table 1) were bought from Nutri feeds PTY, Ltd, Pilane, Botswana.

Measurement of parameters

The guinea fowl were weighed individually at the beginning of the experiment and thereafter on a fortnightly basis from 4 to 16 weeks, using an Adam 6010 model electronic balance (Adam, Gaborone, Botswana).

Statistical analysis

Growth data were analyzed using General Linear Model procedures of statistical analysis system SAS (2009). The model included fixed effect of variety (royal purple, white and crossbred royal purple x white) and sex (male and female) and the interaction between variety and sex. Results on the effects of variety, sex and the interaction between variety and sex are presented as least squares means±SE. Means separation were by paired t-test with Scheffe's adjustment to account for differences in guinea numbers within sex and differences between means were separated at α-level of 0.05.

RESULTS AND DISCUSSION

There were no significant differences between body weights of males and females of the three varieties at all ages (Table 2). There was, however, an increase in body weight among all the varieties from 4 weeks of age up to 16 weeks of age.

Generally, pure-bred royal purple and cross-bred males were non-significantly heavier than their female counterparts from 8 to 16 weeks of age, while the opposite was true in the white guinea fowl variety. Consistent with the current findings, Nahashon et al. (2006) reported no significant differences in body weights

Table 2. Body weights of males and females of different varieties at different ages in weeks (mean ± SE).

Age	Crossbred		Royal purple		White	
	Female	Male	Female	Male	Female	Male
4	215.67±7.93	195.77±25.69	203.88±10.49	202.43±13.73	217.08±14.83	224.63±18.17
6	426.48±11.55	418.85±37.41	378.83±15.27	406.57±20.00	377.33±21.60	344.68±21.60
8	663.71±15.67	666.00±50.77	614.67±20.72	628.86±27.14	618.67±29.31	559.58±29.31
10	847.29±17.57	878.00±56.92	870.50±23.24	896.86±30.43	822.50±32.86	788.00±32.86
12	1041.41±19.97	1016.00±64.70	1114.50±26.41	1114.29±34.58	1034.67±37.35	925.00±37.35
14	1203.00±20.94	1218.00±67.86	1276.36±28.93	1313.14±36.27	1169.67±39.18	1083.67±39.18
16	1325.57±27.62	1365.00±89.50	1390.36±38.16	1446.86±47.84	1446.86±51.67	1085.67±51.67

Table 3. Main effect of variety (combined sex) at different ages in weeks (mean ± SE).

Age	Varieties		
	Crossbred	Royal purple	White
4	205.70±13.44	203.15±8.64	220.85±11.73
6	422.67±19.57	392.70±12.58	361.00±15.27
8	664.86±26.57	621.76±17.07	589.13±20.73
10	862.64±29.78^{ab}	883.68±19.14^{a}	805.25±23.24^{b}
12	1082.71±35.50^{ab}	1129.39±21.75^{a}	979.83±26.41^{b}
14	1294.75±23.20^{ab}	1345.29±46.83^{a}	1126.67±27.70 ^{b}
16	1345.29±46.83^{a}	1418.61±30.60^{a}	1176.00±36.54^{b}

at different ages between males and females of the pearl grey guinea fowl, but observed that males were non-significantly heavier than their age-matched female counterparts. Contrary to the current findings, Kokoszynski et al. (2017) reported a significant difference in body weight between males and females in the pearl grey variety. Lack of sex differences in body weight among three varieties of guinea fowl implies that there should be no preference for a particular sex in the production of meat type guinea fowls in Botswana.

Main effect of strain (combined average body weight of both males and females) on body weight in purebred royal purple and white varieties and crossbred royal purple x white varieties at different ages are presented in Table 3. There were no significant body weight differences (P>0.05) among the three guinea fowl varieties from 4 to 8 weeks of age. There were also no significant weight differences between purebred royal purple and cross-bred royal purple x white guinea fowl from 10 to 16 weeks of age. Royal purple guinea fowl were, however, significantly heavier than their age-matched white counterparts from 10 to 16 weeks of age. Cross-bred guinea fowls were significantly heavier than their white counterparts only at 16 weeks of age. Crossbred guinea fowl were, however, heavier than their white counterparts at all ages from 4 to 16 weeks of age. The royal purple guinea fowls were also heavier than their aged-matched crossbred counterparts from 10 to 16 weeks of age. Crossbreeding was thus effective in improving the growth performance of the white guinea fowl variety but crossbred guinea fowls were out-performed by the royal purple variety. This suggests that the royal purple variety should be promoted as the meat type guinea fowl variety in Botswana.

Consistent with the current findings, Oke et al. (2012) reported an improvement in growth performance in crossbred pearl grey and lavender reciprocal crosses relative to the constituent purebred counterparts. Salo-Ojo et al. (2012) also reported significantly higher body weight in a cross between the Dominant Black strain (DB) and the Fulani Ecotype chicken (FE) and their progeny from the reciprocal crosses, (DB X FE and FE X DB) compared to the purebred constituent breeds at 3, 5 and 7 weeks of age. Better growth performance in crossbred guinea relative to the white variety could be attributed to the combining effect of genes (heterosis) brought into the cross by different pure breeds. Farmers rearing the white guinea fowl variety can therefore, be encouraged to cross-breed with the royal purple variety to enhance growth performance of the white variety.

Body weights of different varieties of guinea fowl within sex at different ages are presented in Table 4. There were no significant differences in body weights among females of the three varieties of guinea fowl at all ages from 4 to 16 weeks of age. There was an increase in body weight among females of the three varieties from 4

Table 4. Comparison of body weights of different varieties within sex at different ages in weeks (mean ± SE).

Ages	Female			Male		
	Crossbred	Royal Purple	White	Crossbred	Royal Purple	White
4	215.67±7.93	203.88±10.49	217.08±14.83	195.77±25.69	202.43±13.73	224.63±18.17
6	426.48±11.55	378.83±15.27	377.33±21.59	418.85±37.41	406.57±20.00	344.67±21.59
8	663.71±15.67	614.67±20.72	618.67±29.31	666.00±50.78	628.86±27.14	559.5±29.31
10	847.29±17.57	870.50±23.23	822.50±32.86	878.00±56.92	896.86±30.43	788.00±32.86
12	1041.43±19.97	1114.50±26.4	1034.67±37.35	1016.00±64.70^{ab}	1144.29±34.58^{a}	925.00±37.35^{b}
14	1203.00±20.94	1276.36±28.93	1169.67±39.18	1218.00±67.86^{ab}	1313.14±36.27^{a}	1083.63±39.18^{b}
16	1325.57±27.62	1390.36±3816	1266.33±51.67	1365.00±89.50^{ab}	1446.86±47.84^{a}	1085.67±51.67^{b}

weeks to 16 weeks of age with royal purple females displaying the highest body weights followed by crossbred females, and lastly white females from 10 to 16 weeks of age. Non-significant differences in body weights among females at various ages among the three varieties is consistent with Boitumelo (2018) who also reported similar body weights among females of lavender, pearl grey, royal purple and white varieties from 4 to 18 weeks of age. In chickens, a significant difference in body weight was reported between Australorp x Tswana crossbred females and purebred Tswana females at 16 weeks of age (Kgwatalala and Segokgo, 2013).

Males of the three varieties displayed non-significant differences in body weight from 4 to 10 weeks of age. Royal purple variety were significantly heavier than their age-matched white counterparts from 12 to 16 weeks of age. There were, however, no significant differences in body weight between crossbred and royal purple males at similar ages. Hagan and Adjel (2012) reported a significant difference in body weight between crossbred male cockerels (Naked neck × frizzled) and purebred naked neck, frizzled and normal males at 14 weeks of age with body weights of 1605, 1411, 1410 and 1305 g, respectively. A significant difference in body weight was also reported between crossbred Australorp × Tswana males and purebred Tswana males from 10 to 16 weeks of age (Kgwatalala and Segokgo, 2013). Cross breeding was therefore, beneficiary in enhancing growth performance of males and had no beneficial effect on female guinea fowl. The beneficial effect of cross-breeding on body weight of males suggests that males should be preferred over females for meat production.

Conclusions

Cross-breeding was evaluated as an alternative method of improving growth performance of different varieties of guinea fowls. Cross-breeding was effective in improving growth performance of the white variety but had no beneficial effect on the growth performance of royal purple variety. The royal purple variety proved to be the best variety in terms of growth performance and is therefore the most recommended variety for meat production in guinea fowls.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adjetey ANA, Atuahene CC, Adjei MB (2014). Protein requirements for laying indigenous guinea fowls (*Numida meleagris*) in the humid tropical zone of Ghana. Journal of Animal Science Advances 4(7):910-920.

Boitumelo K (2018). Growth performance and carcass characteristics of different varieties of domesticated helmeted guinea fowl (N*umida meleagris*) raised under intensive management system. M.Sc. Thesis. University of Botswana, Gaborone.

Ebegbulem VN, Asuquo BO (2018). Growth performance and carcass characteristics of the black and pearl guinea fowl (*Numida meleagris*) and their crosses. Global Journal of Pure and Applied Sciences 24(1):11-16.

Egahi JO, Dim NI, Momoh OM (2013). Crossbreeding and reciprocal effect on egg weight, hatch weight and growth pattern and the interrelationships between these traits in three genetic groups of native chickens of Nigeria. Asian Journal of Biological Sciences 6(3):187-191.

Getu A, Birhan M (2014). Effect of gene segregations on existed performance of chicken ecotypes in Ethiopia. Middle-East Journal of Scientific Research 21(4):675-680.

Hagan JK, Adjei AI (2012). Evaluation of the growth and carcass yield characteristics of crossbred naked-neck and frizzle cockerel phenotypes reared under hot and humid environments. ARPN: Journal of Agricultural and Biological Science 7(7):576-582.

Kgwatalala PM, Segokgo P (2013). Growth performance of Australop x Tswana Cross bred under intensive management system. International Journal of Poultry Science 12(6):358-361.

Kokoszynski D, Bernacki Z, Saleh M, Steczny K, Binkowska M (2017). Body conformation and internal organs characteristics of different commercial broiler lines. Brazilian Journal of Poultry Science 19(1):47-52.

Mohammed DK, Abdalsalam IY (2005). Growth performance of indigenous X exotic crosses of chicken and evaluation of general and specific combining ability under Sudan conditions. International Journal of Poultry Science 4(7):468-471.

Moreki JC, Seabo D (2012). Guinea Fowl production in Botswana. Journal of World's Poultry Research 2(1):1-4.

Nahashon SN, Aggrey SE, Adefope NA, Amenyenu A, Wright D (2006). Growth characteristics of pearl gray guinea fowl as predicted by the Richards, Gompertz, and logistic models. Poultry Science 85(2):359-363.

Oke UK, Onyiro OM, Ukweni IA, Ukpong SP (2012). Crossbreeding effect on growth traits at 8 weeks of age in pearl and lavender guinea fowl and their reciprocal crosses in a humid tropical environment. Journal of Animal Science Advances 2(2):236-243.

Salo-Ojo FE, Ayorinde KL, Toye AA (2012). Comparative study of growth of performance and feed efficiency in dominant black strain, Fulani ecotype and progeny from their reciprocal crosses. Asian Journal of Agriculture and Rural Development 2(2):120-125.

Vol. 16(9), pp. 1233-1238, September, 2020
DOI: 10.5897/AJAR2018.13847
Article Number: 8906DF664721
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Pastoral farming system and its temporal shift: A case of Borana zone, Oromia National Regional State, Ethiopia

Dirriba Mengistu*, Simbone Tefera and Bely Biru

Yabello Pastoral and Dryland Agricultural Research Center, Oromia Agricultural Research Institute , P. O. Box, 085, Yabello, Ethiopia.

Received 30 December, 2018; Accepted 3 May, 2019

The study was conducted in Borana zone, which is located at about 570 km from Addis Ababa with the objective of understanding the farming system of Borana pastoral area. The primary data was collected using survey questionnaires from 160 households selected using multistage sampling design. The study confirmed that the farming system in Borana pastoral area has been increasingly diluted, unlike the earlier decades where livestock were used to stand as the backbone of their economy. The inference from the sample household indicated larger portion of their livelihood is crop-livestock integration dependent, unlike the conventional account. Even though the livelihood diversification is possible to reduce the risk agriculture, in the study area the diversification into crop farming could intensify further devastation of nature by diverting attention to other livelihood option resource if care is not in place. Practically, owned to decline in livestock productivity, it enforced the pastoralists to enhance the trade-off between crops-livestock production or its integration. The survey result also displayed that about 85% of the respondent has been producing at least one crop besides the livestock production. This induces a critical question on the existents of the pastoralists if sustainable livelihood of the pastoralism is not in concern. However, owned to the critical importance of the pastoral system, interventions to enhance the pastoral livelihood need urgent measures. Furthermore, this study recommends for further deep analysis on optimization of the livelihood diversification in pastoral area for enhancing sustainable livelihood.

Key words: Borana, crop pastoral, diversification, farming system, livestock.

INTRODUCTION

Livestock has been the main backbone of the pastoral economy from a long history. However, climate variability is the greatest recurrent threat to the livestock production (Angassa and Oba, 2007). It has been naturally reducing the livestock asset accumulation of the pastoralists recurrently with an intensified frequency of the event. As a result, Borana pastoralists are much poorer today than they were in decades, as livestock a person has declined from 4.1 to 2.3 TLU and more recently found 1.9 TLU (Bati, 2014). The decline in livestock per person over

*Corresponding author. E-mail: dmangistu@gmail.com.

the years is, however, suggests the decline in the pastoral economy.

Later, various livelihood alternatives have been emerged to overcome the risk of climate variability (Coppock, 1994). Acceptance of integrity and complementarily between crop and livestock becomes adapted unlike earlier decades (Tilahun et al., 2017). The anecdotal evidence shows that crop farming was started during the Goba Bule Gada, 1969-1977 (Napier and Desta, 2011). However, crop failure is subsequently higher because of rain shortages and climate variability. It implies that the original livelihood system, pastoralism, was mixed with other alternate production system though the capability of the environment needs further analysis.

Particularly, most of the pastoralists strained to diversify into agricultural production (Angassa and Oba, 2007). They have been practicing small-scale crop farming to meet the unmet demand of food, even though it is gambling with climate variability. Crop production is characterized by frequent failure because of erratic rainfall beyond its unreliability. Increased cultivation, however, was attributable to declining of livestock of a person as worsened by human population growth (Tache, 2008). Unfortunately, lessening smaller herds from the poor pastoralists impels the permanent shift into farming.

However, the livelihood diversification into different alternatives remains to the conventional practices of the pastoralists. These efforts of the community are owned by the self-defense against chronic food insecurity regardless of its environmental outcome. Under current trends, the chronological shift from pastoralism to agro-pastoralism and then to the dryland farming and ranching is not too far, though the traditional livelihood is deeply rooted. However, it is very critical to understand the trade-off and trends of alternative livelihood systems in pastoral area. Thus, this study was undertaken to understand the shift of farming system in Borana pastoral area.

METHODOLOGY

Borana zone is located at 570 km from Addis Ababa to the Southern tip of Ethiopia. It is classified as 10% highland, 20% temperate and 70% lowland with the average temperature ranges between 18 and 280°C and altitude lying between 500 and 2500 masl (Ibrahim, 2005).

In this study, the primary data collected from sample households using a questionnaire after survey questionnaires were pretested before starting the data collection. To capture a better socioeconomic context of the concern, qualitative data collection, such as focus group discussion (FGD) and key informant interview were conducted. Secondary data were collected from the respective office of zone and districts to enrich the data collected from the respondents. Descriptive statistics such as mean, percentage, frequency and were used to analyze the socioeconomic characteristics of the sample households.

Chronologically, we have employed multistage sampling methods. On the first stage, Borana zone was stratified into three homogenous groups based on its livelihood, namely pastoral, agro-pastoral and agriculture where 1-2 sample districts were randomly selected from each strata. On the second stage, these selected districts were stratified into pastoral, agro-pastoral and agriculture where two kebeles were randomly selected from each strata. Finally, sample households were randomly selected from each selected Kebele. So, Yabello, Teltelle, Miyo and Dhas districts were selected, whereas two kebeles have been selected from the selected words. Finally, 123 households were randomly drawn-out at 95% confidence interval with 0.5 degrees of variability at 9% precision level (Yamane, 1967), plus 17 reserved with 140 households in total. The collected data was analyzed using SPSS software produced tabulated data and descriptive statistics.

RESULTS AND DISCUSSION

Socioeconomic characteristics

The proportion of male and female in the household is on average framed a one-to-one (1:1) ratio with the mean of six family size on average. The average male and female frame is proportional with a minimum of three for both and a maximum of 11 and 8 for male and female, respectively. The age of sample households was a mean of 42 years with a maximum of 96. Most of the sample households were male-headed households, which form about 83% of the sample households, and only 17% of the sample households were female-headed (Table 1).

From all sample households, only about 28% can enable read and write in which some of the sample households have access through youth education provided by the government during the night and weekend (Table 1). From the sample households with the capacity to read and write, the respondents were attending a maximum of grade eight and about 1% of the sample households accessed the capacity to read and write through the informal education, zero education. From the chi-square output, there is a significant difference between the literate and illiterate on which the livelihood they are inclined to. Though there is no significant difference among the followers of religion on the choices of the livelihood, male-headed households, and illiterate households are more likely to diversify their livelihood alternative. The mark is that female household is hardly reluctant to shift their livelihood because of physical inability and emotional confidence (risk-taking). On the other hand, though education is an important tool for choosing a better livelihood alternative, the literacy services given to the elderly level are less likely focused on livelihood development.

Indigenous religion followers called "*Waaqeffataa*" followed by Evangelical and Muslim dominate in the area. The Muslim and Evangelical religions are the recently expanded religion, unlike the original "*Waaqeffataa*" religion in the zone. These two religions are expanding at the expense of their indigenous religion, "*Waaqeffataa*".

The essence of pastoral farming system

A farming system is a population of individual farm

Table 1. Sex composition, Education status and Religion of sample households.

Description		Farming		Pastoral		Agro-pastoralism		Total		Chi-square
		N	%	N	%	N	%	N	%	
Sex	Male	8	100	19	73.08	70	97.22	99	90	24.45***
	Female	0	0	7	26.92	2	2.78	11	10	
Education status	Literate	4	50	2	8.7	19	28.79	26	25	12.23*
	Illiterate	3	37.5	21	91.30	46	69.70	3	75	
	Youth	1	12	0	0	1	1.52	2	1.8	
Religion	Muslim	3	37.5	1	3.85	8	11.94	12	11.43	10.51
	Protestant	2	25	2	7.69	9	13.64	14	13.33	
	"Waaqeffannaa"	***3***	37.5	23	88.46	50	74.63	79	75.24	

Pearson χ^2 is significant at ***1%, **5% and *10% significance level, respectively. *Waaqeffataa* is the followers of Oromo indigenous religion, Waqefannaa associated with the Gada system and followers of One God as the Oromo word [wa:k'a] (God).
Source: Own Survey.

systems that have broadly similar resource basis, enterprise patterns, household livelihoods, and constraints, and for which similar development tactics and interventions would be suitable, whereas the household, its resources, and the resource flows and interactions at this individual farm level (Dixon et al., 2001). In the study area, though there are various classifications of the farming system, lack of discrete boundary of classification makes it difficult to acquire data for further discrete analysis. For purposes of this study, the conventional livelihood practices-based-agro-ecology was adapted to characterize the pastoral farming system in Borana zone. Accordingly, the Borana zone could be classified as pastoralists, agro-pastoralists, and dryland farming system based on the traditional livelihood basis. Though it is difficult to assign an isolated definition of household within each farming system, scholars have assigned the subjective definition of each farming system. According to Rass (2006), "Pastoralists are livestock keepers living in the area which receives less than 400 mm of rainfall a year with a growing period 0-75 days, where cropping is not practiced and driving more than 50% of agriculture from livestock rearing through opportunistic tracking on communal land. Similarly, agro-pastoral are livestock keeper earns more than 25% but less than 50% of agricultural income (that is it includes the value of own production consumed within the households) from livestock keeping on communal land in an area with an annual rainfall between 400 and 600 mm and growing periods of 75 to 90 days" (Rass, 2006).

Though there are different definitions, the critical difference is that while the income source of the pastoralists is dominated by income from livestock, the income of the agro-pastoralists is dominated by income from the crop. However, the livestock production of both pastoralists and agro-pastoralists follows similar fashions.

Shift in pastoral livelihood system

In the past 20 years, the shift from pastoralism to agro-pastoralism livelihood system is raised (Wassie and Fekadu, 2015). Before 20 years, the number of households practicing crop production is minor compared with 10 years after. Even before 10 years, the involvements of crop production have been low. However, because of various reasons, principally droughts, expansion of crop farming becomes a superfluous livelihood alternative. The low productivity of livestock (for example Milk) enforces the households to look for other income sources (Hurst et al., 2012).

The Chi-square outcome also showed the shift from pastoral to agro-pastoral livelihood is significant at 95% CI. Livestock only based production decreasing over 20 years because of the involvement in farming become increasing (Figure 1). Though crop production has started before 20 years, most recently the trade-off between crop production and livestock production is now raised (Wassie and Fekadu, 2015).

The result hints that the shift of pastoral livelihood from the orthodox to the other extraneous livelihood alternative at the expense of the original livelihood becomes non-stoppable. Another study also confirmed that the shift from pure pastoralism to subsistence agriculture is the major concern in the Borana pastoral area (Boku and Sjaastad, 2008). This shift was dominantly because of recurrent natural and human-made calamities that limit the conventional pastoralism (Wassie and Fekadu, 2015). Drought, erratic rainfall, land degradation, and bush encroachments domineer the top challenges in the pastoral area coupled with expansion of farming land; deforestation, livestock population; unstructured settlement and farmland expansion add the limiting impact on a livestock production (Negasa et al., 2014).

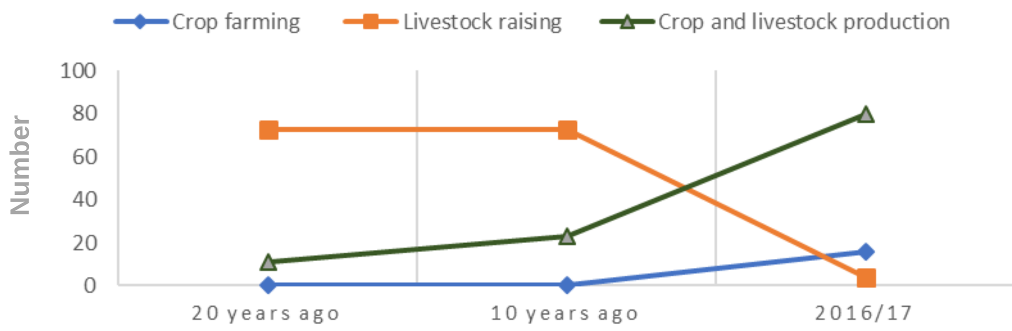


Figure 1. Livelihood trade-off.

This proves that the expansion of dryland farming at the cost of the rangeland hint the declining of livestock dominated production.

Raising

On the other hand, Borana pastoralists are the original sources of Boran cattle, which laid an important foundation for improved livestock breed in the world. The trade-off from livestock to crop production bears an offensive load on the livelihood of the society.

However, analytical gaps in the future of the natural potential are an inquisitive point that needs further effort beyond this study. Nonetheless, the production of different crops was given due attention regardless of their awareness and access to seed and seedling. Irrespective of the area of production, seed sources, seed availability and producers' experience, pastoralists have been practicing at least staple crops such as maize and haricot bean. Nowadays, demands for crop production had already been fueled to fill unmated demand for food, even in the area suggested purely for pastoral households. The past study also confirmed that crop cultivation is firmly expanding in the rangelands and tenure is moving towards the de facto individualization (Boku and Sjaastad, 2008)

Though crop production is a relative infant in pastoral concerns, nowadays the urge for crop production knocks the conscience of every household regardless of the production skill and knowledge (Liao, 2014). From the survey result, about 85, 65 and 30% of the respondents confirm that they were producing maize, haricot bean and Teff, respectively (Table 2). Similarly, these pastoralists earmarked about 85% of their cultivated land for maize production followed by haricot bean and Teff. Another study also shows that maize production leads the crop production in the study area followed by Teff (Tilahun et al., 2017).

However, producers are hardly consuming Teff beyond production. It is considered as commercial, though its productivity is low. Nevertheless, producers' postharvest management challenges their income because of their low crop storage habit, Teff. Most commonly, the producers are tracked into the market immediately after harvest though high supply impels a low price. On the other hand, cattle dominate the inhabitants of livestock in Borana zone besides social heritage. The household survey also confirms that cattle are the top populous livestock followed by goat, sheep, and camel in rank where female livestock dominated the part of livestock sizes.

On average, households owned about 11 animals (TLU) where cattle cover 90% of the part. Though the livestock holding was small, still livestock production outweighs the livelihood of the pastoralists. Even though average camel holding seems high (only less than 10% of the respondents), more than 80% of respondents own cattle and small ruminant (Table 3). Figuratively, the inhabitants of the small ruminants outweigh the inhabitants of livestock, though the population of the cattle outweigh in TLU.

CONCLUSION AND RECOMMENDATION

Climate variability is the greatest recurrent threat to the livestock production that has been naturally destocking the livestock asset at a cost of sustainable livelihood. Drought, erratic rainfall, land degradation, bush encroachments, livestock population, unstructured settlement, and farmland expansion have a limiting effect on a livestock production. However, the declining livestock per individual reflects eroding of the pastoral economy. This favors for the emergence of various livelihood choices to overcome the problems arising from impact of the climate change. Particularly, crop cultivation as a means of partial compensation for long-term trends of livestock restocking shares the lion option in the study area. However, the analytical gaps in the future of the natural potential are an important point that needs further effort beyond this study. Besides crop production, the population of small ruminants outweighs the population of livestock, though pastoralists value their cattle more in

Table 2. Crop produced in the study area.

Crop type	N	The land earmarked		
		Min	Max	Mean ± SE
Maize	101	0.10	5.00	0.96±0.07
Haricot bean	82	0.10	7.00	0.93±0.12
Teff	50	0.10	5.00	0.98±0.13
Chat	16	0.10	0.50	0.34±0.03
Rain fed farmland	50	0.50	3.00	1.6±0.08
Average farmland	94	0.00	5.00	1.79±0.1

Table 3. Average livestock holding (TLU).

Livestock type	N	Min	Max	Mean ± SE
Cattle	97	0.34	60	9.88±0.91
Donkey	39	0.70	14	1.47±0.35
Small ruminant	98	0.6	6.59	1.43±0.12
Horse	2	1.1	11	6.05±4.95
Camel	11	1.25	17.5	5.91±1.52
Poultry	55	0.1	0.15	0.06±0.01
Total	120	0	64.6	11±1.0

history.

Still, the same drought is recurrently fighting the civil society, which has no suitable defensive tools to fight against it except the defeated traditional coping tactics. On the contrary, the human population and the environmental risk are still growing beyond the capacity of local adaptation strategies of livelihood diversification. As a result, the situation gradually multiplies the poor and poverty against the strategies of the country to lessen poverty in Ethiopia.

On the other hand, diversification hardly considers the problem of natural resources because of its planning. Similarly, though farm diversification is an important strategy; this study extends further investigation on enterprise optimization to improve the income of producers aligned with the applicable land use and land classification.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Angassa A, Oba G (2007). Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. Journal of Agricultural Systems 94:715-175.

Bati BM (2014). Climate change, cattle herd vulnerability and food insecurity: adaptation through livestock diversification in the Borana pastoral system of Ethiopia. https://core.ac.uk/download/pdf/56707690.pdf

Boku T, Sjaastad E (2008). Pastoral conceptions of poverty: An analysis of traditionaland and conventional indicators from Borana, Ethiopia. World Development 38(8):1168-1178

Coppock D (1994). The Borana plateau of southern Ethiopia: synthesis of pastoral research, development and change, 1980-91 International Livestock Center for Africa, Addis Ababa.

Dixon J, Gulliver A, Gibbon D (2001). Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. FAO, Rome. http://www.fao.org/3/a-ac349e.pdf

Hurst M, Jensen N, Sharma J, Pendersen A (2012). Changing climate adaptation strategies of Borana pastoralists in southern Ethiopia. CGIAR Research Program on Climate Change, Agriculture and Food Security CCAFS. P 15.

Ibrahim AE (2005). HIV/AIDS, gender and reproductive health promotion: the roles of traditional institutions among the Borana Oromo, southern Ethiopia: contemporary issues in Borana, and the 38th Gumii Gaayoo Assembly, Finfinne [Addis Ababa] 226 p. https://searchworks.stanford.edu/view/6750623

Liao C (2014). Case Study: Borana, Ethiopia, s.l.: ACSF-Oxfam Rural Resilience Project, Natural Resources, Cornell University. www.acsf.cornell.edu

Napier A, Desta S (2011). Review of Pastoral Rangeland Enclosures in Ethiopia. Tufts Range Enclosure Review PLI report. s.l.: PLI Policy Project. Available on: https://fic.tufts.edu/assets/

Negasa B, Bedasa E, Samuel T, Barecha B, Jaldesa D, Nizam H (2014). Control of bush encroachment in Borana zone of southern Ethiopia: effects of different control techniques on rangeland vegetation and tick populations. Pastoralism: Research, Policy and Practice 4:18.

Rass N (2006). Pro-poor livestock policy initiative policies and strategies to address the vulnerability of pastoralists in Sub-Saharan Africa. PPLPI Working Paper 37, Food and Agriculture Organization of the United Nations, Rome.

Tache B (2008). Pastoralism under Stress: Resources, Institutions and Poverty among the Borana Oromo in Southern Ethiopia. http://agris.fao.org/

Tilahun A, Teklu B, Hoang D (2017). Challenges and contributions of crop production in agro-pastoral systems of Borana Plateau, Ethiopia. Pastoralism: Research Policy and Practice 7:2.

Yamane T (1967). Statistics: An Introductory Analysis. 2nd Edition, Harper and Row, New York.

Wassie B, Fekadu B (2015). Climate Variability and Household Adaptation Strategies in Southern Ethiopia. Sustainability P 7.

Vol. 16(9), pp. 1239-1244, September, 2020
DOI: 10.5897/AJAR2020.14953
Article Number: 99E434D64777
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Evaluation of blended fertilizer on growth performance and yield of onion (*Allium cepa* L.) at irrigated conditions Tselemti District North Western Tigray, Ethiopia

Solomon Mebrahtom*, Kinfe Tekulu, Tewolde Berhe, Tsadik Tadele, Weldegebreal Gebrehiwot, Gebresemaeti Kahsu, Samrawit Mebrahtu and Goitom Aregawi

Tigray Agricultural Research Institute, Shire Soil Research Centre, P. O. Box 40, Shire, Ethiopia.

Received 4 May, 2020; Accepted 7 July, 2020

Onion has economically important crop in the study area. However, its low production is due to poor soil fertility management. Thus, the present study was initiated to determine the optimal rate of blended fertilizer required for onion production. A field experiment was conducted for two consecutive years during 2018 and 2019 at farmer's field Tselemti district, the experiment had 8 treatments arranged in a randomized complete block design with three replications. The treatments were 7 levels of NPSB (25, 50, 100, 150, 200, 250 and 300 kg ha^{-1}), recommended rate of N and P (105 N and 92 P_2O_5 kg ha^{-1}), and a basal application of top dress N at rate of 69 kg ha^{-1} were applied for except the plot received recommended NP. The study results showed the application of blended fertilizer not significantly affected most of the crop parameters tested. However, they had a numerical difference among the treatments; since the highest (41157 kg ha^{-1}) and lowest (32650 kg ha^{-1}) marketable yields were obtained from a plot treated by 250 kg ha^{-1} plus a basal application of top dress N at rate of 69 kg ha^{-1} and from plots that received 50 kg ha^{-1} plus a basal application of top dress N at rate of 69 kg ha^{-1}, respectively. Therefore, experiment for onion production should carry out on omitting trial of blended fertilizer in the study area.

Key words: Blended fertilizer, onion, omitting trail, recommended NP.

INTRODUCTION

Onion (*Allium cepa L.*) belongs to the family Alliaceae and the genus *Allium* (Hanelt, 1990). It is one of the mostly vital vegetable crops commercially grown in the world (Grubben and Denton, 2004). Onion has economically important role in Ethiopia. The country has massive potential to produce the crop throughout the year both for domestic use and export market. Its production also contributes to commercialization of the

*Corresponding author. E-mail: solomon.mebrahtom08@gmail.com. Tel: +251344440604.

rural economy and creates many job opportunity (Nikus and Mulugeta, 2010; Guesh, 2015).

Agriculture is the main driving force of Ethiopia's economy and long-term food security. It contributes 43% to the gross domestic product (GDP); employs nearly 85% of the total labor force and contributes about 90% of the national export earnings. The agricultural sector is dominated by small-scale farmers, accounting for 95% of the total area under crop cultivation and more than 93% of the total agricultural output (CSA, 2010).

Crops are the major agricultural commodities on which Ethiopians depend for their daily food. Onion is a major vegetable crop in Ethiopia. It is well adapted to highland and low land soils of the country. Its production in Ethiopia is 9.3 ton/ha and in Tigray region is also 6.3 ton ha^{-1} which is low when compared with the national average. This might be due to low fertility of the soil (CSA, 2018/2019).

Fertilizer usage is one of the instruments implemented as a means of raising production and income of farm and households. However, the extent to which fertilizers are used still differs considerably between various regions of the world. In Ethiopia, diammonium phosphate (DAP) and urea were the commonly used chemical fertilizers for crop production with having a common consideration of nitrogen and phosphorus were the major limiting nutrients for Ethiopian soils. Past researchers carryout many activities under agro-ecologies towards improvement of agricultural productivity using urea and DAP in Ethiopia. Plant growth and crop production require an adequate supply and balanced amounts of all nutrients, but the old practice that only uses urea and DAP lacks the use of micronutrients. Since deficiency of micronutrients is reported in tropical soils, necessitate the application of nutrient sources that reduce such deficiencies. This can only be achieved if the nutrient content of the fertilizer fits to the needs of the crops.

Onion requires intensive supply of plant available macronutrient, namely: nitrogen (N), phosphorus (P) and potassium (K) to attain maximum yield of bulbs because the plants have a shallow, sparsely branched root system and NPK fertilizer at rate 100:33:62 significantly influenced onion yield (Khokhar et al., 2004; Khalid, 2019).

As Khalid (2019) reveled application of micronutrient have a significant improvement on onion yield at a rate of zinc sulfate ($ZnSO_4$ at 0.5%), iron sulfate ($FeSO_4$ at 1.0%), and boron (B at 0.5%).

Blended fertilizers containing both macro and microelements may possess this characteristic. Even if the blended fertilizer formulas of each kebele have been developed, the rate of the blended fertilizer is still not determined. Therefore, Shire Soil Research Center proposes to determine the rate of balanced fertilizers containing nitrogen (N), phosphorus (P), sulfur (S), zinc (Zn), and boron (B) in blend form which recommended to ameliorate site specific nutrient deficiencies.

Objectives

(1) To determine site specific blended fertilizer rates for onion production;
(2) To validate soil fertility map based blended fertilizer in the study site.

MATERIALS AND METHODS

Area description

The field experiment was conducted for two consecutive years during 2017 and 2018 under irrigated conditions at Tselemti district in Medihnalem kebele, North Western zone of Tigray regional state (Figure 1). The geographical location of the study area is: 13°37'4" N and 38° 12' 40' E of latitudes and longitudes, respectively. The study area is located at an altitudinal range of 1310 m as l, in a semi-arid climatic zone and has mixed crop-livestock farming system (OoARD, 2020).

Topographically, the area has 70% sloppy areas and30% flat areas indicating which is characterized by rugged, plains, river valleys and plateau topography in its southern and western parts (OoARD, 2020).

According to the agro-climatic classifications of Ethiopia, Tselemti district fall in dry to moist *Kolla*, dry to wet *Weyna Dega* and moist to wet *Dega* (Hurni, 1998). The particular site is characterized as dry-moist *Kolla* (Darcha et al., 2015; Redda and Abay, 2015).

Experimental design, treatments and biological material

The field experiments contained a total of eight (8) treatments. The treatments were seven (7) levels of NPSB blended fertilizer (25, 50, 100, 150, 200, 250, 300 kg ha^{-1}) plus a basal application 69 kg ha^{-1} top dress, one (1) rate of recommended NP (105 kg ha^{-1} N, 92 kg ha^{-1} P). Hint, a 100 kg of NPSB is an equivalent to 18 kg of N, 36 kg of P_2O_5, 7 kg of S, and 0.54 kg of B. The treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The plot size was 3 m×3.2 m (9.6 m^2). The spacing between plant rows, plots and replications was 0.4, 0.5 and 1 m, respectively. "Bobay red" variety of onion was used for this trial. All recommended cultural practices (plowing, weeding, pesticides, etc.) for onion was done as per the recommendation of the study area. The experimental trial was conducted for two consecutive irrigation season at two farmers' field.

Soil sample collection and analysis

Before planting surface composite soil sample was collected from experimental site for site characterization and the soil sample was taken at a depth of 0 to 20 cm, auger was used for collecting the disturbed sample. The collected sample was properly labeled, packed and transported to the Shire Soil Research Center and prepared for analysis according to the standard procedures.

Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH and electrical conductivity (EC) (1:25 soil to water suspension) of the soil were measured using a pH meter (Rhoades, 1982) and the method described by Jackson (1967), respectively. Thus, ECe was mathematically determined using conversion factor on soil texture (Hazelton and Murphy, 2007).

Organic carbon (OC) (%) was determined following the wet

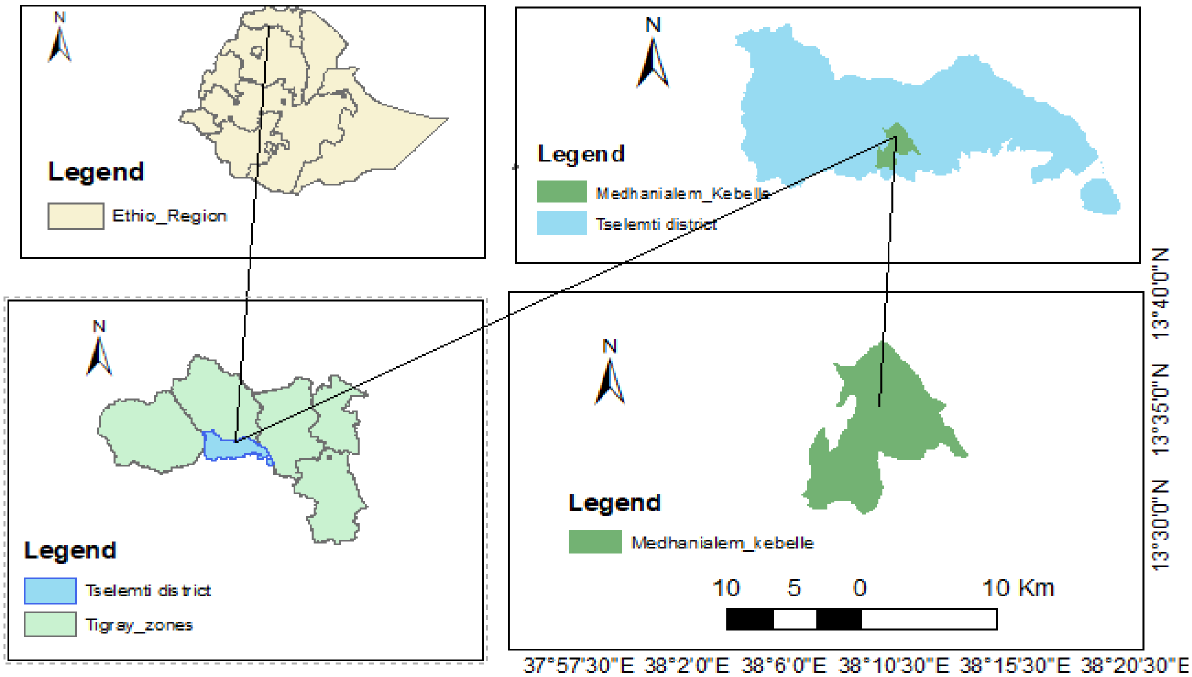


Figure 1. Location of the study area.

Table 1. Pre-sowing physicochemical properties of soil.

Parameter	Values	Ratings	Reference
% Sand	21	-	-
% Silt	19	-	-
% Clay	60	-	-
Textural class	Clay	-	-
OC (%)	0.866	Low	Tekalign (1991)
Total N (%)	0.075	Very low	Tekalign (1991)
pH	6.07	Slightly acidic	Jones (2003)
ECe (dS/m)	1.69	Non saline	Richards (1954)
Ava. P (ppm)	0.16	Very low	Cottenie (1980)
CEC [cmol(+)/kg]	41.4	Very high	Landon (1991)
Exchangeable bases			
Na[cmol(+)/kg]	0.6	Medium	FAO (2006)
K [cmol(+)/kg]	0.23	Low	FAO (2006)
Mg [cmol(+)/kg]	5.2	High	FAO (2006)
Ca [cmol(+)/kg]	18.3	High	FAO (2006)

oxidation method as described by Walkley and Black (1934). Total nitrogen was determined using Kjeldahl method as described by Bremner and Mulvaney (1982). Available P was determined by employing Olsen et al. (1954) method.

Determination of cation exchange capacity CEC at pH 7 was carried out with Ammonium Acetate method as described by Chapman (1965). The amount of exchangeable cations potassium (K) and sodium (Na) was determined by flame photometer as described by Gupta (2000); while exchangeable calcium (Ca) and magnesium (Mg) were determined by titration method (Tucker and Kurtz, 1961). The parameters analyzed in the laboratory are listed in Table 1.

Agronomic data collection and analysis

Data collected for the experiment were days to 90% maturity, plant height (cm), marketable yield (kg ha^{-1}), unmarketable yield (kg ha^{-1}), and total yield (kg ha^{-1}). Data were collected for the experiment on yield and yield components related parameters on plot basis and converted to hectare.

Statistical analysis

The collected data were subjected to statistical analysis of variance (ANOVA) using SAS version of 9.0 (SAS, 2002). Significant difference between and among treatment means were assessed using the least significant difference (LSD) at 0.05 level of probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Evaluation of NPSB on onion phenological parameter

Days to 90% physiological maturity

Result showed that days to 90% maturity were not statistically significantly affected (P ≥0.05) by the rates of blended fertilizer, but they have numerical difference among the treatments (Table 2). This result happen to be due to the fact that fertilizers does not have an impact on physiological maturity on single variety unless with variety difference (Tekulu et al., 2019).

Therefore, the longest days to maturity was recorded for plots received a blended fertilizer rate of 25 kg/ha (NPSB) + 69 kg/ha N top dress, while the shortest days to 90% maturity was recorded for plot received 300 kg/ha (NPSB) + 69 kg/ha N top dress (Tekulu et al., 2019).

Evaluation of NPSB on onion yield and yield component parameter

Plant height

Result showed that plant height was not statistically significantly affected (P ≥ 0.05) by the blended fertilizer rates, but there have been numerically difference among the treatments (Table 2).

Therefore, the longest plant height was recorded for plots received a blended fertilizer rate of 300 kg/ha (NPSB) + 69 kg/ha N top dress (T8), while the shortest plant height was recorded for both plots received 100 kg/ha (NPSB) + 69 kg/ha N top dress on onion at Tselemti district.

This result is contradictory with the findings of Morsy et al. (2012) and Nasreen et al. (2007) who reported that onion plant height significantly increased as nitrogen fertilizer rates increased.

Marketable yield

As the analysis of variance revealed that marketable yield was not statistically significantly affected (P ≥ 0.05) by the blended fertilizer rates, but they have numerical difference among the treatments (Table 3).

Therefore, the highest marketable yield (41157 kg/ha) was recorded for plots received a blended fertilizer rate of 250 kg/ha (NPSB) + 69 kg/ha N top dress (T7), while the lowest marketable yield (32650 kg/ha) was recorded for both plots received 50 kg/ha (NPSB) + 69 kg/ha N top dress on onion. This non significance result for marketable onion yield occurs due to the low amount of nitrogen in blended fertilizer and uniform to dress application of urea (69 kg/ha N).

This result is contradictory with the findings of Muluneh (2016) who reported that onion yield significantly increased as blended fertilizer rates increased.

Unmarketable yield

Unmarketable yield was not statistically significantly affected (P ≥ 0.05) by the blended fertilizer rates, but they have numerical difference among the treatments (Table 3).

Hence, the maximum unmarketable yield (1273.1 kg/ha) was recorded for plots that received a blended fertilizer rate of 300 kg/ha (NPSB) + 69 kg/ha N top dress (T8), while the minimum unmarketable yield (520.8 kg/ha) was recorded for both plots received 25 kg/ha (NPSB) + 69 kg/ha N top dress on onion trial.

Total yield

The ANOVA result revealed that total yield was not statistically significantly affected (P ≥ 0.05) by the blended fertilizer rates, but they have numerical difference among the treatments (Table 3).

Hence, the highest total yield (42378 kg/ha) was recorded for plots received a blended fertilizer rate of 250 kg/ha (NPSB) + 69 kg/ha N top dress (T7), while the lowest total yield (33507 kg/ha) was recorded for both plots received 50 kg/ha (NPSB) + 69 kg/ha N top dress on onion experimental examination.

CONCLUSIONS AND RECOMMENDATIONS

Application of different rates of blended fertilizer does not significantly affect most of the crop parameters tested, such as crop phonology, growth parameters, yield and yield components at both sites in the two consecutive years.

Therefore, it can be concluded that even though blended fertilizer does not have significant difference among the treatments in all agronomic attributes, but there is a numerical increment when blended fertilizer rate increases. Therefore, based on the results of the study, it can be recommended that further study should

Table 2. Mean values of two year as regards as days to 90% maturity, plant height of onion as influenced by different levels of blended fertilizer (NPSB) during 2018/2019.

TRT code	Treatments	DPM (days)	PH (cm)
1	Recommended NP (105 kg/ha N, 92 kg/ha P)	109.22	45.11
2	25 kg/ha (NPSB) + 69 kg/ha N top dress	110.11	45.73
3	50 kg/ha (NPSB) + 69 kg/ha N top dress	109.44	45.36
4	100 kg/ha (NPSB) + 69 kg/ha N top dress	109.56	43.78
5	150 kg/ha (NPSB) + 69 kg/ha N top dress	109.78	47.07
6	200 kg/ha (NPSB) + 69 kg/ha N top dress	109.67	47.18
7	250 kg/ha (NPSB) + 69 kg/ha N top dress	109.67	46.64
8	300kg/ha (NPSB) + 69 kg/ha N top dress	108.89	48.62
Mean		109.54	46.19
LSD(P≤0.05)		NS	NS
P-value		0.99	0.19
CV (%)		2.98	7.95

DPM= Days to 90% physiological maturity, PH= plant height, LSD= least significant difference, CV= coefficient of variance, ns= non-significant; means followed by the same letters are not significantly different (P ≥ 0.05) according to LSD tests.

Table 3. Mean values of two year as regards as Marketable yield, Unmarketable, and Total yield of onion as influenced by different levels of blended fertilizer (NPSB) during 2018/2019

TRT code	Treatments	MY (kg/ha)	UMY (kg/ha)	TY (kg/ha)
1	Recommended NP (105 kg/ha N, 92 kg/ha P)	34861.0	1207.2	36068.0
2	25 kg/ha (NPSB) + 69 kg/ha N top dress	33105.0	520.8	33626.0
3	50 kg/ha (NPSB) + 69 kg/ha N top dress	32650.0	856.5	33507.0
4	100 kg/ha (NPSB) + 69 kg/ha N top dress	34167.0	795.1	34962.0
5	150 kg/ha (NPSB) + 69 kg/ha N top dress	35023.0	822.9	35846.0
6	200 kg/ha (NPSB) + 69 kg/ha N top dress	38831.0	929.4	39760.0
7	250 kg/ha (NPSB) + 69 kg/ha N top dress	41157.0	1221.1	42378.0
8	300kg/ha (NPSB) + 69 kg/ha N top dress	39005.0	1273.1	40278.0
Mean		36099.97	953.27	37053.24
LSD(P≤0.05)		NS	NS	NS
P-value		0.83	0.23	0.78
CV (%)		13.22	12.30	13.76

MY= Marketable yield, UMY= unmarketable yield, TY= total yield.

be conducted on split application of blended fertilizer, further studies should be conducted on omitting trail on nutrients of blended formula and soil test based application of blended fertilizer should be done on site specific conditions because the availability of the element may vary depending on the nature of the soil type.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The institutional support of Agricultural Growth Program (AGP II) under Tigray Agricultural Research Institute (TARI) for its financial support of this study is highly cherished. The authors also thank Shire Soil Research Center (SSRC) for providing laboratory facilities.

REFERENCES

Bouyoucos J (1962). Hydrometer method improved for making particle size analysis of soil. Agronomy Journals 54(5):464-465.

Bremner JM, Mulvaney CS (1982). Nitrogen - Total. In: A.L. Page, R.H. Miller and D.R.Keeney (eds.). Methods of soil analysis. Part 2, Second Edition. American Society of Agronomy and Soil Science Society of America, Madison pp. 1119-1123.

Chapman HD (1965). Cation-exchange capacity. In: C. A. Black (ed.) Methods of soil analysis - Chemical and microbiological properties. Agronomy 9:891-901.

Cottenie A (1980). Soil and plant testing as a basis of fertilizer recommendations. FAO Soil Bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome.

Central Statistics Agency (CSA) (2007). Agricultural Sample Survey 2007 .Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Addis Ababa.

Central Statistics Agency (CSA) (2010). Agricultural Sample Survey 2010 .Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Addis Ababa.

Central Statistics Agency (CSA) (2017/2018). Agricultural Sample Survey 2017/2018 (2010 E.C.). Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin 586, Addis Ababa.

Darcha G, Birhane E, Abadi N (2015). Woody Species Diversity in Oxytenanthera abyssinica Based Homestead Agroforestry Systems of Serako, Northern Ethiopia. Journal of Natural Sciences Research 5(9):18-27*.*

Food and Agriculture Organization (FAO) (2006). Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant nutrition Bulletin 16, Rome.

Gomez AA, Gomez H (1984). Statistical analysis for agricultural research. John Willy and Sons Inc. pp. 120-155.

Grubben JH, Denton DA (2004). Plant resources of tropical Africa. PROTA Foundation, Wageningen; Back huys, Leiden; CTA, Wageningen.

Guesh T (2015). Growth, yield, and quality of onion (*allium cepa* l.) as influenced by intra-row spacing and nitrogen fertilizer levels in central zone of Tigray, Northern Ethiopia. M.Sc. Thesis. Haramaya university, Haramaya

Gupta PK (2000). Soil, Plant, Water and Fertilizer Analysis. AGROBIOS Publisher, India.

Hanelt P (1990). Taxonomy, evolution and history. In: Rabinowitch, H.D. and J.L. Brewster Onions and Allied Crops CRC Press, Boca Raton, Florida 1:1-26.

Hurni H (1998). Agro ecological belts of Ethiopia. Explanatory notes on three maps at a scale of *1*(1,000,000). Soil Conservation Research Program Ethiopia.

Jackson ML (1967). Soil chemical analysis. Prentice-Hall of India Pvt. Ltd., New Delhi 498 p.

Khalid MK (2019). Mineral nutrient management for onion bulb crops – a review. The Journal of Horticultural Science and Biotechnology pp. 2380-4084.

Khokhar KM, Khokhar MA, Tariq M, Hussain SI, Hidayatullah U, Laghari MH (2004). Comparative economics, monetary and yield advantages from NPK fertilization to onion. Pakistan Journal of Agricultural Research 18:46-50.

Landon JR (1991). Booker Tropical Soil Manual: A hand book for soil survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 474p. OR John Wiley and Sons Inc., New York.

Morsy MG, Marey RA, Karam SS, Abo-Dahab AMA (2012). Productivity and storability of onion as influenced by the different levels of NPK fertilization. Agricultural Research Kafer El-Sheikh University 38(1):171-187.

Muluneh N (2013). Assessment of onion production practices and effects of N:P2O5:S fertilizers rates on yield and yield components of onion *(allium cepa l.)* under irrigated farming system in Dembiya district, Amhara region, Ethiopia. M.Sc. Thesis. Bahir dar university, Bahir Dar.

Nasreen S, Haque MM, Hossain MA, Farid ATM (2007). Nutrient uptake and yield of onion as influenced by nitrogen and sulphur fertilization. Bangladesh Journal of Agricultural Research 32(3):413-420.

Nikus O, Mulugeta F (2010). Onion seed production techniques. A manual for extension agents and seed producers, Asella, Ethiopia P 1.

Olsen R, Cole S, Watanabe F, Dean L (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture Circular P 939.

OoARD (Bureau of Agriculture and Rural Development) (2020). Annual report of Bureau of the Agricultural and Rural Development of Tselemti District.

Hazelton P, Murphy B (2007). Interpreting soil test results: what do all the number mean? [2nd Ed.]. pp. 631-42.

Redda A, Abay F (2015). Agronomic Performance of Integrated Use of Organic and Inorganic Fertilizers on Rice (*Oryza sativa* L.) in Tselemti District. Journal of Environment and Earth Science 5(9):30-42.

Rhoades JD (1982). In Methods of Soil Analysis, Part 2. Second Edition (A.L. Page. Miller and D.R. Keeney, Eds.), American Society of Agronomy. Madison, USA.

Richards LA (1954). Diagnosis and improvement of saline and alkaline soils. USDA Handbook No. 60, Washington, DC.

SAS (2002). SAS/STAT User's Guide, Version 9.1.3. SAS institute Inc., Cary, NC.

Tekalign T (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia. and Subtropics. Longman Scientific and Technical, Essex, New York 474 p

Tekulu K, Tadele T, Berhe T, Gebrehiwot W, Kahsu G, Mebrahtom S, Aregawi G (2019). Evaluation of NPSZnB fertilizer levels on yield and yield component of maize (*Zea mays* L.) at Laelay Adiyabo and Medebay Zana districts, Western Tigray, Ethiopia. Journal of Cereals and Oilseeds 10(2):54-63.

Tucker BB, Kurtz LT (1961). Calcium and magnesium determinations by EDTA titrations. Soil Science Society of America Journal 25(1):27-29.

Walkley A, Black IA (1934). An examination of the method for determining soil organic matter and proposed chromic acid titration method. Soil Science 37:29-38.

Vol. 16(9), pp. 1245-1252, September, 2020
DOI: 10.5897/AJAR2020.14992
Article Number: 9F974CB64779
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Household determinants of food security in rural Central Uganda

John Baptist Semazzi* and Moses Kakungulu

Department of Economics, Uganda Martyrs University, P. O. Box 5498, Kampala, Uganda.

Received 22 May, 2020; Accepted 8 September, 2020

This study contributes to the literature by presenting empirical evidence on the drivers of rural household food security, which is critical for food security policy implementation. We used household survey data collected from 265 households from rural central Uganda, and a binary logistic regression model to estimate the determinants of household food security. Households with more land size, no livestock, and smaller household size were found as being more food secure. The results suggest the need to: review policies on land tenure system and land use, promote food storage and market for produce and to design strategies to increase household incomes.

Key words: Food security, determinants, Logit model, households**,** Gomba, Uganda.

INTRODUCTION

Food security is at the center stage in the world's economic development debate. This concern is due to the fact that the world's population is increasing very fast and is expected to reach 9.8 billion by the year 2050 (DESA, 2017). This will increase pressures on the environment, global food supplies and energy resources. In her article, "Food Insecurity and Food Stamp Program", Jensen (2002) reports that, in the face of abundant supplies of food worldwide, nearly 800 million people suffered from malnutrition and undernourishment. Most of these undernourished live in low income countries.

According to 2014 national population and housing census (UNHS) results, annual population growth rate between 2002 and 2014 censuses was 3.03% (UBOS, 2018). This rapid population growth will lead to acute land constraints and accelerated land degradation if not controlled. Land degradation due to deforestation, and the rapid conversion of natural vegetation into arable lands, exposing big areas to sheet erosion and reducing their productivity happens to be a threat. This problem is partly attributed to the poorly defined land ownership rights (National Environment Management Authority - NEMA, 2016). Declining soil fertility means farmers are experiencing less yields with lower value and less nutrient intensive crops. In addition, land use affects the land available for food production. For example, mining, urbanization and industrialization affect land available for food production leading to food insecurity. Use of land for cash crops also reduces land available for food production. Rural – Urban migration reduces labor available for cultivation hence decreasing food production.

The overall goal of the Uganda food and nutrition Policy

*Corresponding author. Email: jbsemazzi@gmail.com.

(2003) is to ensure food security and adequate nutrition for all the people of Uganda, for their health as well as their social and economic well-being, while the overall objective of the policy is to promote the nutritional status of the people of Uganda, ensuring availability, accessibility and affordability of food in the quantities and qualities sufficient to satisfy the dietary needs of individuals sustainably (MAAIF and MOH, 2003). This is in response to the very fact that rural households in sub Saharan Africa are increasingly faced with challenges of food insecurity (Nyariki and Wiggins, 1997), with the situation being worsened by increasing population and reduced land productivity.

Despite continuing economic growth, Uganda faces persistent challenges to achieve food security. The effectiveness of policy and development strategies to help rural households achieve food security must improve, since rural households follow diverse livelihood strategies, which differ across the regions and with their degree of food availability. The diversity of livelihood strategies must be considered when targeting interventions (Wichern et al., 2017).

Indeed, the government of Uganda through the plan for modernization of agriculture (this is a framework which sets out the strategic vision and principles upon which interventions to address poverty eradication through transformation of the agricultural sector can be developed), has made endeavors in promotion of food production by identifying key determinants that can reverse the situation of food insecurity. These determinants at household level include: land size, land usage, availability of factors of production such as labor, effective storage, and processing. This entails developing effective utilization of farm land to maximize production per unit; diversification of farming activities through mixed farming to minimize losses due to natural calamities; linkages to appropriate markets to ensure good price thus boosting farmers' incomes; promotion of cooperatives and farmer organization to facilitate effective production and appropriate utilization of family and community resources to subsidize cost of production (OPM, 2005). Modernization of agriculture is expected to contribute towards improvement of incomes by raising farm productivity, increasing the share of agricultural production that is marketed and creating more on farm and off farm employment opportunities (OPM, 2005). Incidentally, when one analyzes the above key determinants, their effectiveness remains not well established. This article therefore, is aimed at establishing the effectiveness of these key determinants in the battle against food insecurity. This is the reason we carried out a research study on various determinants of food security in rural central Uganda. We contribute to the literature by presenting empirical evidence on the drivers of rural household food security. Understanding what drives household food security dynamics in developing countries is critical for food security policy implementation.

This study is based on four pillars namely: food availability, food accessibility, food utilization and food stability (Food and Agriculture Organization - FAO, 1996; World Food Programme - WFP, 2013). In this study, food availability refers to foods grown and harvested by individual households for home consumption; food accessibility is based on incomes of individual households, from sale of own food and other sources; food utilization is determined by what individual households harvest from own production, and their net incomes (food entitlement); Food stability is to what extent a household can afford enough portions of qualitative and quantitative food in a year. When one talks of food security, it does not necessarily mean quantity or quality of food a household consumes, but also how much income a household earns in terms of money, and for how long this household can maintain qualitative and quantitative food consumption. In most cases, food grown by a household is supplemented by income to fulfil the principle of food security. Food insecurity is more of a rural phenomenon across all food security indicators except for caloric deficiency. Rural dwellers tend to consume more calories by bulking up on staples to fuel them to carry out a higher level of manual work (WFP, 2013).

In a review made by the Uganda Parliamentary Forum on food security, it was noted that Uganda was not doing well in terms of global nutrition ranking (EPRC, 2017). The review also warned that the absence of food storage at national level shows Uganda's lack of preparedness to manage emergencies (EPRC, 2017). The review put more emphasis on food utilization, food availability and food stability, than food accessibility. For a country to ensure enough food for all, there need be surplus food production for storage, but also for sale by households for an income.

In a research carried out in south-central Uganda on determinants of seasonal food security, results showed that land size and crop yields were more important for smallholder food security than soil quality (Apanovich and Mazur, 2018). This article focused primarily on food availability, with disregard to soil quality. Soil quality is very essential in production of a variety of crops (including fruits) that promote a balanced diet in households, increase household incomes, ensures food availability and food stability.

In order to address the food insecurity problem, Makerere University College of agricultural and environmental studies (CAES) in partnership with the Ministry of Agriculture Animal Industries and Fisheries (MAAIF), on 30th August, 2018 held Uganda's action planning meeting to assess the implementation of the Malabo declaration. This declaration was aimed at accelerating agricultural growth and transformation for shared prosperity, and improved livelihoods mostly centered in small scale farmers' agriculture. This meant ending hunger by the year 2025. The outcome of the above meeting showed that Uganda had not been performing well in fulfilling the Malabo declaration, and yet agriculture is now a business many smallholder farmers aspire to engage in. It was also observed in that same meeting that, there is need to engage the youth in whatever is done in agriculture to embrace rapid growth (Wamai, 2018). Incidentally, it is not clear what measurement, the above partners used to determine the present food security status in the country.

In review of the above findings, it is evident that: the government through Plan for Modernization of Agriculture (PMA) was expected to contribute towards improvement of incomes by raising farm productivity, increasing the share of agricultural production that is marketed and creating more on farm and off farm employment opportunities, but the effectiveness of all these economic activities is not yet well established; Uganda Parliamentary Forum on Food Security put more emphasis on food utilization, food availability and food stability than food accessibility; a research by Apanovich and Mazur (2018) focused primarily on food availability (Apanovich and Mazur, 2018); while Uganda's action planning meeting revealed the current food security status in the country, but the measurement used to come to this is not clear. Therefore, the effectiveness of the above studies remain wanting or need further research. This article therefore examines the protracted determinants of food security in rural communities in Uganda using the binary logistic regression model, with emphasis on food availability, food accessibility, food utilization and food stability. Household food security is meant to embrace all its four pillars at ago to give a meaningful outcome. Therefore, the very fact that this article assesses the effectiveness of all the four aspects of household food security is enough justification for its publication.

MATERIALS AND METHODS

This study was conducted in Gomba district in rural central Uganda (Figure 1). The district is characterized by food insecurity, especially during dry spells. Traditionally, households in the research area are farm-households, deriving the majority of their income from mixed cropping. The most commonly cultivated crops include maize, bananas, sweet potatoes, cassava and beans. The area is predominantly characterized by traditional food production and subsistence orientation. We conducted a household survey in the area in May 2014. The survey included 265 households, selected in a multistage sampling design. In the first stage, four rural parishes of Kisoga, Mamba, Bukundugulu, and Nsambwe in Kyegonza sub-county were selected. In the second stage, one village was selected from each of the selected parishes. In the third stage, 265 households were selected from the four selected villages using Krejcie and Morgan (1970) procedure. Systematic random sampling was used to select these households. That is, every third household was selected skipping two households in between. A structured quantitative questionnaire was used and survey data included information on household demographics, productive assets, living standards, and income sources from agricultural production and marketing (both crops and livestock). Household survey data was complemented with qualitative information from semi-structured interviews with district agricultural officers, community development officers and sub-county chiefs on rural livelihood strategies.

The method used in measuring household food security is based on Sen (1982) entitlement approach. The dependent variable (The four pillars of household food security) was measured as follows: food availability was calculated by converting all food harvested by an individual household for home consumption in one year into Uganda shillings; food accessibility was estimated in Uganda shillings in accordance with all the net incomes of a given household in one year; food utilization was determined in Uganda shillings by a combination of food available and food accessible to a given household in one year; all the above 3 pillars were considered for a period of one year, hence determining food stability. Food available plus food accessible to a given household equals to expected food utilization of that household (food entitlement). A standard measure (of required quantity and quality of food per household in a year, that is, Uganda shillings 2500 times number of people in a household times 365 days) in Uganda shillings for a food secure household, taking into consideration the number of household members, was established. Households equaling to, or above that measure were considered food secure. Uganda shillings 2500, the equivalent of one US dollar then, was estimated to cover one individual member of a household in a day. A balanced diet (required quality of food) means that, a household should try to eat at least 5 portions of a variety of fruit and vegetables every day. The common of these in the rural areas of Uganda are: bananas, mangoes, oranges, avocados, sweet corn, pineapples, cabbage, pepper, onions, and tomatoes. In addition to this, base meals on higher fiber starchy foods like potatoes, peas, beans, nuts and potatoes with skin need to be consumed. Other protein foods like poultry and eggs are also necessary. These foods need to be consumed on a regular basis. There are many other kinds of foods to be consumed for a balanced diet, but the above are the most commonly available ones in Uganda's rural areas.

The quantitative data collected was analyzed to describe the household level characteristics using t-tests and chi-square along with the binary logistic regression to examine the determinants of household food security. Stata 12 was used.

Household food security is influenced by a number of factors. They range from socio-economic to institutional factors. Modelling a relationship between food secure and food insecure households requires use of discrete choice models (Kabunga et al., 2011; Wellington et al., 2013). Therefore, the logit model was used in this study since it is easier and simpler to interpret and thus has been widely applied in decision studies (Adesina and Seidi, 1995). The household food security logit model is then specified as follows (Cameron and Trivedi, 2005);

$$\Pr(y_{ji} = 1|X) = \emptyset(X'\beta) = \frac{e^{X'\beta}}{1+e^{X'\beta}}$$

Where $\emptyset(.)$ is a logistic cumulative distribution function (CDF). The logit model was estimated using maximum likelihood estimation (MLE), assuming independence across observations and that the ML estimator of $\boldsymbol{\beta}$ is consistent and asymptotically normally distributed. However, the estimation rests on the strong assumption that the latent error term is normally distributed and homoscedastic.

RESULTS AND DISCUSSION

Household characteristics

In Table 1, we present the summary statistics for household characteristics for food secure and food

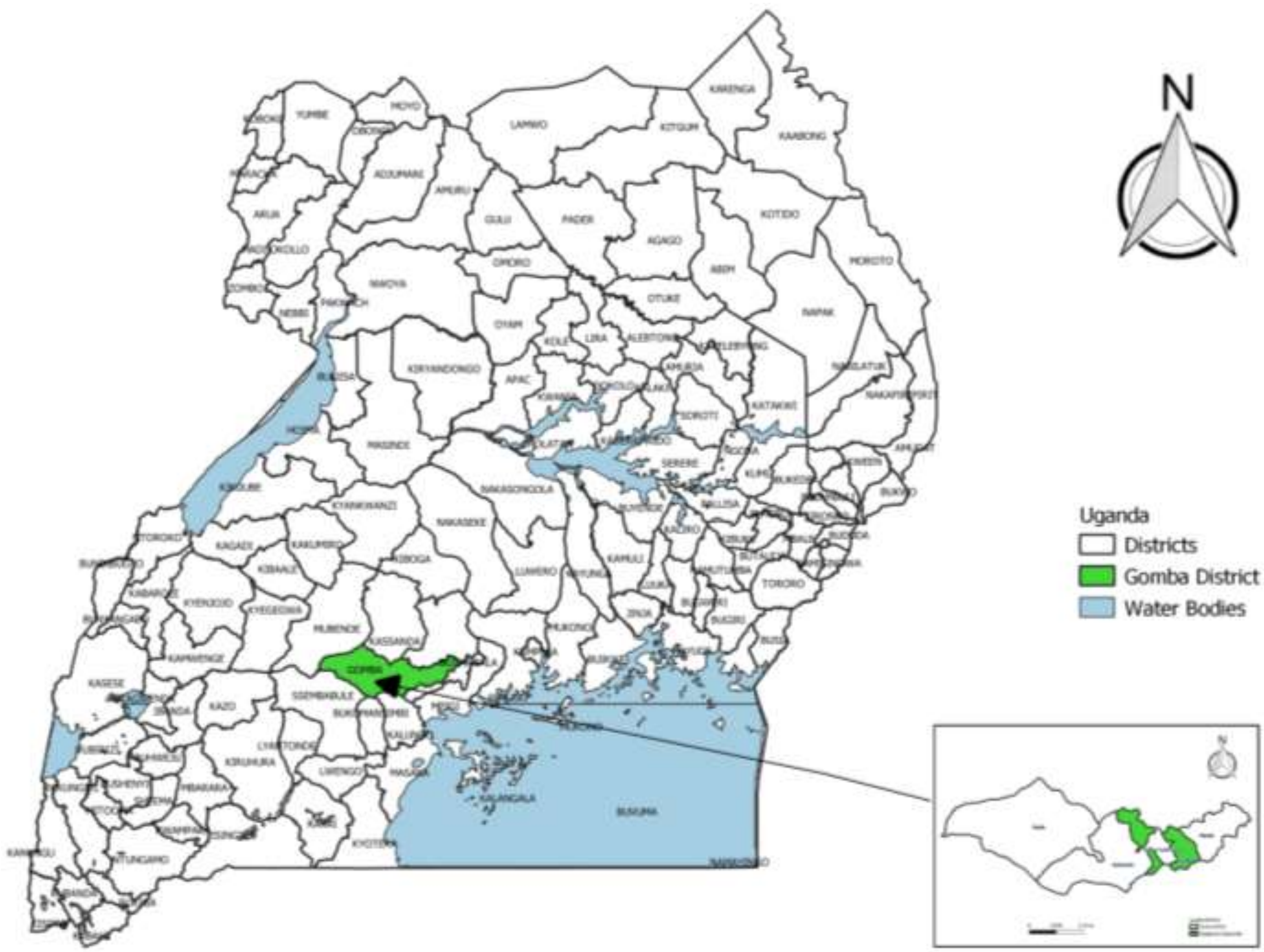


Figure 1. Map of Uganda showing the Study Area in Gomba district, Kyegonza sub-county
Source: QGIS mapping program.

insecure households. We found that 75% of the households in the sample are male-headed; the average age of the household head is 42 years and the average household size is 6 members. The average age shows that the farmers interviewed are still economically active, and that decisions regarding household food security are greatly influenced by males. Majority of the respondents (69%) have primary education, whereas 68% are married. This shows that the education levels are still low in the study area. Most of the households interviewed (57%) are Kibanja holders. This implies that majority of the respondents do not have full user rights (tenure security) of the land. Households who are food secure are more likely to be headed by young males and are smaller in size as compared to food insecure households. In addition, food secure households are less likely to be Kibanja holders but more likely to be having leasehold as compared to food insecure households.

Assets and welfare indicators of the households

In Figure 2, we present the summary statistics for the assets and welfare indicators of the households in terms of livestock, land, household income and food storage status, and compare these for food secure and food insecure households.

We found that food secure households are likely to have more land with less livestock units. The average land size for the food secure and food insecure households was about 4.9 and 2.8 acres respectively. This implies that households with bigger land are in position to utilize it for more food production. On average, 81% of the food insecure households own livestock as compared to only 44% of the food secure households. This could be the fact that the food insecure households spent much of their time in grazing cattle instead of concentrating on crop cultivation. Food secure

Table 1. Mean comparison of household characteristics and welfare indicators for food secure and food-insecure households.

Characteristic	Total sample	Food Insecure	Food secure
Household characteristics			
Gender HH head (1=Male)	0.75 (0.43)	0.73 (0.45)	0.79 (0.41)
Age HH head (years)	41.5 (12.2)	42.2 (12.1)	40.7 (12.3)
Household size	5.9 (3.1)	6.3 (3.1)	5.3*** (3.0)
Share of HH heads with: (%)			
No education	9.4	9.7	9.1
Primary	69.4	69.0	70.0
Secondary	16.6	16.1	17.3
Tertiary	4.5	5.2	3.6
Share of HH heads who are: (%)			
Single	20.0	18.7	20.9
Married	68.3	66.5	70.9
Land tenure (%)			
Leasehold	37.7	31.6	46.4**
Kibanja holder	56.6	63.2	47.3***
Mailo Land	1.1	0.6	1.8
Hired/Borrowed	4.5	4.5	4.5
Number of observations	**265**	**155**	**110**

Mean comparison t-tests were used to compare household characteristics for food secure with food-insecure households. Significant differences are indicated with *** p<0.01, ** p<0.05 or * p<0.1. Standard deviations of the mean are reported between parentheses.

households have more annual average incomes and are more likely to store food as compared to food insecure households. The average household income for food secure and food insecure households is 8,101,432 UGX and 1,945,694 Uganda shillings respectively. The percentage of households that have the ability to store food is very low in the study area. On average, 36% of the food secure households are able to store food as compared to only 23% of the food insecure households. This implies that majority of the households are vulnerable to food shortage in the study area.

Econometric results

In Table 2, we present the results of the logistic regression showing the household determinants of food security status. The results show that land size leads to an improved household food security situation. Keeping other factors constant, the increase in land size is associated with the increased likely hood of the household being food secure. We found that land size in the categories 3 to less than 6 ha; 6 to 9 ha and more than 9 ha increases the likelihood of the household being food secure by 0.347, 0.495 and 0.684 respectively. This finding is consistent with that of Bogale and Shimelis (2009), and Van der Veen and Gebrehiwot (2011) but contradicts the results of Sikwela (2008). This implies that food production could be increased through expansion of land areas under cultivation.

We also find that livestock rearing reduces household food security. Results show that keeping livestock reduces the likelihood of the household being food secure by 0.319. It is likely that animals reared by individual households are too few to make an impact. Instead of solving the problem of food insecurity, these animals may end up consuming rather than improving the household food security status. These findings are consistent with Mayanja et al. (2015) where one of the highly significant factor associated with increasing household food insecurity in the rainy season, was low livestock holdings for agro-pastoralists. They contradict results of Mbolanyi et al. (2017), where livestock ownership positively influenced household food security (Mbolanyi et al., 2017). The results also contradict those by Bashir et al. (2012) where both large and small livestock assets significantly improve food security (Bashir et al., 2012). It also contradicts findings of Beyene and Muche (2010), Muhoyi et al. (2014) and Owolade et al. (2013). The above findings give an

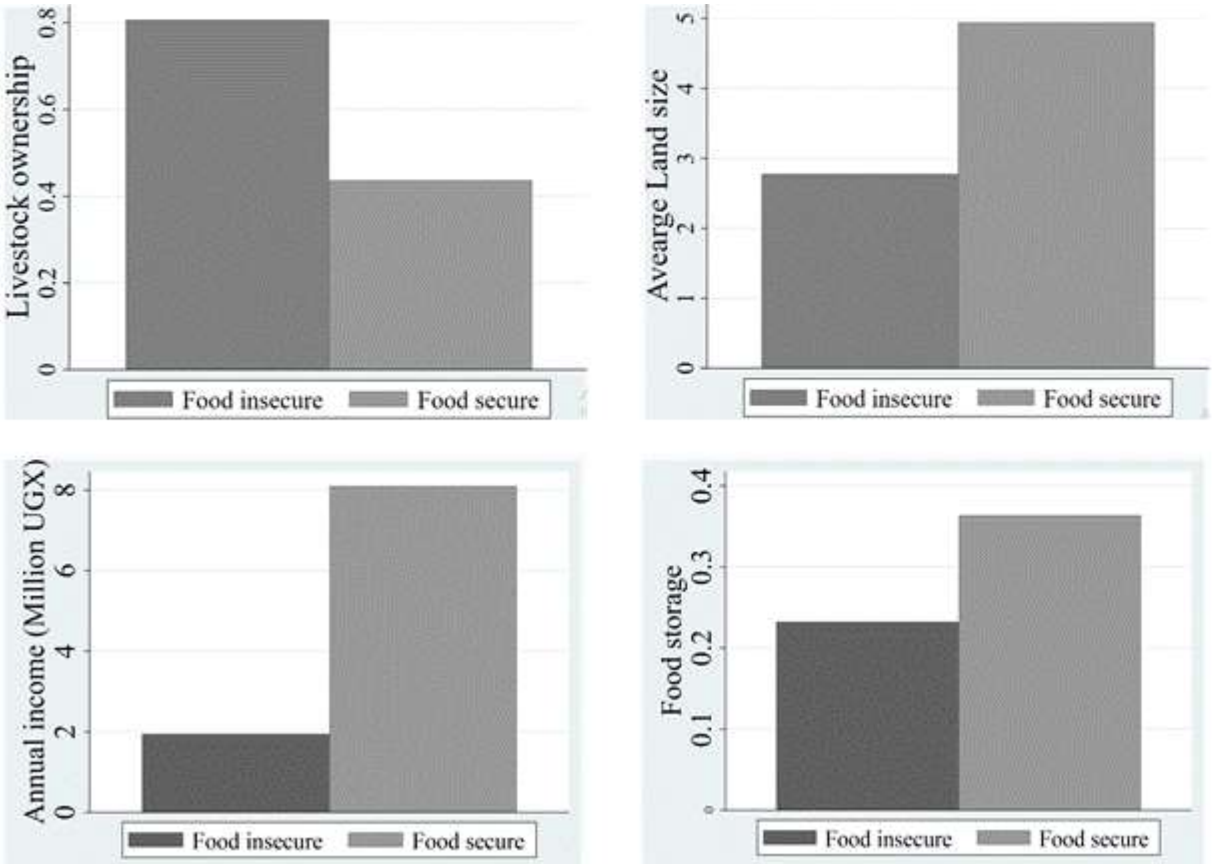


Figure 2. Mean comparison of Assets and Welfare indicators for food secure and insecure households.
Source: Authors' calculations from survey data.

impression that food security can be improved with increased livestock holdings.

Household size is also associated with reduced household food security. We found that household size in the categories 5 to 8 members; 9 to 12 members and more than 12 members decreases the likelihood of the household being food secure by 0.321, 0.409 and 0.493 respectively when other factors are held constant. The explanation could be that increase in household size results in increased demand for food, which may not be accompanied by food production This is consistent with the studies conducted by Olayemi (2012) and Paddy (2003), which show a negative correlation between household size and household food security.

CONCLUSIONS AND POLICY RECOMMENDATIONS

In this study, we provide evidence on the household determinants of food security in rural Uganda. Previous studies have analyzed the determinants at macro-economic levels without focusing on what influences food security at household level. Evidence on food security at household level is highly relevant given the high levels of food shortages in developing countries, and the beneficial nutritional effects associated with food availability. We address this research gap using survey data from farm households in rural central Uganda in Gomba district where food insecurity is prevalent. Our results suggest that household factors in terms of the nature of social and asset composition in rural areas can be an important instrument for reducing food insecurity and accelerating rural development in developing countries. Our analysis contributes to the discussion on whether household factors can be important drivers of food security in rural areas of developing countries. Our analysis is done at the household level, and our results imply that availability of land at household increases food security while livestock ownership reduces food security. In addition, household size decreases food security. In developing countries, land is the main factor of production. Therefore, possession of land can importantly contribute to food production especially in rural areas. Based on this, land owners with big chunks of land which is redundant can be advised to lease it or hire it out to those with the capacity to grow food; farmers can be taught modern farming

Table 2. Logistic regression results for the determinants of food security.

Variable name	Coefficient	Marginal effects	Odds ratios	Robust Std. Err.
Land holdings				
Below 3 ha	1			
3 to less than 6 ha	2.147	0.347	8.558***	0.449
6 to 9 ha	3.085	0.495	21.857***	0.626
More than 9 ha	4.870	0.684	130.374***	1.021
Land tenure				
Leasehold	1			
Kibanja holder	0.205	0.029	1.227	0.381
Mailo land	1.067	0.160	2.907	1.396
Hired/Borrowed land	1.301	0.196	3.673*	0.695
HH owns Livestock (1=Yes)	-2.159	-0.319	0.115***	0.369
Household size				
1 to 4 members	1			
5 to 8 members	-2.225	-0.321	0.108***	0.417
9 to 12 members	-2.984	-0.409	0.051***	0.629
Above 12 members	-3.893	-0.493	0.020**	1.548
HH stores food (1=Yes)	0.506	0.075	0.603	0.353
Constant	3.247	0.075	25.708***	0.874***
Number of observations	265			
Wald $chi^2(11)$	79.51			
Prob > chi^2	0.000			
Pseudo R^2	0.331			

Significant effects are indicated with * p<0.1, ** p<0.05 or ***p<0.01.

practices like climate smart agriculture to improve their production and incomes, especially during these times of severe climate change; lazy household members need to be cautioned and made to work; households need to be sensitized on the importance of livestock products for improved health, soil enrichment and higher incomes; and how to come up with traditional but good storage facilities for keeping their food. Stored food can help during famine or emergency times like this period of corona virus pandemic. It is therefore recommended that government: reviews the land tenure and land use acts while also protecting the landlords, for improved food production at household and national level, and for higher income taxes to government to enable it improve the necessary social services; puts in place national food storage facilities to improve its preparedness to manage emergencies; promotes climate smart agriculture, through changing the behavior, strategies and agricultural practices of small scale agricultural farmers; institutes a policy which ensures increased livestock rearing at household level; through cooperative unions purchases agricultural produce from rural households at a good price to motivate them to grow more for improved food security status.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

Sincere gratitude goes to Mary Nanfuka, and Joseph Muhereza of Uganda Martyrs University, and Tom Lutalo of Uganda Virus Research Institute for technical support. Appreciation also goes to the contribution made by Josephine Bwogi through reviewing and editing this article.

REFERENCES

Adesina A, Seidi S (1995). Farmers perceptions and adoption of new agricultural technology: analysis of modern mangrove rice varieties in Guinea Bissau. Quarterly Journal of International Agriculture 34(4):358-371.

Apanovich N, Mazur RE (2018). Determinants of seasonal food security among smallholder farmers in south-central Uganda. Agriculture and Food Security 7:87.

Bashir MK, Schilizzi S, Pandit R (2012). Livestock and rural household food security: The case of small farmers of the Punjab, Pakistan, Working Paper 1207, School of Agricultural and Resource Economics, University of Western Australia,, Crawley, Australia

Beyene F, Muche M (2010). Determinants of food security among rural households of Central Ethiopia: an empirical analysis. Quarterly Journal of International Agriculture 49(4):299-318.

Bogale A, Shimelis A (2009). Household level determinants of food insecurity in rural areas of Dire Dawa, Eastern Ethiopia. African Journal of Food, Agriculture, Nutrition and Development 9:9.

Cameron AC, Trivedi PK, (2005). Microeconometrics. Methods and Applications. Cambridge University Press

Department of Economic and Social Affairs (DESA) (2017). The World Population Prospects: The 2017 Revision.

EPRC (2017). Ensure food security or forget middle income dream.

Food and Agriculture Organization (FAO) (1996). Declaration on World Food Security, World Food Summit, Rome,Italy.

Jensen HH (2002). Food insecurity and the food stamp program. American Journal of Agricultural Economics 84:1215-1228.

Kabunga NS, Dubois T, Qaim M (2011). Information asymmetries and technology adoption: The case of tissue culture bananas in Kenya, Courant Research Centre: Poverty, Equity and Growth-Discussion Papers.

Krejcie RV, Morgan DW (1970). Determining sample size for research activities. Educational and psychological measurement 30:607-610.

MAAIF, MOH (2003). The Uganda Food and Nutrition Policy. The Republic of Uganda.

Mayanja MN, Rubaire-Akiiki C, Greiner T, Morton JF (2015). Characterising food insecurity in pastoral and agro-pastoral communities in Uganda using a consumption coping strategy index. Pastoralism 5:11.

Mbolanyi B, Egeru A, Mfitumukiza D (2017). Determinants of household food security in a rangeland area of Uganda. African Journal of Rural Development 2(2):213-223.

Muhoyi E, Mukura T, Ndedzu D, Makova T, Munamati O (2014). Determinants of household food security in Murehwa District. Journal of Economics and Sustainable Development 5(3):84-92.

National Environment Management Authority (NEMA) (2016). State of the environment report for Uganda 2014, National Environment Management Authority (NEMA) Kampala P 82.

Nyariki DM, Wiggins S (1997). Household food insecurity in Sub-Saharan Africa: Lessons from Kenya. British Food Journal 99(7):249-262.

Olayemi AO (2012). Effects of family size on household food security in Osun State, Nigeria. Asian journal of agriculture and rural development 2(2):136-141.

OPM (2005). Evaluation Report : The plan for the modernisation of Agriculture 12.

Owolade E, Oyesola O, Yekinni O, Popoola M (2013). Determinants of Food Security among Rural Livestock Farmers in Southwestern Nigeria. Journal of Agricultural Extension 17(2):147-181.

Paddy F (2003). Gender differentials in land ownership and their impact on household food security: a case study of Masaka district. A Masters Thesis, Uganda Press, Baltimore and London. www. troz.unihohenheim.de/research/Thesis/MScAES/Paddy.pdf

Sen A (1982). Poverty and famines: an essay on entitlement and deprivation Oxford university press, New York.

Sikwela M (2008). Determinants of household food security in the semi-arid areas of Zimbabwe: A case study of irrigated and non-irrigated farmers in Lupane and Hwange districts. University of South Africa.

Uganda Bureau Of Statistics (UBOS) (2018). 2018 Statistics Abstract P. 11.

Van der Veen A, Gebrehiwot T (2011). Effect of policy interventions on food security in Tigray, Northern Ethiopia. Ecology and Society 16(1):18.

Wamai M (2018). Mak and MAAIF Hold CAADP Malabo Declaration action planning meeting, NEWS Makerere University.

Wellington EM, Boxall AB, Cross P, Feil EJ, Gaze WH, Hawkey PM, Johnson-Rollings AS, Jones DL, Lee NM, Otten W (2013). The role of the natural environment in the emergence of antibiotic resistance in Gram-negative bacteria. The Lancet infectious diseases 13(2):155-165.

World Food Programme (WFP) (2013). Uganda Comprehensive Food Security and Vulnerability Analysis (CFSVA) World Food Programme.

Wichern J, van Wijk MT, Descheemaeker K, Romain F, Asten PJA, Giller KE (2017). Food availabilty and livelihood strategies among rural households across Uganda. Food security 9:1385-1403.

Vol. 16(9), pp. 1253-1269, September, 2020
DOI: 10.5897/AJAR2020.15023
Article Number: 5FDB28964797
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Banana pest risk assessment along banana trade axes running from low to high altitude sites, in the Eastern DR Congo and in Burundi

Guy Blomme[1]*, Walter Ocimati[2], Serge Amato[3], Alexandra zum Felde[4], Muller Kamira[5], Mariam Bumba[5], Liliane Bahati[5], Daniel Amini[5] and Jules Ntamwira[5]

[1]Bioversity International, P.O. Box 5689; Addis Ababa Ethiopia.
[2]Bioversity International, P.O. Box 24384, Kampala, Uganda.
[3]International Institute of Tropical Agriculture, Kalambo Research Station, Bukavu, South Kivu Province, Democratic Republic of Congo.
[4]Independent Consultant, Germany.
[5]Bioversity International, Bukavu, South Kivu Province, Democratic Republic of Congo..

Received 16 June, 2020; Accepted 27 July, 2020

Pests and diseases greatly contribute to the decline in banana yields, food and income insecurity in the Great Lakes region of Africa. Understanding people's role in pest and disease spread at landscape level is crucial for effective pest and disease management. To determine this, focus group discussions (FGDs) targeting 10 experienced farmers (50% female and 50% male) were conducted in 27 villages along four banana trade routes in western Burundi and eastern DR Congo. FGDs determined the presence and risk of spread of key banana pests and diseases via the movement of banana bunches, planting material and other products, labourers, traders and farm tools. Black leaf streak (BLS), Fusarium wilt and banana bunchy top disease (BBTD) were reported to have been in the landscape for over 40 years while Xanthomonas wilt (XW) was a more recent introduction (1-7 years). BBTD, XW and weevils were the most prevalent constraints. BBTD was observed at previously unsuitable high-altitude zones, which should be a cause of concern, especially with the current risk of climate change. Climate change, and linked temperature increases, could also worsen the prevalence of XW, weevils, nematodes and BLS. Movement of farming tools by labourers and traders, of planting material/suckers and banana bunches emerged as the most common human practices potentially responsible for the spread and/or build-up of banana pests/diseases. Strengthening farmer's knowledge and institutional capacities of actors on these different modes of disease spread in banana value chains in the region is recommended.

Key words: Black leaf streak, bunchy top disease, Fusarium wilt, nematodes, weevils, Xanthomonas wilt.

INTRODUCTION

In the African Great Lakes Region (AGLR), bananas and plantains (hereafter banana) play a very important social

*Corresponding author. E-mail: G.Blomme@cgiar.org. Tel: +251-921927808.

and economic role (Baret and Van Damme, 2010). In the Democratic Republic of the Congo (DR Congo), banana production area covered about 1.2 million ha, with a total production of 5.1 million tonnes of banana in 2018 (FAO, 2019). In Eastern DR Congo, representing one of the main banana production zones, bananas are consumed daily by about 70% of the population in various forms, including traditional banana beer (Mukwa et al., 2015). In Burundi, banana is the most widely produced crop, with an annual production of 1.7 million tonnes on an estimated production area of 208,603 ha in 2018 (FAO, 2019), accounting for 17 to 20% of arable land and about 45% of Burundian crop production (FAO, 2019).

Grown on small areas around homesteads, bananas play a multifunctional role for banana-based households in the AGLR (Ndungo et al., 2008; Kamira et al., 2014; Ocimati et al., 2018a). In the DR Congo and Burundi, bananas contribute enormously to food security and nutrition of millions of people. They are an important source of vitamins and minerals, while providing more than half of calories consumed daily in these countries (IITA, 2015). Bananas also represent a vital source of regular income to households in the east and central African region. This income helps farmers cover important expenses such as school fees and health-care related costs (Baret and Van Damme, 2010) and enables the rural poor to take on a greater number of social roles in their communities (IITA, 2015).

However, in recent years, banana production and area planted have declined between 20 and 60% in DR Congo (Mobambo et al., 2010) and between 20 and 50% in Burundi (Actualitix, 2016). Pests and diseases greatly contribute to these declines (Kamira et al., 2013; Blomme et al., 2014; Niyongere et al., 2015). The main pests include nematodes, particularly endo-parasitic ones, like *Radopholus similis* and *Pratylenchus* species and weevils (*Cosmopolites sordidus*) (Kamira et al., 2013). The common diseases include Xanthomonas wilt of banana (caused by the bacteria *Xanthomonas vasicola* pv. *musacearum*, Xcm), black sigatoka or black leaf streak (BLS) (a foliar disease caused by the fungus *Pseudocercospora fijiensis,* formerly: *Mycosphaerella fijiensis*), Banana Bunchy Top Disease (BBTD) caused by the banana bunchy top virus (BBTV) and transmitted by the banana aphid (*Pentalonia nigronervosa*), Fusarium wilt or Panama disease (a wilt disease caused by the fungus *Fusarium oxysporum* f. sp. *cubense*) and Banana Streak Virus (BSV).

These pests and diseases represent significant threats to banana production and have the potential to devastate entire plantations, which equates to crippling reliable livelihood(s) with serious consequences on household incomes and food security. Preventing losses due to pests and diseases can be achieved if the importance of various mechanisms of spread is known.

Given the importance of banana, banana products are regularly traded across the region. While some banana diseases are spread abiotically (e.g. black leaf streak/black sigatoka ascospores being blown from plant to plant in a field by the wind (Ploetz, 2001) or Fusarium wilt spores travelling in surface water from an infected area to new areas along drainage ditches (Hwang and Ko, 2004), most diseases and pests can and are readily spread by other factors. Contaminated planting material or plant parts (e.g. banana leaves used to wrap foods) as well as tools or footwear of workers exiting contaminated fields, can carry pathogens, their spores or pests directly or in soil adhering to them. Pest and disease spread through infected planting materials is also common in the region. Environmental factors such as altitude and/or temperature effects, precipitation and vegetation cover have also been reported to directly or indirectly impact on the severity of these pests and diseases in the region. For example, above 1,600 m, the banana weevil (*C. sordidus*) does not multiply well (Gold and Messiaen, 2000) while the banana aphid (*P. nigronervosa*) has been reported not to transmit the banana bunchy top virus as efficiently as it does at lower altitudes (Niyongere et al., 2012). Insect vector transmission of Xcm also declines with increasing elevation (Shimelash et al., 2008; Rutikanga et al., 2015), as insect populations and levels of insect activity significantly decline. The nematode *R. similis* is known to thrive at altitudes below 1,400 m, but their numbers and vigour drop off at higher altitudes (Speijer and De Waele, 1997). Climate change is thus likely to influence disease and pest spread, prevalence and incidence levels. For example, an increase in temperature could increase, at higher elevations, aphid transmission of BBTV and insect-mediated spread of Xcm. The potential interaction of human activities with changes in the climate could thus profoundly undermine the current benefits of low disease pressure and/or slower disease spread in the high-altitude sites.

Against this background, there is an outstanding need to assess the potential risk for the spread of these pests and diseases across banana production landscapes in the AGLR, especially in zones with altitude gradients. This need arises from the experience of outbreaks of many banana diseases over the last decades and their persistence in the affected landscapes. Information on banana pest and disease spread at a landscape level and the extent of the role of human agents in this spread is not well known. This study assessed the risk of banana pests and diseases spreading along four banana trade routes in western Burundi and eastern DR Congo. More specifically, the objectives were to: (i) identify the banana pests and diseases present in the study area and (ii) assess their potential to spread via the movement of: banana products along trade routes, labourers and their tools, taking into account the possible effect of altitude on their presence and spread.

These case studies are expected to provide reliable evidence on current disease/pest presence and an understanding of the risk of spread through human

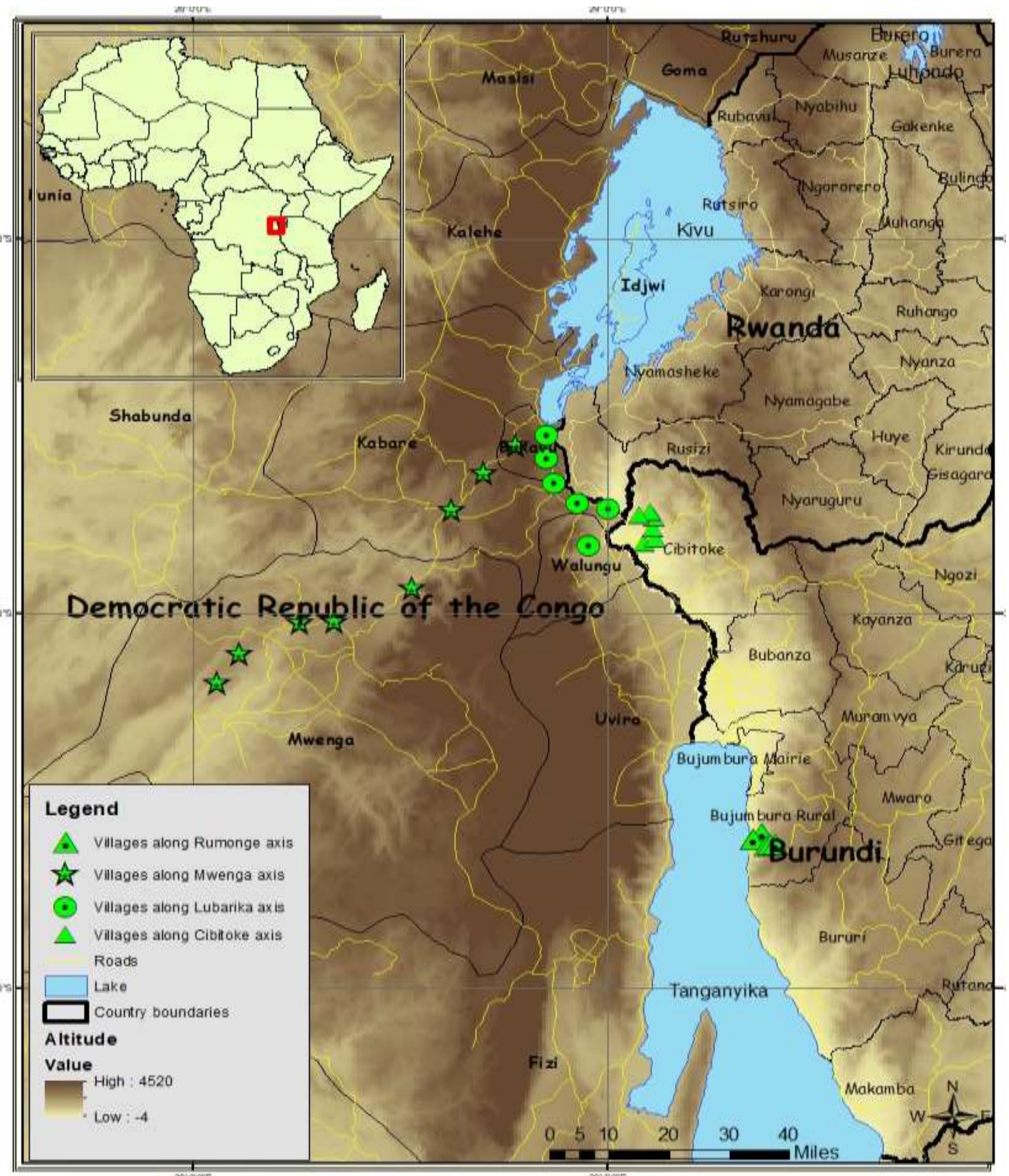


Figure 1. Map of study area with villages along the banana trade axes marked.

agents at landscape level in western Burundi and eastern DR Congo. The findings of the study will serve as a basis for suggesting management options which can reduce the risks of pest and disease spread across banana producing landscapes in the AGLR.

MATERIALS AND METHODS

This study was carried out along four banana trade axes, two in western Burundi and two in eastern DR Congo (Figure 1). This study determined the presence and the risk of spread of the most common and important banana pests and diseases, via the movement of banana bunches, other banana products (e.g. leaves for packaging, suckers for planting), labourers, traders and farm tools.

In eastern DR Congo, the pest risk assessment was conducted along two trade axes that run from lowland production regions in South Kivu Province towards the town of Bukavu (1,498 m) – the main banana consumption centre. In South Kivu, bananas are an important crop and cover 20 to 30% of cultivated land (Neyrinck, 2011). The first axis *Mwenga-Bukavu* starts from the village of Kibe (685 m) in Mwenga territory and moves towards Kasiru (1,996 m) in

Kabare territory; the *Lubarika-Bukavu* axis goes from the village of Lubarika (927 m) in Uvira territory to Mabijo (1,740 m) in Kabare territory (Figure 1).

In contrast, in Burundi, the two banana trade axes ran from high to low altitude production areas. These 2 axes are at a distance from the main market of Bujumbura, though products of the high-altitude zones are transported to Bujumbura through the lowland zones along Lake Tanganyika and the Rusizi valley. The *Rumonge* axis goes from the village of Gabaniro (799 m) to Muhowe (1,841 m), both in Muhuta province. The *Cibitoke* axis goes from the village of Munyika-1 (906 m) in Rugombo province to Mpinga (1,713 m) in Mabayi province (Figure 1). These 2 axes in Burundi, in contrast to the DR Congo axes, are located along shorter but very steep altitude gradients. The gradients for *Cibitoke* and *Rumonge* axes are 32.1 and 172 m/km, respectively, compared with -13.7 and -5.6 m/km for *Lubarika* and *Mwenga*, respectively.

Focus group discussions (FGDs) were carried out in a total of 27 villages along the 4 trade axes and the average distance between the villages was 15 km. The location (country and territory/province; axis) and altitude of these villages are presented in Supplementary Table S1 and Figure 1. In each village, 10 farmers (50% female; 50% male) who had been active in banana production and/or trade and aged between 30 and 80 years were selected to participate in the FGDs. It was assumed that these farmers had a rich experience and good knowledge of banana production and marketing activities in their respective regions. The geographical position of each village/ FGD was recorded using a hand-held GPS at a precision of approximately 10 m (Figure 1 and Supplementary Table S1).

Structured questionnaires were used to guide the FGDs. In addition, the FGD facilitators used a checklist to elicit information on the characteristics and management of their banana farms, key biotic constraints and trade related practices. Where necessary, participants were probed to triangulate responses and caution was taken to foster participation of all FGD participants. With respect to farm characteristics and management, farmers provided information on whether banana was predominantly intercropped or grown as sole crops across the village; grown for food or sold on the market, or both; and the role of men and women in banana farming. FGDs also provided information on the type and sources of labour used within villages; distance labourers travel; use in space and time of farm tools and associated tool sanitation practices; banana cultivars grown, and planting material types used. For the biotic stresses, the FGD participants were presented with images of disease/pest symptoms and/or illustrations of common pests, and were asked to confirm their presence in their landscapes. In addition, they were asked when a biotic constraint was first observed or reported. The FGDs also reported on the key management practices used within their landscapes for managing the abiotic constraints and their access to extension services. Through the FGDs, the risk of disease spread through trade was also explored. The FGD participants reported about the banana products traded, frequency of trade, distance to markets, and sanitation practices applied by farmers and traders on farm.

The actual presence of diseases and pests in the village was confirmed by experienced and trained researchers through on farm assessments on randomly selected farms. FGD participants were not informed in advance of the subsequent field assessments to avoid bias in the responses. In each of the villages, small plots of fifty banana mats made known to have these constraints were selected and examined, depending on reported presence, for visible symptoms of Fusarium wilt, BBTD, black sigatoka and XW. The number of infected mats was recorded and used to compute the percentage of infected mats per plot. Nematode and weevil damage was assessed on 5 mats per village. Nematode damage was assessed following the procedure described by Speijer and De Waele (1997) to calculate the root necrosis index. Banana roots in a 25 × 25 × 25 cm cube section, 10 cm from the plant pseudostem were dug out for nematode cord root damage assessment. Five functional cord roots were randomly selected per sampled plant, trimmed to 10 cm length, sliced lengthwise and percentage root necrosis in the exposed cortical tissue scored. Each of the five 10 cm root piece accounted for a maximum necrosis score of 20%, thus totaling to a necrosis score of 100% (Speijer and De Waele, 1997).

Banana weevil rhizome/corm damage was assessed on 5 harvest-ready mats, using a scale of 0 to 3, where 0: no damage, 1: slight damage (<10% rhizome cross section covered with weevil larvae tunnels), 2: moderate damage (11-30%) and 3: severe damage (>30% tunnel coverage).

The risk of the spread or introduction (entry and establishment) of pests and diseases in the study area was assessed using information related to the movement of banana products, labourers and traders, distances products move or people travel from infected areas, as well as presence and importance of hosts and other possible pathways by which pests and diseases can spread.

Quantitative information provided during FGDs or collected through on farm assessments to quantify the prevalence and damage levels of banana pests and diseases was directly analyzed to generate descriptive statistics using STATA version 14 (StataCorp, 2015). The qualitative information was used to explain the quantitative information after being summarized/synthesized with MS Excel. Regressions of the dependent variables (disease/pest incidence and prevalence) against altitude were conducted using the MS excel package.

RESULTS

Importance of banana

The importance of banana varied greatly from axis to axis, with banana ranked as the main crop in most of the villages along the *Lubarika* (67%) and *Cibitoke* axes (83%) compared with only 22% and 17% of villages along the *Mwenga* and *Rumonge* axes, respectively. In the study region, bananas are grown on a semi-commercial scale and are often produced for both cash (sale of bunches and banana beer) and food. In *Lubarika* and *Cibitoke*, 100% of the villages grew banana for both food and income. In *Mwenga*, 22% of the villages solely grew bananas for food, with the others growing for both food and income. In *Rumonge*, in contrast, 33% grew bananas solely as a cash crop, with the other 77% growing the crop for both food and income.

Banana pests and diseases

The key banana diseases that include BBTD, XW and two fungal diseases (BLS and Fusarium wilt) were encountered in nearly all the studied axes. Pests encountered included the banana weevil and nematodes. Nematodes were not identified to the species level in this survey, though *Pratylenchus goodeyi* is known to dominate in East African Highland banana production systems (Gaidashova et al., 2009; Kamira et al., 2013). For all pest and disease constraints, no significant associations (R^2 <0.1) were observed with the altitude. The oldest banana disease in the area in accordance with farmers' reports was BLS (64 years), followed by

Table 1. Pests and diseases as recognized by farmers and in brackets the time they have been present on their farms or landscape. Data were collected through Focus Group Discussions (FGDs) in villages located in different altitude ranges along four banana trade axes in eastern DR Congo and western Burundi.

Road axis	Altitude range (m)	No. of FGDs	Banana pests and diseases (% villages/FGDs reporting)					
			BBTD*	XW*	BLS*	Fusarium wilt	Banana weevils	Nematodes**
	<900	2	100.0 #(20.5)	0.0	0.0	100.0 (19.5)	100.0 (22.0)	0.0
	900-1200	2	100.0 (30.0)	0.0	0.0	50.0 (44.0)	100.0 (18.5)	50.0
Mwenga	1200-1500	3	100.0 (18.0)	0.0	33.3 (9.0)	33.3 (54.0)	66.7 (12.5)	33.3
	>1500	2	100.0 (14.0)	50.0 (1.0)	100.0 (64.0)	50.0 (14.0)	0.0 (-)	0.0
	Mean	9	100	12.5	33.3	58.3	66.7	20.8
	<900	0	-	-	-	-	-	-
	900-1200	2	100.0 (45.0)	100.0 (1.5)	50.0	0.0	0.0 (50.0)	0.0
Lubarika	1200-1500	1	100.0 (26.5)	100.0 (1.0)	0.0	0.0	0.0	0.0
	>1500	3	100.0 (21.5)	66.7 (4.5)	0.0	33.3 (5.0)	33.3 (36.3)	0.0
	Mean	6	100.0	88.9	16.7	11.1	11.1	0.0
	<900	1	100.0 (39.0)	100.0 (5.0)	0.0	0.0	100.0 (43.0)	0.0
	900-1200	1	100.0 (15.0)	100.0 (3.0)	100.0	0.0	100.0 (50.0)	0.0
Rumonge	1200-1500	0	100.0 (25.0)	100.0 (7.0)	0.0	0.0	100.0 (30.0)	0.0
	>1500	4	100.0 (17.3)	100.0 (2.7)	0.0	0.0	100.0 (36.3)	33.3 (41.0)
	Mean	6	100.0	100.0	25.0	0.0	100.0	8.3
	<900	0	-	-	-	-	-	-
	900-1200	4	100.0 (29.3)	100.0 (3.7)	0.0	25.0 (19.0)	50.0 (26.0)	0.0
Cibitoke	1200-1500	0	-	-	-	-	-	-
	>1500	2	100.0 (40.0)	100.0 (3.5)	0.0	50.0 (40.0)	0.0	0.0
	Mean	6	100.0	100.0	0.0	37.5	25.0	0.0
Overall mean		27	100.0	75.4	18.7	26.7	50.7	7.3

**Nematodes were not identified to genus or species level. *BBTD: Banana Bunchy Top Disease; XW: Xanthomonas wilt of banana; BLS: Black Leaf Streak. "-": no observation as there were no villages within this altitude range along the axis.

Fusarium wilt (54 years) and BBTD (45 years). XW was a more recent introduction in the area (1-7 years) (Table 1). Based on FGDs, BBTD was the most widespread disease (100% of the villages visited (Table 1). XW and weevils were also frequently mentioned. Fusarium wilt, black sigatoka and nematodes were much less frequently reported (Table 1). Along the *Mwenga axis*, XW was reported only for sites above 1500 m. This can be attributed to the fact that the XW outbreak in DR Congo first occurred in the eastern high-altitude areas around Masisi and is currently spreading westwards in the direction of the low-lying altitudes (Ocimati et al., 2019). In contrast, XW was reported at all sites along the *Lubarika*, *Rumonge* and *Cibitoke* axes (Table 1). In the DR Congo, BLS was reported in villages above 1200 m along the *Mwenga axis*, and only in those below 1200 m along the *Lubarika axis*. In Burundi, black sigatoka was only reported in villages between 900 and 1200 m in the *Rumonge* axis, and not at all along the *Cibitoke* axis. Fusarium wilt was reported in all altitude ranges along the *Mwenga* and *Cibitoke axes*, but only above 1500 m along the *Lubarika* axis and not at all along the *Rumonge axis* (Table 1). Banana weevils were reported in all villages along the *Rumonge axis,* in those below 1200 m and two thirds of those at 1200 to 1500 m along the *Mwenga axis,* and to a much lesser degree along the two other axes. On average, less than 8% of villages reported having observed the symptoms of nematodes, with only farmers located in villages between 900 and 1500 m along the *Mwenga axis* and those above 1500 m along the *Rumonge axis* reporting having observed nematode characteristic symptoms (that is, plant toppling) (Table 1).

Field assessments revealed BBTD to be present throughout the sites, within every altitude range though not in every village (Table 2). No XW infected plants were observed on farms in the villages along the *Mwenga axis*, while incidences ranging from 1 to 50%, were recorded in villages along the *Lubarika*, *Rumonge* and *Cibitoke axes* (Table 2). For the most part, FGD results and field observations of diseases such as BBTD, black sigatoka

Table 2. Pests and diseases recorded during researcher-led field assessments in villages located within different altitude ranges along the studied banana trade axes in eastern DR Congo and western Burundi. Field assessments in a landscape were conducted after the focus group discussions.

Road axis	Altitude range (m)	No. of Villages	Banana pests and disease incidence (%)					Nematode root necrosis index**
			BBTV*	XW*	BLS*	Fusarium wilt	Banana weevils	
Mwenga	<900	2	35.0	0.0	0.0	15.0	20.0	0.1
	900-1200	2	70.0	0.0	0.0	70.0	60.0	0.6
	1200-1500	3	31.7	0.0	30.0	5.0	65.0	3.6
	>1500	2	27.5	0.0	10.0	20.0	-	3.3
	Mean	9	41.1	0.0	10.0	27.5	48.3	1.9
Lubarika	<900	0	-	-	-	-	-	-
	900-1200	2	25.0	25.0	5.0	0.0	0.0	2.0
	1200-1500	1	10.0	1.0	0.0	0.0	0.0	2.5
	>1500	3	11.3	1.0	0.0	1.0	20.0	4.5
	Mean	6	15.4	9.0	1.7	0.3	6.7	3.0
Rumonge	<900	1	5.0	15.0	0.0	0.0	10.0	7.4
	900-1200	1	10.0	50.0	40.0	5.0	20.0	1.0
	1200-1500	0	20.0	40.0	0.0	0.0	5.0	0.6
	>1500	4	18.3	28.3	0.0	0.0	11.7	1.0
	Mean	6	13.3	33.3	10.0	1.3	11.7	2.5
Cibitoke	<900	0	-	-	-	-	-	-
	900-1200	4	11.3	5.0	0.0	20.0	12.0	2.0
	1200-1500	0	-	-	-	-	-	-
	>1500	2	5.0	50.0	0.0	15.0	0.0	2.0
	Mean	6	8.2	27.5	0.0	17.5	6.0	2.0
Overall mean			19.5	17.5	5.4	11.6	18.2	2.4

**Nematode presence was inferred from the Root Necrosis Index, as described in Speijer and De Waele (1997). *BBTD: Banana Bunchy Top Disease; XW: Xanthomonas wilt of banana; BLS: Black Leaf Streak. "-": No observation as there were no villages within this altitude range along the axis.

and Fusarium wilt overlapped, though the proportion reported by the FGDs was always greater than that observed in the field by scientists across all the sites and altitude ranges. Banana weevils were observed on plots across sites, including in areas where farmers had not reported seeing them in the past (Table 3). Mean nematode damage varied between 0.1 and 7.4% across the transects, with the highest nematode damage observed along the *Rumonge* axis (Table 2). No nematode damage was observed in *Lubarika*. Along the two other axes, nematodes were only found in a few plots within a single altitude range (Table 2). As for the reports given by farmers during the FGDs, the field pest and disease prevalence and incidence values were not influenced by the altitude (R^2 <0.1).

Risks of pest and disease spread and establishment due to human practices

Disease and pest spread, and establishment can be influenced by several agronomic practices that include: planting material type and movement, crop mixtures, cultivar diversity on farms and the use and management of farming tools.

Planting material type and movement

Planting materials play a critical role in the spread of banana pests and diseases. Access to clean and safe planting material was found to be a challenge across all the axes studied. Farmers predominantly used suckers to establish new fields or fill gaps in established fields, and no nurseries producing clean planting materials were present in the study area. Most farmers obtained suckers from their own farm (Table 3), though many farmers also obtained suckers in exchange for other goods, especially those in villages along the *Cibitoke axis*. Only in villages along the *Rumonge* and *Mwenga* axes do farmers buy suckers, with farmers in *Mwenga* purchasing suckers of all four banana types. The farmer's willingness to pay for

Table 3. Percentage of communities (represented by FGD groups) along the banana trade axes in eastern DR Congo and western Burundi who obtain suckers of various banana types from different sources, are willing to pay for clean planting material and the price they would pay for that material.

Road axis (n)	Banana type	% of communities who obtain suckers:				% of communities willing to pay for clean planting material	Price farmers are willing to pay for a clean planting material (US$)
		From own farm	As a gift	In exchange	From merchant		
Mwenga (9)	Beer	77.7	55.5	44.4	0.6	44.4	0.59
	Cooking	77.7	22.2	55.5	1.3	55.5	1.33
	Dessert	55.5	77.7	44.4	1.0	44.4	1.03
	Plantain	55.5	55.5	22.2	1.0	22.2	1.03
Lubarika (6)	Beer	100.0	0.0	50.0	0.6	50.0	0.58
	Cooking	83.3	0.0	50.0	0.4	50.0	0.36
	Dessert	100.0	0.0	33.3	0.4	33.3	0.36
	Plantain	100.0	0.0	33.3	0.4	33.3	0.36
Rumonge (6)	Beer	83.3	0.0	16.7	0.2	16.7	0.19
	Cooking	66.7	16.7	16.7	0.4	16.7	0.41
	Dessert	83.3	0.0	16.7	0.2	16.7	0.19
	Plantain	33.3	16.7	0.0	0.0	0.0	0.0
Cibitoke (6)	Beer	50.0	0.0	83.3	0.2	83.3	0.20
	Cooking	83.3	0.0	83.3	0.2	83.3	0.20
	Dessert	50.0	0.0	83.3	0.6	83.3	0.55
	Plantain	50.0	0.0	66.7	1.8	66.7	1.75

clean banana planting material was very high in *Cibitoke* (67-83%), moderate in *Mwenga* (22-56%) and *Lubarika* (33-50%) and low in the *Rumonge* (0-17%) axis (Table 3). Along the *Mwenga* axis, farmers were willing to pay from $0.59 to $1.33 for a clean planting material, depending on the banana type. The highest price for clean planting material was recorded for plantains ($1.75) along the *Cibitoke* axis. Elsewhere, farmers were only willing to pay lower prices for clean banana planting material, varying from $0.19 to $0.60 (Table 3).

About 81% of the Focus Groups reported that the planting material used came from within the village in which the farmers live (Table 4), while 25% reported that planting materials were obtained from within their parish, 11% from within their district, 4% from within the province and 3% from a neighbouring country. Though the 4 axes were located close to the border between Burundi and the DR Congo (Figure 1), not much cross-border sucker trade occurred. Some farmers travelled considerable distances to acquire suckers of specific banana types (e.g. *Mwenga* farmers travelled up to 50 km for beer banana suckers), while others barely travel at all, sourcing their suckers mostly from their own fields or neighbours in the village (e.g. farmers living along the *Lubarika axis*) (Table 4). The size of the area (from village to country) from which planting material is obtained greatly increases the chances of spreading diseases and pests over large distances.

Risk factors related to crop mixtures

On average, 76% of villages reported to intercrop banana with other crops (89% in *Mwenga*, 50% in *Lubarika*, 67% in *Rumonge* and 100% along the *Cibitoke* axis). The crops most frequently intercropped with bananas along the trade axes were legumes (71%) and tuber crops (68%) (Figure 2). No relationship was however observed between the intercropping practices and the prevalence of the pests and diseases.

Diversity of cultivars grown

Communities in visited villages grew a wide diversity of banana and plantain cultivars. The total number of cultivars grown varied between 20 and 58 across the axes (Table 5), while it varied between 6 and 18 per sampled village. In east DR Congo, the number of banana cultivars grown along the two axes was very dissimilar (58 in Mwenga vs. 21 in Lubarika). Of the banana cultivars grown in the DR Congo, plantains (36%) and beer types (38%) were the dominant banana types in Mwenga and Lubarika, respectively.

Along the *Rumonge* and *Cibitoke* axes, the beer (50%) and cooking (38%) banana cultivars, respectively, were the most abundant (Table 5). The green cooking cultivars are predominantly east African highland (*Musa* AAA) types. The predominant beer types comprised of the east

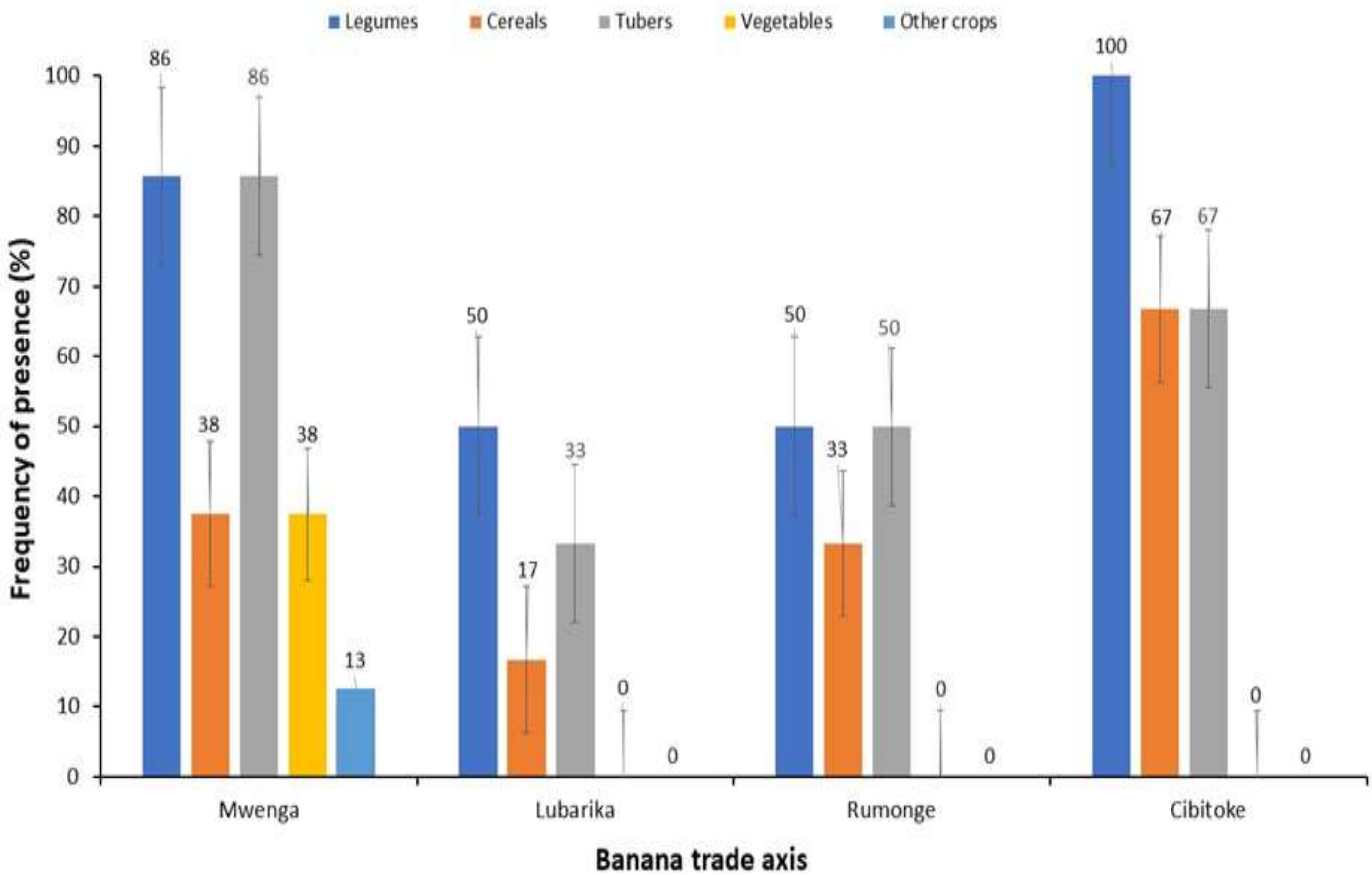


Figure 2. Occurrence (%) of various crops intercropped with bananas in plots along four studied banana trade axes in eastern DR Congo and western Burundi.

African highland banana types (in the high-altitude areas of *Mwenga, Lubarika, Rumonge* and *Cibitoke* axes), *Musa* ABB types (low altitude sites of *Rumonge* and *Cibitoke* axes) and km5 (*Musa* AAA) in the *Cibitoke* axes. The common dessert types included the Cavendish (*Musa* AAA), Gros Michel (*Musa* AAA) and apple bananas (*Musa* AAB).

Risks related to labourer and tool movements

Labour types (family or hired) varied across all the four axes. Only 33.3% of communities along the *Mwenga* axis reported using hired labour exclusively. Family labour exclusively and/or both types of labour sources combined were more prevalent across the road axes. Exclusive use of family labour occurred in 67, 50 and 17% of landscapes in *Mwenga*, *Rumonge* and *Lubarika*, respectively, while a combination of both family and hired labour occurred in 100%, 83% and 50% of the landscapes in *Lubarika*, *Cibitoke* and *Rumonge*.

The type (family or hired), source and movement of labour can increase the probability of spreading some diseases and pests, especially as labourers often move with their own tools from infected to non-infected areas. Between 33 and 100% of villages across the 4 study transects used hired labour from other villages/ communities in their banana plots (Table 6). The furthest distance the hired labourers travelled varied between 10 and 35 km. Risky practices of lending farming tools (83-100%) and joining labour groups (50-100%) were common across all the sites and can potentially expose non-infested plots to contamination.

Pest and disease risks related to banana product trade

The analysis of the movement of banana products via trade transactions focused on suckers, bunches, leaves, fibres, as well as handicrafts with attention to the way pathogens can be spread. Results revealed that banana bunches (100% of sites) and suckers (0-33%) were the main banana products traded (Table 7). Banana leaves, fibres and handicrafts were not found for sale or traded in the local markets or at the farm gate. The local markets within villages and parishes were the main destination of the banana bunches and suckers (Table 7).

The distance of markets for banana bunches were on average (56% of the villages) within one km of the villages (Table 8). Longer distances were travelled along the *Mwenga* and *Rumonge* transects to sell banana bunches (Table 8). Banana suckers were only traded along the *Mwenga* and *Lubarika* road axes, with all the trade occurring within a 0 to 5 km radius of the villages.

Even though banana is traditionally a man's crop in the study area, both men and women are involved in banana product marketing (Table 9). For example, in the eastern DR Congo transects, between 50 and 100% of villages reported that women play an important role in marketing bunches, compared to between 33 and 50% in Burundi. As for suckers only women were involved along the *Mwenga* transect whereas few men traded suckers in the *Lubarika* transect (Table 9).

The frequency of transactions was high for banana bunches while very low for suckers (Table 10). Between 67 and 83% of the communities reported trade in banana bunches once or twice in a week across the four transects. In contrast, 85% of the communities did not trade in suckers, with half of those that reported to trade in suckers, transacting once over the period in which suckers are actively planted. This is probably explained by the fact that commercialization of suckers is still limited, with most farmers being reliant on suckers from their own farms or from within their village (c.f. Table 3). It is also not common for small-scale farmers in the highland zones to sell or buy planting materials. At low elevation sites along the *Mwenga* axis cooking and plantain suckers were traded, while in the lowland sites along the *Lubarika* axis plantain and FHIA suckers were the predominant planting materials traded.

Potential role of traders in disease spread

Trade through either the movement of products and/or harvesting of bunches and suckers by traders have been reported to also contribute to disease spread. Along the four transects in this study, 33, 66.7, 100 and 66.7% of the communities in *Mwenga, Lubarika, Rumonge* and *Cibitoke* axes, respectively reported that traders use own tools to harvest banana bunches and to a much lesser extent suckers from their farms. More still, traders were reported to most often not sterilize their tools in between farm visits, a measure that is crucial for the control of XW spread.

Access to extension support

Access to knowledge and information on disease epidemiology and management is very important for minimising the risks associated with spread of pests and diseases. Access to extension services was low in Mwenga (33%) and very high in the other three road axes (83-100%) (Table 11). However, the frequency of access within a year was generally very low (2-5 times a year), with the highest frequency recorded for the Mwenga axis. Some of the communities along the Mwenga axis (22%) also had community by-laws, action plans and disease control committees. The presence of several international NGOs along the Mwenga axis might have contributed to the higher-level of contact with extension bodies and the use of by-laws/action plans and committees (Table 11). Except for Lubarika (11 km), distances to offices of extension bodies were short (1-3 km).

DISCUSSION

Pest and disease prevalence across four trade axes along low-high altitude gradients

BBTD which arrived in the central African rift valley region over 60 years ago (initially at the INEAC Lubarika Research Station in eastern DR Congo) (Blomme et al., 2013) is omnipresent in the study regions, including the high-altitude sites above 1500 m. This is supported by the low regression observed in the study between BBDT incidence and altitude. For long it had only been reported at low- to mid-elevation sites (<1500 m). The observed high prevalence of the disease at the high elevation sites above 1500 m in this study is of concern as the disease may gradually invade the high-altitude banana production zones of east and central Africa adjacent to the rift valley depression, especially under changing climatic conditions. BBTD is mainly spread through banana aphids and planting materials (Niyongere et al., 2012, 2015). Aphid-mediated spread at high altitudes is reported to be negligible (Niyongere et al., 2012, 2015). Given that the disease has been present in the study sites for 15 to 45 years, the observed spread to and within the high altitudes could be mainly attributed to short distance spread through infected planting materials which must have gradually occurred over numerous years. The weak extension support in the study locations over past decades could have only contributed to this spread. Farmers in the study region relied entirely on planting material from their own farms or their neighbourhood (on average 9 km) (cf. Table 4). Labour exchange between communities was common and labourers often move around with suckers from high-yielding cultivars that are not yet present on their farms or from highly-marketable cultivars. Xanthomonas wilt disease, though a more recent introduction (between 1 and 7 years), is already widely spread across most sections of all axes in the study region and is a cause of great concern. The rapid spread of XW can be attributed to its complex/multiple modes of spread that include: movement of infected planting materials, cross farm/cross village use of farm tools, and insect, bird and bat vectors that visit diseased and healthy banana

Table 4. Percentage of communities (represented by FGD groups) along the studied banana trade axes in eastern DR Congo and western Burundi who used various sources of suckers and their estimated travel distances irrespective of administrative boundaries to obtain planting material based on banana type.

Road axis (n)	Banana type	Sources of banana planting material used by farmers					Average distance farmers travel (km)
		Village	Parish	District	Province	Out of the country	
Mwenga (9)	Beer	77.7	55.5	44.4	11.1	0.0	51.2
	Cooking	88.8	33.3	11.1	0.0	0.0	11.4
	Dessert	100.0	33.3	22.2	11.1	11.1	18.5
	Plantain	55.5	33.3	11.1	0.0	0.0	26.3
	Mean	80.5	38.9	22.2	5.6	2.8	26.9
Lubarika (6)	Beer	100.0	0.0	0.0	0.0	0.0	1
	Cooking	100.0	0.0	0.0	0.0	0.0	1
	Dessert	83.3	0.0	0.0	0.0	0.0	1.2
	Plantain	100.0	0.0	0.0	0.0	0.0	1.2
	Mean	95.8	0.0	0.0	0.0	0.0	1.1
Rumonge (6)	Beer	100.0	33.3	0.0	0.0	0.0	1.7
	Cooking	66.7	0.0	0.0	0.0	16.7	13
	Dessert	83.3	16.7	0.0	0.0	0.0	1.2
	Plantain	16.7	33.3	0.0	0.0	0.0	1.8
	Mean	66.7	20.8	0.0	0.0	4.2	4.4
Cibitoke (6)	Beer	83.8	33.3	16.7	0.0	0.0	5
	Cooking	66.7	50.0	33.3	16.7	0.0	0.8
	Dessert	100.0	33.3	16.7	16.7	16.7	6
	Plantain	66.7	50.0	16.7	0.0	0.0	3.0
	Mean	79.3	41.7	20.9	8.4	4.2	3.0
Overall average		80.6	25.3	10.8	3.5	2.8	8.9

Table 5. Number and types of banana cultivars grown along the four banana trade axes studied in eastern DR Congo and western Burundi.

Road axis	Number (%) of banana cultivars by type/use group				Total number of cultivars	Range of N° of cultivars by axis
	Green cooking (%)	Beer (%)	Dessert (%)	Plantain (%)		
Mwenga	12 (21)	18 (31)	7 (12)	21 (36)	58	7 - 16
Lubarika	6 (29)	8 (38)	5 (24)	2 (10)	21	6 - 11
Rumonge	4 (20)	10 (50)	5 (25)	1 (5)	20	6 - 14
Cibitoke	13 (38)	11 (32)	8 (24)	2 (6)	34	6 - 18

In brackets, cultivar numbers are expressed as a percentage of the total number of cultivars for a given axis.

Table 6. Labour practices that can influence the spread of pests and diseases along the studied banana road axes in east DR Congo and Burundi.

Road axis	Hired labourers from other villages (%)	Furthest distance labourers travel to work (km)	Lending of farm tools (%)	Joining group labour (%)
Mwenga (9)	88.8	27.1	100.0	100.0
Lubarika (6)	100.0	35.2	83.3	100.0
Rumonge (6)	33.0	10.3	100.0	50.0
Cibitoke (6)	83.3	34.3	100.0	50.0
Mean (27)	76.3	26.7	95.8	75.0

Values represent averages calculated from responses given during Focus Group Discussions.

Table 7. Banana products traded in villages along the banana road axes studied in the DR Congo and Burundi.

Road axis (n)	Banana bunches		Banana suckers		
	Local market	Farm gate	No trade	Local market	Farm gate
Mwenga (9)	88.9	11.1	66.7	33.3	0.0
Lubarika (6)	100.0	0.0	83.3	0.0	16.7
Rumonge (6)	100.0	0.0	100.0	0.0	0.0
Cibitoke (6)	100.0	0.0	100.0	0.0	0.0
Mean (27)	95.2	4.8	85.2	11.1	3.7

Table 8. Percentage of villages that sell their banana products at local markets along the banana road axes studied in east DR Congo and Burundi.

Road axis (n)	Banana bunches				Banana suckers				
	0-1 km	>1-5 km	>5-10 km	>10 km	No sales	0-1 km	>1-5 km	>5-10 km	>10 km
Mwenga (9)	44.4	44.4	0.0	11.2	66.7	11.1	22.2	0.0	0.0
Lubarika (6)	83.3	0.0	0.0	16.7	83.3	16.7	0.0	0.0	0.0
Rumonge (6)	33.3	50.0	16.7	0.0	100	0.0	0.0	0.0	0.0
Cibitoke (6)	66.7	16.7	16.7	0.0	100	0.0	0.0	0.0	0.0
Mean (27)	55.6	29.6	7.4	7.4	85.2	7.4	7.4	0.0	0.0

Table 9. Household members involved in marketing banana bunches and suckers across villages along four road axes studied in east DR Congo and Burundi.

Road axis	Bunches			Suckers			
	Man	Woman	Both	No marketing	Man	Woman	Both
Mwenga	0.0	77.8	22.2	66.7	0.0	33.3	0.0
Lubarika	50.0	33.3	16.7	83.3	16.7	0.0	0.0
Rumonge	66.7	0.0	33.3	100	0.0	0.0	0.0
Cibitoke	50.0	0.0	50	100	0.0	0.0	0.0
Mean	37.0	33.3	29.6	85.2	3.7	11.1	0.0

Table 10. Frequency of banana trade transactions along the banana road axes studied in the DR Congo and Burundi.

Road axis	Banana bunches				Banana suckers			
	Twice per week	Once a week	Twice a month	Once a month	No trading	Twice a week	Once a week	Once a month
Mwenga	44.4	33.3	0.0	22.2	67.7	0.0	11.1	22.2
Lubarika	50.0	33.3	16.7	0.0	83.3	16.7	0.0	0.0
Rumonge	16.7	50.0	33.3	0.0	100	0.0	0.0	0.0
Cibitoke	83.3	0.0	16.7	0.0	100	0.0	0.0	0.0
Overall	48.2	29.6	14.8	7.4	85.2	3.7	3.7	7.4

Trading in suckers reflects transactions within rainy seasons when suckers are planted (planting takes place in the highlands dominated by AAA-EAH type bananas from September till March, while planting in the lowland plantain-dominated zones takes place during September and October).

inflorescences (Blomme et al., 2017, Blomme and Ocimati, 2018; Ocimati et al., 2019). For example, farmers entirely relied on planting material from own or neighbours' fields, the latter potentially contributing to cross-farm disease spread. Sharing and cross-farm use of farm tools was also common. These practices play

Table 11. Community access to extension services along four transects in eastern DR Congo and Burundi.

Road axis	Access to extension services (government, local and int. NGOs)	Number of contacts with extension agents over the past year	Presence of community by-laws, action plans, control committees	Distance to nearest extension office
Mwenga	33.3	5.0	22.0	3.0
Lubarika	83.3	2.0	0.0	10.7
Rumonge	100.0	2.0	0.0	1.0
Cibitoke	83.3	2.0	0.0	1.1
Overall	75.0	2.7	5.5	4.0

crucial role in XW spread. XW spread through trade, mainly by banana traders that harvest bunches indiscriminately across villages and farms using their own tools without sterilization has also been reported (Blomme et al., 2014; Nakato et al., 2013). However, trade in bunches was predominantly over short distances (that is, local markets) and this could have contributed to short distance and local spread of diseases, e.g. XW disease through infected crop residues (that is, fruit peels and peduncles).

Black leaf streak, Fusarium wilt, banana weevils and nematodes were present across most study axes. This agrees with Blomme et al. (2013) who reported the omnipresence of these biotic constraints across the whole of east and central African production zones. However, farmers' report of year of first observation of BLS (that is, as early as 1962) contradicts the first scientific reports that place the introduction of the disease in the AGLR in the 1980s (Sebasigari, 1990; Blomme et al., 2013). Farmers could have potentially confused the symptoms of BLS to yellow sigatoka (*Mycospharella musicola*). In Africa, *M. musicola* was reported in Uganda in 1938 (Stover, 1962). Six months from the first report in Uganda, separate outbreaks, about 160 to 320 km apart were reported along the East African coast. In 1941, *M.* musicola was also reported in Cameroon, West Africa, about 2,400 km away (Stover, 1962). BLS prevalence has been reported to be high at hot and humid lower altitude sites (Erima et al., 2017). The fact that no BLS was observed in lowland zones (<1200 m) along the Mwenga axis in eastern DR Congo can be explained by the short lifespan of plantains caused by poor suckering and weevil damage. Farmers mainly harvest the parent plant and sometimes the first ratoon. Regular plantain replanting is the norm in these production zones, which prevents disease build up. The omnipresence of the BLS-resistant 'km5' cultivar along the Lubarika and both Burundi axes might explain the often low BLS incidence values that were reported/observed.

Farmers' report of when they first observed Fusarium wilt (that is, as early as 1962) also contradicts the official scientific reports that place its introduction to a much later period, that is, before the 1980's (Blomme et al., 2013). However, already in the 1950s Fusarium wilt was reported in countries neighbouring DR Congo, Burundi and Rwanda (Blomme et al., 2013), suggesting that the disease could have arrived in DR Congo at an earlier date than what was officially reported. *Fusarium* species is commonly spread through planting materials and infected soils (adhered to e.g. shoes/boots, tools, motorcycle and car tires) (Ploetz, 2015; Dita et al., 2018).

Risk factors for pest and disease spread and build-up

Planting materials are an excellent means for the spread of banana pests and diseases and have been reported to play a major role in the spread of XW, BBTD, Fusarium wilt, nematodes and weevils in banana (Jacobsen et al., 2019). The short distance household members travelled to obtain banana planting materials (mean furthest distance of 9 km) suggests a possibly limited long distance spread of diseases and pests through planting materials. This suggests that planting material-borne diseases will only gradually spread over time. However, within short distance disease and pest spread (e.g. within villages) and build up through exchange or recycling of planting materials within fields would be high given most households mainly relied on suckers from own fields or from neighbouring fields.

Access to clean planting materials was limited across all the study sites due to the complete absence of tissue culture or macro-propagation facilities producing clean planting materials in eastern DR Congo and a long distance to such facilities in Burundi. Farmers' willingness to buy clean planting materials was however very variable (16-83%) and high along the *Cibitoke* axis, moderate along *Mwenga* and *Lubarika* axes while low at *Rumonge* axis. The high variation in farmers' willingness to invest in planting material could be influenced by agro-ecological conditions at their farms and villages, prevalence of pests and diseases and access to markets. For example, the demand for clean planting material in the *Cibitoke*, *Lubarika* and *Rumonge* axes was mainly attributed to the need for clean material to replant fields devastated by BBTD. In contrast, in the low elevation hot and humid forested regions of *Mwenga*, bananas were reported to have a short plantation life, thus farmers have to regularly re-establish banana plantations, thus the high demand for clean planting material. This short plantation life span can be attributed to the low suckering ability of plantains at this altitude and the high banana weevil burden observed in the study site compared with the other axes. Earlier studies by e.g. Sikyolo et al. (2013), have also reported low suckering, especially for plantains planted at low altitudes in eastern DR Congo, meanwhile in Uganda, the high weevil burden at the low elevation sites of central Uganda has been reported to primarily be responsible for the historical shift of banana production into the then pest-free south-western highland zones of Uganda (Gold et al., 1999). Despite the expressed demand for clean planting material, with the exception of Mwenga where farmers were willing to pay up to $1 per clean planting material, farmers in the other three axes were mainly willing to pay lesser amounts that may not attract or sustain investments in the production of clean planting materials in these regions.

A high banana cultivar diversity was reported across the four axes. The diversity of cultivars on farms can affect the spread and establishment of pests and diseases. Ocimati et al. (2018b) observed a lower XW incidence and prevalence with increasing number of banana cultivars, especially in mixtures consisting of the ABB cultivars (e.g. 'Pisang Awak') that are susceptible to insect mediated infections and cultivars with traits that escape insect-mediated infection (e.g. the east African highland banana 'Mbwazirume'). The cultivars with these traits have either persistent or semi persistent non-fruit forming/male flowers and male-bud bracts. Banana cultivar mixtures have also been shown to reduce the incidence of black sigatoka, banana weevils and nematodes (Mulumba et al., 2012). Although some genome groups in the study sites have a good level of tolerance or resistance to some of the pests and diseases, no clear patterns were observed between the level of pest and disease presence and the predominant *Musa* genome groups in a site.

Intercropping of bananas was predominant across the four axes. Intercropping with non-host crops has been reported to slow down the spread of some pests and diseases within fields and reduce disease incidence and severity (Mukiibi, 1982; Allen et al., 1989; Poeydebat et al., 2016; Vidal et al., 2017). The depression of pest and disease incidence in cultivar and or crop mixtures can be attributed to factors such as physical barriers to vectors and aerial pathogens, altered microclimate, a dilution effect, pathogen inhibition and host alteration (Sumner et al., 1981; Boudreau, 2013; Vidal et al., 2017). In contrast, banana intercropping with annual crops and other root and tuber crops in the study regions has often been associated with cutting of banana leaves to allow for more light to the understory crops (e.g. beans) and weeding/ earthing up using farm tools that often damage banana roots. These practices have been shown to potentially spread XW disease within banana fields (Ocimati et al., 2013, 2019; Blomme et al., 2017).

Hiring of external labour was a common practice across the study sites, with these labourers coming from other villages in 76% of cases. These labourers were reported to mainly move around with their own farm tools, boots and clothes. This can potentially allow for spread of soil borne nematodes and disease pathogens e.g. *Fusarium* spp. (in case of tools and boots) (Dita et al., 2018), fungal diseases e.g. black leaf streak (boots and clothes) (IICA, 2006) and XW disease (farm tools) (Blomme et al., 2017; Blomme and Ocimati, 2018). Labour was hired from or sold to an average distance of 27 km from the farms, suggesting that labourers can contribute to disease spread over low to moderate distances. Other risky practices included lending of farm tools and provision of labour in groups on a rotational basis. In both cases, the tools used, boots and clothes worn can spread diseases as described above.

Banana bunches and to a small extent suckers were the main banana products traded, mainly at the local markets that were between 1 and 10 km from the farm gate. The potential role of trade in disease spread through asymptomatic banana bunches containing ooze or traders tool used across farms has been reported for XW (Nakato et al., 2013). For example, the disease can be introduced into a farm if the buyer peels an infected fruit with a knife and thereafter uses it for e.g. pruning on own farm. The scope of the effect of sale of banana products is likely to vary from within the villages to as far as 100 km, though farmers had no knowledge of the exact distance their buyers travelled. For example, Bukavu which is 120 km from *Mwenga* is one of the destinations for banana bunches from *Mwenga*. Traders, in 33 to 100% of cases used their own tools to harvest bunches on banana fields. This practice has been reported to play an important role in XW spread in east and central Africa (Blomme et al., 2017).

Access to knowledge extension services was generally low across all study sites. Access to information on management and epidemiology of diseases is crucial for containment (Ocimati et al., 2019; Kikulwe et al., 2019), thus needs to be fostered.

This study points to various modes of disease/pest spread, which most likely also occurred over past decades. Regression analysis did not show a significant link between pest/disease presence and altitude, mainly due to the current omnipresence of the pest/diseases in the landscapes. Except for XW that is a more recent introduction but nevertheless spreads rapidly, the other pests and diseases were reported to be present in the region since several decades, over which time they have gradually spread. This has not been helped by the weak extension service support and interlinked low farmer knowledge on pest/disease control and prevented spread, over past decades, in both Burundi and eastern DR Congo.

Data for this study were collected through FGDs at landscape level. This limited/constrained the analysis to a landscape level. As such, further data exploration through a multivariate statistical analysis did not yield any relevant information. A regression analysis was carried out to determine the relations between disease and pest variables and altitude.

Information generated through this study is however relevant for the study sites and other banana growing locations in e.g. east and central Africa. This study could contribute to insights on the timely management of new pests and diseases of banana and could even provide useful insights applicable to other vegetatively propagated crops.

Climate change vs. pests and diseases

The observed prevalence of banana weevils and BBTD at the high-altitude sites raises a huge concern with respect to the current trends in climate change. Warming conditions with increasing rainfall and humidity could improve conditions for the survival of weevils at the high-altitude sites, previously known to be unfavourable for the multiplication of banana weevils. Though present at the high elevation banana production zones, the aphid that spreads BBTV has been known to be inefficient in BBTD spread at the high-altitude areas with lower temperatures. The acquisition and inoculation of banana bunchy top virus (BBTV) by the aphid *P. nigronervosa* has been shown to be affected by temperature (Wu and Su, 1990; Anhalt and Almeida, 2008). Wu and Su (1990) observed no BBTV transmission at 16°C and a maximum transmission efficiency at 27°C. Anhalt and Almeida (2008) observed a higher transmission efficiency of BBTV by the aphids at 25 and 30°C but a low efficiency a 20°C. Anhalt and Almeida (2008) also observed similar temperature effects on aphid fecundity and hypothesized a longer latent period at the lower temperature of 20°C. Given the current prevalence of BBTD at the cooler high elevations (presumed to be gradually and mainly spreading through planting materials), increasing temperatures at the high altitudes would create conducive conditions for the transmission of BBTV and increase the rate of disease spread and overall BBTD burden. This could also, gradually, place the highland production zones in eastern Africa at modest to high risk.

Warming of conditions at the high altitudes will also create a more conducive environment for the development and spread of BLS. BLS has in the past not been found at altitudes above 1350 m (Erima et al., 2017). However, more recent studies in the East and Central African region have reported *P. fijiensis* the causal agent of BLS at higher and cooler altitudes and this has been attributed to increasing temperatures (Erima et al., 2017; Kimunye et al., 2020). Higher altitude eco-regions are cool, favouring the reproduction of *P. goodeyi* (Pinochet et al., 1995; Gaidashova et al., 2009). A reduction in the area occupied by *P. goodeyi* and an increase in other nematode spp. (e.g. *R. similis*) currently limited to lowland zones could also be expected under increasing temperature regimes.

Currently the spread of XW at high elevation sites can be predominantly attributed to movement of contaminated farm tools and infected planting materials. At these altitudes, the activities of the insect vectors of XW are low (Rutikanga et al., 2015; Shimelash et al., 2008). Warmer climates would increasingly support insect-mediated spread of XW and thus increase its prevalence and severity at higher altitudes.

Conclusions

The present study identified key banana pests and diseases and several potential risk factors responsible for their spread and build up across different axes, with due consideration of altitude effects. The key banana pests of concern included nematodes and weevils while the diseases included XW, BBTD, Fusarium wilt and BLS. This study also provides insights in modes of spread that most likely already contributed to disease/pest spread over past decades in the study region. The main potential pathways of pest and disease spread included the movement of farming tools by labourers and traders (respectively, 10-35 km and often over 100 km), planting material/suckers (often less than 5 km) and banana products, especially bunches (mainly less than 5 km, but occasionally over 10 km; traders can transport bunches over larger distances to main urban markets).

Apart from Cibitoke (>65%) the willingness to buy clean banana planting materials was low (<50%). With the exception of Mwenga (for all cultivars), in the Cibitoke (dessert and plantains) and Lubarika axis (beer types only), farmers were willing to pay between \$0.6 and \$1.75 per clean planting material. The current price for clean planting materials in the region varies between \$0.6 and \$0.7 (Ntamwira Jules, personal communication, 2018) and values less than this could be a disincentive to the development of banana planting material enterprises in the study regions and a major bottleneck towards the management of pests and diseases. Use of crop or cultivar mixtures was common and could be harnessed to reduce the spread and build-up of pests and diseases. Envisaged changes in climate are likely to affect pest and disease build up and spread, and in case of warmer and more humid conditions, will lead to increased spread of BBTD, XW, BLS, weevils and some damaging nematode species at higher altitude zones. Fostering knowledge extension on pest and disease epidemiology and management can also help improve the demand for clean planting material and overall management of the biotic constraints, thus reducing further spread and/or build-up of these pests and diseases. This may also necessitate strengthening institutional capacities of actors (such as farmer institutions, labour associations, trader association) and stakeholders intervening in banana value chains in the region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

This study was supported by funds from the CGIAR Research Program on Roots, Tubers and Bananas, and the CGIAR Fund Donors.

REFERENCES

Actualitix (2016). Burundi: Ranking - Banana - Production (Tons). https://en.actualitix.com/country/bdi/burundi-banana-production.php (accessed on 1 August 2019).

Allen DJ, Dessert M, Trutmann P, Voss J (1989). Common beans in Africa and their constraints. pp. 9-31. In: Schwartz, H.F. and Pastor-Corrales. Bean production problems in the Tropics. CIAT, Cali, Colombia.

Anhalt MD, Almeida RPP (2008). Effect of temperature, vector life stage, and plant access period on transmission of Banana bunchy top virus to banana. Phytopathology 98(6):743-748.

Baret P, Van Damme J (2010). La culture bananière. Réponse à la sécurité alimentaire. Louvain P 184.

Blomme G, Dita M, Jacobsen KS, Pérez Vicente L, Molina A, Ocimati W, Poussier S, Prior P (2017). Bacterial Diseases of Bananas and Enset: Current State of Knowledge and Integrated Approaches toward Sustainable Management. Frontiers in Plant Science 8:1290. doi:10.3389/fpls.2017.01290.

Blomme G, Jacobsen K, Ocimati W, Beed F, Ntamwira J, Sivirihauma C, Ssekiwoko F, Nakato V, Kubiriba J, Tripathi L, Tinzaara W, Mbolela F, Lutete L, Karamura E (2014). Fine-tuning banana Xanthomonas wilt control options over the past decade in East and Central Africa. European Journal of Plant Pathology 139:265-281.

Blomme G, Ocimati W (2018). Xanthomonas bacterial wilt. Chapter 5: Diseases caused by bacteria and phytoplasmas. Handbook of diseases of banana, abacá and enset. (Ed. Jones, D.R.). CAB International pp. 296-313.

Blomme G, Ploetz R, Jones D, De Langhe E, Price N, Gold C, Geering A, Viljoen A, Karamura D, Pillay M, Tinzaara W, Teycheney PY, Lepoint P, Karamura E, Buddenhagen I (2013). A historical overview of the appearance and spread of Musa pests and pathogens on the African continent: highlighting the importance of clean Musa planting materials and quarantine measures. Annals of Applied Biology 162:4-26.

Boudreau MA (2013). Diseases in intercropping systems. Annual Review of Phytopathology 51:499-519.

Dita M, Barquero M, Heck D, Mizubuti E, Staver C (2018). Fusarium Wilt of Banana: Current Knowledge on Epidemiology and Research Needs Toward Sustainable Disease Management. Frontiers in Plant Science 9:1468.

Erima R, Kubiriba J, Komutunga E, Nowakunda K, Namanya P, Seruga R, Nabulya G, Ahumuza E, Tushemereirwe WK (2017). Banana pests and diseases spread to higher altitudes due to increasing temperature over the last 20 years. African Journal of Environmental Science and Technology 11:601-608.

Food and Agriculture Organization (FAO) (2019). Crops. [http://www.fao.org/faostat/en/#data/QC]. (Accessed on 6 June 2018).

Gaidashova S, Delvaux B, van Asten P, De Waele D (2009). Relationship between soil properties, crop management, plant growth and vigour, nematode occurrence and root damage in East African Highland banana-cropping systems: a case study in Rwanda. Nematology 11(6):883-894.

Gold CS, Karamura EB, Kiggundu A, Bagamba F, Abera AMK (1999). Monograph on geographic shifts in highland cooking banana (*Musa*, group AAA-EA) production in Uganda. African Crop Science Journal 7(3):223-298.

Gold CS, Messiaen S (2000). The Banana Weevil Cosmopolites Sordidus. Musa Pest Fact Sheet No. 4. pp.4. https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/The_banana_weevil_Cosmopolites_sordidus_696.pdf (accessed on 28 March 2020).

Hwang SC, Ko WH (2004). Cavendish Banana Cultivars Resistant to Fusarium Wilt Acquired through Somaclonal Variation in Taiwan. Plant Disease 88(6):580-588.

IICA (2006). Action Plan for Black Sigatoka *Mycosphaerella fijiensis* (Morelet). Miscellaneous Publications ISSN-0534-5391 CaRC/LC-06-004., Saint Lucia. P. 23. http://orton.catie.ac.cr/REPDOC/A0967I/A0967I.PDF (accessed on 24 July 2019).

IITA (2015). Value Chain Analysis of Major Food Crops in South Kivu and North Katanga. DR Congo. http://www.gcp21.org/wcrtc/ppt/S17presentation/S17-10.DontsopNguezetPaul.SIGNED.ID4625.424.pdf. (accessed on 30 March 2020).

Jacobsen K, Omondi BA, Almekinders C, Alvarez E, Blomme G, Dita M, Iskra-Caruana ML, Ocimati W, Tinzaara W, Kumar PL, Staver C (2019). Seed degeneration of banana planting materials: strategies for improved farmer access to healthy seed. Plant Pathology 68:207-228.

Kamira M, Hauser S, van Asten P, Coyne D, Talwana HL (2013). Plant parasitic nematodes associated with banana and plantain in eastern and western Democratic Republic of Congo. Nematropica 43:216-225.

Kamira M, Sivirihauma C, Ntamwira J, Ocimati W, Katungu MG, Bigabwa JB, Vutseme L, Blomme G (2014). Household uses of the banana plant in eastern Democratic Republic of Congo. Journal of Applied Biosciences 94:8915-8929.

Kikulwe EM, Kyanjo JL, Kato E, Ssali RT, Erima R, Mpiira S, Ocimati W, Tinzaara W, Kubiriba J, Gotor E, Stoian D, Karamura E (2019). Management of Banana Xanthomonas Wilt: Evidence from Impact of Adoption of Cultural Control Practices in Uganda. Sustainability 11(9):2610.

Kimunye JN, Were E, Mussa F, Tazuba A, Jomanga K, Viljoen A, Swennen R, Muthoni FK, Mahuku G (2020). Distribution of *Pseudocercospora* species causing Sigatoka leaf diseases of banana in Uganda and Tanzania. Plant Pathology 69(1):50-59.

Mobambo P, Staver C, Hauser S, Dheda B, Vangu G (2010). An innovation capacity analysis to identify strategies for improving plantain and banana (*Musa* spp.) productivity and value addition in the Democratic Republic of Congo. Acta Horticulturae 879:821-828.

Mukiibi JK (1982). Effects of intercropping on some diseases of beans and groundnuts. pp. 110-114. In: Keswani, C.L. and Ndunguru, B.J. ed., Proc. Second Symp. on Intercropping in Semi-Arid Areas. IDRC – 186e. IDRC, Ottawa.

Mukwa LFT, Muengula M, Zinga I, Kalonji A, Iskra Caruana ML, Bragard C (2015). Occurrence and distribution of Banana bunchy top virus related agro-ecosystem in South Western. Democratic Republic of Congo. American Journal of Plant Sciences 5(5):647-658.

Mulumba JW, Nankya R, Adokorach J, Kiwuka C, Fadda C, De Santis P, Jarvis DI (2012). A risk-minimizing argument for traditional crop varietal diversity use to reduce pest and disease damage in agricultural ecosystems of Uganda. Agriculture, Ecosystems and Environment 157:70-86.

Nakato GV, Beed F, Ramathani I, Rwomushana I, Opio F (2013). Risk of banana Xanthomonas wilt spread through trade. Journal of Crop Protection 2(2):151-161.

Ndungo V, Fiaboe KKM, Mwangi M (2008). Banana Xanthomonas Wilt in the DR Congo: Impact. spread and management. Journal of Applied Biosciences 1(1):1-7.

Neyrinck C (2011). L'impact du paillage et du non labour sur le ruissellement et l'érosion dans les systèmes bananes haricots dans

la région du Sud-Kivu. Master Thesis. Université Catholique de Louvain. Belgium.
Niyongere C, Losenge T, Ateka EM, Nkezabahizi D, Blomme G, Lepoint P (2012). Occurrence and Distribution of Banana Bunchy Top Disease in the Great Lakes Region of Africa. Tree and Forestry Science and Biotechnology 6(1):102-107.
Niyongere C, Omondi AB, Blomme G (2015). The Banana bunchy top disease. In: Tennant P. and Fermin G. (eds). *Virus diseases of tropical and subtropical crops*. CAB International Plant Protection Series 12/2015. Wallingford, United Kingdom. pp. 17-26. http://www.cabi.org/bookshop/book/9781780644264
Ocimati W, Bouwmeester H, Groot JC, Tittonell P, Brown D, Blomme G (2019). The risk posed by Xanthomonas wilt disease of banana: Mapping of disease hotspots, fronts and vulnerable landscapes. PloS ONE 14(4):e0213691.
Ocimati W, Groot JCJ, Tittonell P, Taulya G, Blomme G (2018a). Effects of Xanthomonas wilt and other banana diseases on ecosystem services in banana-based agroecosystems. In: *International Symposium on Banana/ISHS-ProMusa symposium: Agroecological approaches to promote innovative banana production systems.* International Society for Horticultural Science pp. 19-32.
Ocimati W, Ssekiwoko F, Karamura EB, Tinzaara W, Blomme G (2013). Does *Xanthomonas campestris* pv. *musacearum* colonize banana cord root tissue? Acta Horticulturae 986:103-109.
Ocimati W, Were E, Groot JC, Tittonell P, Nakato GV, Blomme G (2018b). Risks posed by intercrops and weeds as alternative hosts to *Xanthomonas campestris* pv. *musacearum* in banana fields. Frontiers in Plant Science 9:1471.
Pinochet J, Fernandez C, Sarah JL (1995). Influence of temperature of *in vitro* reproduction of *Pratylenchus coffeae*, *P. goodeyi*, and *Radopholus similis*. Fundamental and Applied Nematology 18(4):391-392.
Ploetz RC (2001). Black Sigatoka of Banana: The most important disease of a most important fruit. The Plant Health Instructor P. 7. https://www.apsnet.org/edcenter/apsnetfeatures/Pages/BlackSigatoka.aspx
Ploetz RC (2015). Fusarium wilt of banana. Phytopathology 105:1512-1521.
Poeydebat C, Carval D, De Lapeyre de Bellaire L, Tixier P (2016). Balancing competition for resources with multiple pest regulation in diversified agroecosystems: a process-based approach to reconcile diversification and productivity. Ecology and Evolution 6(23):8607-8616.
Rutikanga A, Night G, Tusiime G, Ocimati W, Blomme G (2015). Spatial and temporal distribution of insect vectors of *Xanthomonas campestris* pv. *musacearum* and their activity across banana cultivars grown in Rwanda. In Proceedings of the 7th Congress on Plant Protection" Integrated Plant Protection- a Knowledge-Based Step Towards Sustainable Agriculture. Forestry and Landscape Architecture". November 24-28. 2014. Zlatibor. Serbia (pp. 139-153). Plant Protection Society of Serbia (PPSS).
Sebasigari K (1990). Effect of black Sigatoka (*Mycosphaerella fijiensis* Morelet) on bananas and plantains in the Imbo Plain in Rwanda and Burundi. In: Sigatoka leaf spot diseases of bananas: Proceedings of an international workshop'. Costa Rica. (Eds RA Fullerton, RH Stover). (INIBAP).
Shimelash D, Alemu T, Addis T, Turyagyenda FL, Blomme G (2008). Banana Xanthomonas wilt in Ethiopia: occurrence and insect vector transmission. African Crop Science Journal 16:75-87.
Sikyolo I, Sivirihauma C, Ndungo V, De Langhe E, Ocimati W, Blomme G (2013). Growth and Yield of Plantain Cultivars at Four Sites of Differing Altitude in North Kivu, Eastern Democratic Republic of Congo. In: Blomme, G., van Asten, P. & Vanlauwe, B. (eds.): Banana systems in the humid highlands of sub-Saharan Africa: Enhancing resilience and productivity. CABI, Wallingford, Oxfordshire, UK. pp. 48-57.
Speijer PR, De Waele D (1997). Screening of Musa germplasm for resistance and tolerance to nematodes (Vol. 1). IITA.
StataCorp (2015). Stata Statistical Software: Release 14. College Station, TX: StataCorp LP.
Stover RH (1962). Intercontinental spread of banana leaf spot (*Mycosphaerella musicola* Leach). Tropical Agriculture (Trinidad) 39:327-338.
Sumner DR, Doupnik Jr B, Boosalis MG (1981). Effects of reduced tillage and multiple cropping on plant diseases. Annual Review of Phytopathology 19:167-187.
Vidal T, Boixel A, Durand B, de Vallavieille-Pope C, Huber L, Saint-Jean S (2017). Reduction of fungal disease spread in cultivar mixtures: Impact of canopy architecture on rain-splash dispersal and on crop microclimate. Agricultural and Forest Meteorology 246:154-161.
Wu RY, Su HJ (1990). Transmission of banana bunchy top virus by aphids to banana plantlets from tissue culture. Botanical Bulletin of Academia Sinica 31(1):7-10.

Table S1. Location of villages in which focus group discussions were held along the four banana trade axes studied in western Burundi and eastern DR Congo, and distances along a straight axis from the main markets (that is, Bukavu for DR Congo and Bujumbura for Burundi).

Country	Banana trade axis	Territory / province	Village name	Village altitude (m)	Distance along a straight axis from main market (km)
DR Congo	*Mwenga*	Mwenga	Kibe	685	114.1
			Tukenga	689	116.4
			Kilungutwe	1032	-
			Ngenje	1146	60.5
			Kibanja	1203	81.7
			Kalole	1310	90.0
		Walungu	Bwahungu	1454	34.9
			Cikamba	1641	22.7
		Kabare	Kasiru	1996	10.7
	Lubarika	Uvira	Lubarika	927	43.0
		Walungu	Kashenyi	980	28.7
			Rushebeyi	1260	27.4
			Nyamurabwe	1611	19.5
		Kabare	Cihugi-1	1657	10.8
			Mabijo	1740	3.7
Burundi	*Rumonge*	Muhuta	Gabaniro	799	27.2
		Kabezi	Ceri	1062	25.3
		Muhuta	Muhuta-2	1603	26.7
			Gatwenzi	1713	28.8
			Muhuta-1	1765	28.5
			Muhow	1841	28.6
	Cibitoke	Rugombo	Munyika-1	906	67.5
			Rugerere	1088	67.9
			Kinama	1167	73.6
		Mugina	Muyange	1199	71.9
		Mabayi	Kirinzi	1582	75.4
			Mpinga	1713	76.2

Vol. 16(9), pp. 1270-1277, September, 2020
DOI: 10.5897/AJAR2020.14950
Article Number: 922910E64817
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Enhancing maize production in a *Striga* infested environment through weed management practices, sowing date and improved crop varieties

Aliyu Baba Mohammed*, Emmanuel Daniya and Musa Gimba Matthew Kolo

Department of Crop Production, Federal University of Technology, P.M.B. 65, Minna, Nigeria.

Received 3 May, 2020; Accepted 14 August, 2020

A two-year investigation into the effects of weed management practices, sowing dates and maize varieties was made in a *Striga* endemic field at Minna, Nigeria. The treatment was a factorial combination of variety (SAMMAZ 15, 17, 37, 40 and SUWAN-1-SR-Y), weed management practices (weedy check, two hoe weeding (HW) at 3 + 6 weeks after sowing (WAS), pre-emergence (PE) Atrazine at 2.4 kg a.i ha^{-1} + 1 HW at 6 WAS and PE Atrazine at 2.4 kg ha^{-1} + post-emergence (POE) Nicosulfuron at 0.06 kg ha^{-1} at 6 WAS) and sowing dates: early (28th May), mid-season (18th June) and late-season (9th July) in 2018 and early-season (26th May), mid-season (16th June) and late-season (7th July) in 2019 laid in a split plot arranged in a randomized complete block with three replications. Maize variety and weed management practices were combined as the main plot and sowing dates constituted the subplot. Delayed *Striga* shoot emergence and reduced shoot density were observed in SAMMAZ 15 and 40 and higher grain yield with SAMMAZ 17 in 2018 and 2019. Application of Atrazine plus Nicosulfuron significantly delayed *Striga* shoot emergence, reduced shoot density and higher maize grain yield in both years. Sowing in May significantly delayed *Striga* shoot emergence and reduced shoot density in both years. Sowing in June significantly increased maize grain yield in 2018 and 2019. These results suggest that SAMMAZ 15 and 40 in combination with PE Atrazine at 2.4 kg a.i ha^{-1} and POE Nicosulfuron at 0.06 kg a.i ha^{-1} and sowing in May effectively reduced *Striga* infestation. SAMMAZ 17 in combination with PE Atrazine at 2.4 kg a.i ha^{-1} and POE Nicosulfuron at 0.06 kg a.i ha^{-1} and sowing in June increased maize grain yield.

Key words: Maize variety, sowing date, *Striga,* weed management.

INTRODUCTION

The witchweed (*Striga hermonthica* (Del.) Benth) is among the serious biotic constraints affecting cereal crops production in sub-Sahara Africa (Ekeleme et al., 2011). These authors also claim that about 17 million hectares representing 64% of land put to cereal production in West Africa are under *Striga* infestation. *Striga* infestation remains endemic in many maize producing belts of Nigeria and accounts for grain yield losses that vary between 30 to 70% (Kamara et al., 2014). Under these circumstances, farmers have been made to abandon their farmlands.

It is thus suggested that the use of improved cultivars

*Corresponding author. E-mail: mohammedaliyubaba@gmail.com. Tel: +234 7062630200.

and appropriate sowing dates can help to control *Striga* infestation (Ekeleme et al., 2011). To reduce losses in maize yield due to *Striga* infestation, the use of tolerant or resistant varieties has been suggested (Kanampiu et al., 2018). Progress has been made by researchers in maize breeding in the area of identifying genotypes that are tolerant or resistant to *Striga* (Kanampiu et al., 2018; Adesina and Akinwale, 2014). It is practicable and compatible with the low-cost input technology of the resource-poor farmer (Kamara et al., 2014). Olaniyan (2015) noted that several *Striga* infections can cause total crop loss in maize and sorghum and losses can be much higher under heavy infestation, even resulting in total crop failure.

Manipulating the sowing date of maize can be used to reduce the yield losses caused by *Striga* infestation. As noted by Ekeleme et al. (2011), sowing date can be used as an essential component of crop management to control *Striga* infestation in cereal crop production. In a previous study, in the northern and southern Guinea savanna of Nigeria, Ekeleme et al. (2011) noted a reduction in *Striga* infestation when maize was sown in mid-July compared to mid-May or mid-June. Also, Dugje et al. (2008) reported that grain yield was lower when maize was sown in mid-July compared to mid-June in the Guinea savanna of Nigeria.

Herbicide use has been reported to be more efficient than hoe-weeding in the production of various crops in Nigeria (Imoloame, 2014). Hoe weeding is a weed management method used in controlling *Striga* and increasing maize yield, but it is laborious and time-consuming. Despite the use of several management methods adopted in controlling *Striga*, no single control approach has been reported to be effective in controlling the weed, as such, the development of integrated *Striga* control is the alternative for maize production in a *Striga* infested environment (Teka, 2014).

Research on performance of *Striga* tolerant maize varieties with different weed management practices and sown at different dates under naturally *Striga* infested condition are scarce in this agro-ecology of Nigeria. Therefore, the objective of this study was to assess the combined effects of weed management practices and time of sowing on *Striga* infestation, growth, yield and yield attributes of some *Striga* tolerant maize varieties.

MATERIALS AND METHODS

Experimental site

A field study was conducted at the Teaching and Research Farm of the Federal University of Technology, Gidan Kwano (latitude 09° 31′N, longitude 06° 27′E, 212 m above sea level) during the rainy seasons (May – October) of 2018 and 2019. The experimental site is located in the southern Guinea savanna of Niger State, Nigeria. The soil at Gidan Kwano, prior to field establishment was loamy sand, with organic carbon of 3.6 g kg^{-1}, N 0.014 g kg^{-1}, P 11.5 mg kg^{-1}, K 0.08 cmol kg^{-1} and pH ($CaCl_2$) 5.5 in 2018. Prior to trial establishment in 2019, the soil was loamy sand, with organic carbon of 2.3 g kg^{-1}, N 0.012 g kg^{-1}, P 10.3 mg kg^{-1}, K 0.09 cmol kg^{-1} and pH ($CaCl_2$) 5.2. The area has an average annual rainfall of 1247 mm, a maximum and minimum temperatures of 33.54 and 22.55°C respectively (Olayemi et al., 2014). The field used was chosen based on verified history of notable build-up of *Striga* infection due to continuous cultivation of maize and sorghum over the years.

Experimental treatments and design

Five maize varieties (SAMMAZ 15, 17, 37, 40) and SUWAN-1-SR-Y were evaluated. The SAMMAZ varieties are medium maturing, open-pollinated, tolerant to *Striga*, non-tillering, and have high yield potential and are adapted specifically for the savanna zones of Nigeria; and SUWAN-1-SR-Y is a *Striga* susceptible variety). The treatments were a factorial combination of variety (SAMMAZ 15, 17, 37, 40 and SUWAN-1-SR-Y) and weed management practices [weedy check, two hoe weeding (HW) at 3 + 6 weeks after sowing (WAS)], pre-emergence (PE) Atrazine at 2.4 kg a.i ha^{-1} + 1 HW at 6 WAS and PE Atrazine at 2.4 kg ha^{-1} + post-emergence (POE) Nicosulfuron at 0.06 kg ha^{-1} at 6 WAS) and sowing dates: early (28th May), mid-season (18th June) and late-season (9th July) in 2018 and early-season (26th May), mid-season (16th June) and late-season (7th July) in 2019. Sowing dates were determined based on the establishment of rainfall in the experimental area. Main plot treatments were variety and weed management practices, and sowing date was assigned to the subplot. The experiment was a split-plot arranged in a randomized complete block design and replicated three times. Gross plot size was 4 x 3 m of four ridges 4 m long each.

Cultural practices

Before sowing, the land was manually cleared and ridged with a handheld hoe at 75 cm apart. Each maize variety was treated with Apron Star® 42 WS (thiamethoxam 200 g kg^{-1}, metalaxyl-M 200 g kg^{-1} and Difenoconazole 20 g kg^{-1}) at 10 g per 4 kg of seed. Three seeds of maize were sown per hole on ridges at an intra-row spacing of 50 cm and later thinned to two plants per stand at 2 WAS. Weed management was done as per the treatment combinations of the study. Fertilizer NPK 15:15:15 was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O. A basal dose rate of 60 kg N, 60 kg P_2O_5 and 60 kg K_2O was applied at 3 WAS by side placement, 5 cm from the plant stand. The remnant dose of nitrogen at 60 kg N from urea was side dressed at 6 WAS.

Data collection

Days to first *Striga* shoot emergence was determined as the number of days from sowing to when the emergence of *Striga* was observed in each plot. *Striga* shoot density was taken by counting the number of *Striga* shoots within a plot at 8 and 10 WAS and converted to per meter square. Maize plant height was measured in centimetres, from five randomly tagged plants from the soil level to the collar of the uppermost leaf at 6 and 9 WAS. For yield determination, all the ears were harvested from each treatment net plot at mass maturity, dehusked, and further sun-dried to constant weight. Cob length was measured in centimetre from the base of the cob to the tip from five randomly selected cobs and the mean used for analysis. Grain yield was determined by shelling and winnowing the cobs harvested in each treatment net plot to obtain clean grains. The grains were weighed and expressed in kg ha^{-1}.

Data analysis

Data on *Striga* count was square root transformed to improve the

Table 1. Effect of maize variety, weed management practices and sowing date on number of days to first *Striga* shoot emergence in 2018 and 2019 rainy seasons.

Treatment	Number of days to *Striga* shoot emergence	
	2018	2019
Variety (V)		
SAMMAZ 15	43.0	50.0
SAMMAZ 17	42.0	47.0
SAMMAZ 37	41.0	46.0
SAMMAZ 40	44.0	51.0
SUWAN-1-SR-Y	39.0	42.0
LSD (0.05)	1.67	2.92
Weed management (M)		
Weedy check	37.0	35.0
2 HW	43.0	48.0
PE Atrazine + 1 HW	44.0	48.0
PE Atrazine + POE Nicosulfuron	43.0	56.0
LSD (0.05)	1.50	2.61
Sowing date (S)		
Early	44.0	58.0
Mid	41.0	47.0
Late	40.0	36.0
LSD (0.05)	1.30	2.63
Interaction		
V x M	NS	NS
S x V	*	*
S x M	NS	NS
S x V x M	NS	NS

LSD, least significant difference; NS, not significant; * - significant at 5 % level of probability.

normality prior to statistical analysis. All the data obtained from the experiment were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) version 9.0 (SAS Institute, 2009). Treatments were compared using the least significant difference (LSD) at 5 % level of probability.

RESULTS

Days to first *Striga* shoot emergence

The results show that SAMMAZ 15 and SAMMAZ 40 recorded significantly longer days to *Striga* shoot emergence than the other varieties in the two years of study (Table 1). Plots with two hoe weeding at 3 and 6 WAS, application of PE Atrazine + hoe weeding at 6 WAS and PE Atrazine + POE Nicosulfuron at 6 WAS similarly delayed *Striga* shoot emergence than weedy check plot in 2018 (Table 1). In 2019, the application of PE Atrazine + POE Nicosulfuron significantly delayed *Striga* shoot emergence than the other weed management practices. In terms of sowing date, early-season sowing consistently and significantly delayed days to first *Striga* shoot emergence compared to other sowing dates (Table 1).

The interaction between sowing date and variety on days to first *Striga* shoot emergence in 2018 and 2019 is shown in Table 2. In 2018, under SAMMAZ 17, SAMMAZ 40 and SUWAN-1, there was no significant response on days to first *Striga* shoot emergence as sowing date was delayed. However, under SAMMAZ 15 and SAMMAZ 37, early season sowing delayed days to first *Striga* shoot emergence in this study. In 2019, irrespective of the varieties, there was a greater delay in days to first *Striga* shoot emergence with early-season sowing of maize.

Striga shoot density

The number of *Striga* shoot density m^{-2} was lowest in SAMMAZ 15 at 8 and 10 WAS in both years of study and similar with SAMMAZ 17, 37 and 40 at 8 and 10 WAS in

Table 2. Interaction effects between sowing date and variety on number of days to first *Striga* shoot emergence in 2018 and 2019 rainy seasons.

Sowing date	Variety				
	SAMMAZ 15	**SAMMAZ 17**	**SAMMAZ 37**	**SAMMAZ 40**	**SUWAN-1**
Days to first *Striga* shoot emergence in 2018					
Early	47.0	44.0	46.0	43.0	40.0
Mid	42.0	41.0	39.0	45.0	39.0
Late	41.0	41.0	37.0	43.0	37.0
LSD (0.05)			3.01		
Days to first *Striga* shoot emergence in 2019					
Early	58.0	59.0	57.0	64.0	52.0
Mid	54.0	45.0	45.0	52.0	41.0
Late	37.0	36.0	35.0	37.0	33.0
LSD (0.05)			5.25		

LSD, least significant difference.

Table 3. Effects of maize variety, weed management practices and sowing date on *Striga* shoot density m^{-2} at 8 and 10 WAS in 2018 and 2019.

Treatment	*Striga* shoot density m^{-2}			
	2018		2019	
	8 WAS	**10 WAS**	**8 WAS**	**10 WAS**
Variety (V)				
SAMMAZ 15	2.0	2.0	1.0	2.0
SAMMAZ 17	2.0	3.0	1.0	2.0
SAMMAZ 37	2.0	3.0	1.0	2.0
SAMMAZ 40	2.0	3.0	1.0	2.0
SUWAN-1-SR-Y	3.0	3.0	2.0	3.0
LSD (0.05)	0.14	0.13	0.12	0.16
Weed management (M)				
Weedy check	3.0	4.0	3.0	4.0
2 HW	2.0	3.0	1.0	2.0
PE Atrazine + 1 HW	2.0	3.0	1.0	2.0
PE Atrazine + POE Nicosulfuron	1.0	1.0	0.0	0.0
LSD (0.05)	0.13	0.12	0.11	0.14
Sowing date (S)				
Early	2.0	2.0	1.0	1.0
Mid	2.0	3.0	1.0	2.0
Late	2.0	3.0	2.0	2.0
LSD (0.05)	0.11	0.10	0.09	0.12
Interaction				
V x M	NS	**	NS	NS
S x V	NS	**	NS	NS
S x M	NS	NS	NS	**
S x V x M	NS	NS	NS	NS

LSD, least significant difference; NS, not significant; *significant at 5% level of probability.

2019 (Table 3). Application of PE Atrazine + POE Nicosulfuron at 8 and 10 WAS in 2018 and 2019 had significantly lower *Striga* shoots than the other treatments (Table 3). However, early-season sowing had the least

Table 4. Interaction effects between variety and weed management practices on *Striga* shoot density at 10 WAS in 2018.

Variety	Weed management practices			
	Weedy check	2 HW	PE Atrazine + 1 HW	PE Atrazine + POE Nicosulfuron
SAMMAZ 15	4.0	3.0	2.0	1.0
SAMMAZ 17	4.0	4.0	3.0	1.0
SAMMAZ 37	4.0	4.0	3.0	1.0
SAMMAZ 40	4.0	3.0	2.0	1.0
SUWAN-1	4.0	4.0	4.0	2.0
LSD (0.05)			0.20	

LSD, least significant difference.

Table 5. Interaction effects between sowing date and variety on *Striga* shoot density at 10 WAS in 2018.

Sowing date	Variety				
	SAMMAZ 15	SAMMAZ 17	SAMMAZ 37	SAMMAZ 40	SUWAN-1
Early	2.0	3.0	3.0	2.0	3.0
Mid	3.0	3.0	3.0	3.0	4.0
Late	3.0	3.0	3.0	3.0	4.0
LSD (0.05)			0.24		

LSD, least significant difference.

number of *Striga* shoots at all the sampling times than all the other sowing times (Table 3).

The interaction between variety and weed management practices on *Striga* shoot density at 10 WAS in 2018 was significant (Table 4). In this case, irrespective of the variety there was a low *Striga* shoot density with the application of PE Atrazine + POE Nicosulfuron. The effect was similar to the application of PE Atrazine + hoe weeding at 6 WAS with SAMMAZ 15 or SAMMAZ 40.

The interaction effects were significant between sowing date and variety on *Striga* shoot density at 10 WAS in 2018 which showed that early season sowing with SAMMAZ 15 or SAMMAZ 40 had lower *Striga* shoot density than the other treatment combinations (Table 5).

The interaction effects were significant between sowing date and weed management practices on *Striga* shoot density at 10 WAS in 2019 which showed that mid- and late-season sowing under PE Atrazine + POE Nicosulfuron had lower *Striga* shoot density than the other treatment combinations (Table 6).

Maize grain yield

Grain yield of maize was significantly higher in SAMMAZ 17 plots compared with other varieties in the two years of study (Table 7). Furthermore, application of PE Atrazine + POE Nicosulfuron at 6 WAS produced significantly higher grain yield but at par with plots given PE Atrazine + hoe weeding at 6 WAS in 2018 (Table 7). The weedy check had the lowest maize grain yield in both years. However, under sowing date, mid-season sowing had a significantly higher grain yield compared to maize sown early and late in the season in both years (Table 7).

Sowing date and weed management practices showed significant interaction effects on maize grain yield in 2018 and 2019 such that there was an increase in grain yield from early- to mid-season sowing beyond which there was a significant decline in both years (Table 8). Plots with mid-season sowing in combination with either hoe weeding at 3 and 6 WAS, in 2018 or application of PE Atrazine + POE Nicosulfuron in 2018 and 2019 had the highest grain yield of maize in this study.

DISCUSSION

The ability of SAMMAZ 15 to delay *Striga* shoot emergence and reduced *Striga* shoot density could be due to the less strigol stimulant secretion and release into the soil environment by the host crop which inhibited *Striga* germination and/or slowed seedling growth and shoot emergence. Also, the variety genetic inheritance might have inhibited *Striga* seed germination, seedling attachment or shoot emergence than the other varieties. This finding is in agreement with the work of Magani et al. (2011) who reported that genetic variation exists among maize germplasm in response to *Striga* parasitism.

Table 6. Interaction between sowing date and weed management practices on *Striga* shoot count (m^{-2}) at 10 WAS in 2019.

Sowing date	Weed management practices			
	Weedy check	2 HW	PE Atrazine + 1 HW	PE Atrazine + POE Nicosulfuron
Early	3.0	1.0	1.0	0.0
Mid	4.0	2.0	2.0	0.0
Late	4.0	3.0	2.0	1.0
LSD (0.05)			0.33	

LSD, least significant difference.

Table 7. Effect of maize variety, weed management practices and sowing date on grain yield in 2018 and 2019.

Treatment	Grain yield (kg ha^{-1})	
	2018	2019
Variety (V)		
SAMMAZ 15	4015.70	2768.89
SAMMAZ 17	4986.00	3365.28
SAMMAZ 37	4151.90	2609.72
SAMMAZ 40	4235.60	2886.11
SUWAN-1-SR-Y	3919.20	2274.17
LSD (0.05)	327.62	114.71
Weed management (M)		
Weedy check	3244.40	1772.22
2 HW	4375.10	2813.78
PE Atrazine + 1 HW	4621.10	3090.67
PE Atrazine + POE Nicosulfuron	4806.70	3446.67
LSD (0.05)	293.03	102.60
Sowing date (S)		
Early	4438.80	2955.83
Mid	4972.50	3150.00
Late	3374.20	2236.67
LSD (0.05)	253.77	88.85
Interaction		
V x M	NS	NS
S x V	NS	NS
S x M	**	*
S x V x M	NS	NS

LSD, least significant difference; NS, not significant; *significant at 5% level of probability, **highly significant at 1 % level of probability.

The highest grain yield produced by SAMMAZ 17 suggests its superior tolerance to *Striga* parasitism over the other maize varieties studied since it supported more *Striga* shoots but still had better growth and higher yield of maize. Isah et al. (2010) also observed higher growth and yield in some genotypes of maize than the others and attributed it to variation in tolerance and resistance that exist among the host crop genotypes to *Striga* parasitism. Also, our result agrees with the work of Ekeleme et al. (2014) who reported that sorghum KSV 8 cultivar tolerated *Striga* as it supported more *Striga* shoots, and also out yielded the other cultivars.

Treatment with PE Atrazine + POE Nicosulfuron suppressed *Striga* growth (days to first *Striga* shoot

Table 8. Interaction effects between sowing date and weed management practices on grain yield in 2018 and 2019.

Sowing date	Weed management practices			
	Weedy check	2 HW	PE Atrazine + 1 HW	PE Atrazine + POE Nicosulfuron
Grain yield in 2018				
Early	3629.99	4553.00	4511.11	5061.11
Mid	3777.78	5563.31	5211.11	5337.78
Late	2325.55	3008.89	4141.11	4021.11
LSD (0.05)			697.70	
Grain yield in 2019				
Early	1980.00	3001.33	3282.00	3560.00
Mid	2010.00	3140.00	3503.33	3946.67
Late	1326.67	2300.00	2486.67	2833.33
LSD (0.05)			244.30	

LSD, least significant difference.

emergence and *Striga* shoot density) better and had the highest maize grain yield. This may be attributed to effective *Striga* control in our study, which in turn enhanced the use of growth factors in the absence of crop competition and/or parasitism with weeds.

Early season sowing (May) delayed *Striga* shoot emergence and reduced *Striga* shoot density. Efficient *Striga* control was probably made possible due to inadequate soil moisture during the early season for preconditioning of *Striga* seeds in the soil for germination. This finding conforms with the earlier reports by Ekeleme et al*.* (2014) who observed that early sowing is prone to drought risk, but can favour most cereals crop growth and development before *Striga* seeds are preconditioned and get germinated.

The highest grain yield produced by mid-season sowing may be due to adequate moisture in the soil which resulted in wet dormancy of *Striga* seeds in the soil which in turn supported efficient utilization of growth factors. Our result is in line with the findings of Liaqat et al. (2018) who observed higher grain yield in early season sowing (15th June) due to adequate and optimal utilization of growth factors.

The delay in *Striga* shoot emergence in maize interaction between sowing date and variety was due to the combined effect of the availability of soil moisture at the time of sowing which might have caused wet dormancy of *Striga* seed, and the genetic potential of the maize varieties in tolerating the adverse effect of the *Striga* seedlings. Besides, differences in the production of *Striga* germination stimulants are known to exist among maize cultivars and is likely the reason for the reduction in *Striga* shoot emergence in this study (Midega et al., 2016).

The reduction in *Striga* shoot density in maize of interaction between variety and weed management practice was due to the differences in the genetic potentials of the maize varieties to tolerate *Striga* infestation in combination with the effectiveness of the weed management practice on *Striga* control. In our study, plots with *Striga* tolerant maize varieties and pre- and post-emergence application of herbicides proved to be superior in reducing *Striga* infestation and in enhancing maize growth and yield.

The least *Striga* shoot density in maize of interaction between sowing date and variety was due to the combined effect of the availability of soil moisture at the time of sowing and differences in the genetic potentials of the maize varieties to inhibit *Striga* infestation. In this study, plots with *Striga* tolerant maize varieties and early season sowing proved to be superior in reducing *Striga* infestation.

The reduction in *Striga* shoot density and improved maize grain yield of interaction between sowing date and weed management practice was due to available soil moisture at sowing time which suppressed *Striga* germination and its subsequent attachment to the host maize. Also, the weed control method was effective in controlling *Striga* which supported better *Striga* suppression and use of available growth factors and hence higher maize grain yield. In our study, early season sowing with pre-emergence application of Atrazine and post-emergence Nicosulfuron reduced *Striga* growth and improved maize grain yield.

Conclusion

The study has shown that farmers can reduce *Striga* infestation by using *Striga* tolerant maize varieties, such as SAMMAZ 15 and SAMMAZ 40 in combination with the application of PE Atrazine + POE Nicosulfuron with early-season sowing (May) for maize production. SAMMAZ 17 in combination with the application of PE Atrazine + POE

Nicosulfuron with mid-season sowing (June) resulted in the highest maize grain yield, and therefore recommended for the production of maize in a *Striga* infested environment in this agro-ecological zone in Nigeria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENT

The authors are grateful to all the people who provided support during data collection.

REFERENCES

Adesina GO, Akinwale RO (2014). Response of *Striga* resistant maize varieties to natural weed conditions and weed control measures under rainforest condition. Annals of Plant Science Journal 3(3):631-637.

Dugje IY, Kamara AY, Omoigui LO (2008). Influence of farmers' crop management practices on *Striga hermonthica* infestation and grain yield of maize (*Zea mays* L.) in the savanna zones of Northeast Nigeria. Journal of Agronomy 7(1):33-40.

Ekeleme F, Kamara AY, Omoigui LO, Chikoye D, Dugje IY, Tegbaru A (2011). Effect of sowing date on *Striga* infestation and yield of sorghum [*Sorghum bicolor* (L.) Moench] cultivars in the Sudan savanna of northern Nigeria. African Journal of Agricultural Research 6:3240-3246.

Ekeleme F, Jibrin JM, Kamara AY, Oluoch M, Samndi AM, Fagge AA (2014). Assessment of the relationship between soil properties, *Striga hermonthica* infestation and the On-farm yields of maize in the dry Savannas of Nigeria. Crop Protection 62:90-97.

Imoloame E (2014). The effect of different weed control methods on weed infestation, growth and yield of soybeans [*Glycine max* (L.) Merril] in the Southern Guinea savanna of Nigeria. Agrosearch 14(2):129-143.

Isah KM, Lagoke STO, Philip BB, Adeniji IA (2010). Evaluation of open pollinated maize varieties for resistance/tolerance to *Striga hermonthica* Del. Benth at Mokwa southern guinea savannah of Nigeria. Journal of Agricultural Science and Environment 10(1):10-17.

Kamara AY, Ekeleme F, Jibrin MJ, Tarawali G (2014). Assessment of level, extent and factors influencing *Striga* infestation of cereals and cowpea in Sudan Savanna ecology of Northern Nigeria. Journal of Agriculture, Ecosystem and Environment 188:111-121.

Kanampiu F, Makumbi D, Mageto E, Omanya G, Waruingi S, Musyoka P, Ransom J (2018). Assessment of management options on *Striga* infestation and maize grain yield in Kenya. Journal of Weed Science of America 66(4):10-17.

Liaqat W, Akmal M, Ali J (2018). Sowing dates effect on production of high yielding maize varieties. Sarhad Journal of Agriculture 34(1):102-113.

Magani EI, Ibrahim A, Ahom RI (2011). Integrated management of parasitic plant *Striga hermonthica* in maize using *Fusarium oxysporum* (Mycoherbicide) and post-emergence herbicides in the Nigeria Savanna. Tropical and Subtropical Agroecosystem 14(2):731-738.

Midega CAO, Pickett J, Hooper A, Pittchar J, Khan ZR (2016). Maize landraces are less affected by *Striga hermonthica* relative to hybrids in Western Kenya. Weed Technology 30(1):21-28.

Olaniyan AB (2015). Maize: Panaceae of hunger in Nigeria. African Journal of Plant Science 9(3):155-174.

Olayemi IK, Idris B, Ejima IAA, Adeniyi K, Ukubuiwe AC, Isah B (2014). The climatie of North-central Nigeria and potential influence on mosquito (*Diptera*: *Culicidae*) vectorial capacity, for disease transmission. Global Journal of Multidisciplinary and Applied Science 2(2):26-31.

Statistical Analysis System (SAS) (2009). SAS user's guide: Statistical version 9.0 Cary, NC, USA: SAS Institute Inc.

Teka HB (2014). Advance research on Striga control: A review. African Journal of Plant Science 8(110):492-506.

Vol. 16(9), pp. 1278-1288, September, 2020
DOI: 10.5897/AJAR2020.14730
Article Number: 153987064843
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Floral activity of *Apis mellifera* (Hymenoptera: Apidae) on *Bidens steppia* (Asteraceae), *Cordia africana* (Boraginaceae), *Pittosporum viridiflorum* (Pittosporaceae) and *Psychotria mahonii* (Rubiaceae) in Nyambaka (Adamawa, Cameroon)

Nentcherse Mbere[1,2]*, Michelson Azo'o Ela[3], Tchobsala[2,4] and Fernand-Nestor Tchuenguem Fohouo[1]

[1]Department of Biological Sciences, Laboratory of Applied Zoology, University of Ngaoundere. P. O. Box 454 Ngaoundere, Cameroon.
[2]Department of Biological Sciences, Laboratory of Biodiversity and Sustainable Development, University of Ngaoundere. P. O. Box 454 Ngaoundere Cameroon.
[3]Department of Biological Sciences, Laboratory of Entomology, University of Maroua, P. O. Box 814 Maroua Cameroon.
[4]Department of Biological Sciences, Laboratory of Botany, University of Maroua, P. O. Box 814 Maroua Cameroon.

Received 20 January, 2020; Accepted 2 April, 2020

Experiments were conducted at Nyambaka in the Adamawa Region of Cameroon, from March 2017 to November 2018, for assessing the apicultural potential of *Bidens steppia, Cordia africana, Pittosporum viridiflorum* and *Psychotria mahonii.* In order to improve the beekeeping productivity, it is important to investigate the diversity of bee plants in a given apiary site. To that end, the foraging behaviour of *Apis mellifera* workers was studied on the flowers of each plant species twice a week during the whole blooming period. The abundance of opened flowers per plant, floral products harvested by foragers, mean duration of floral visit, mean density of foragers, sugar content of nectar of each plant species, and number of effective visits of *A. mellifera* on flowers were assessed. Results indicated that, honeybee workers harvested nectar of each plant species; *B. steppia* and *P. viridiflorum* were intensely foraged for pollen harvesting too. The abundance of workers/1000 flowers varied from 123 on *P. mahonii* to 724 on *C. africana*. The mean value of the sugar content of nectar oscillated from 19.50% (*C. africana*) to 38% (*B. steppia*). *C. africana* and *P. mahonii* were highly nectariferous plant species while *B. steppia* was very highly polliniferous and slightly nectariferous and *P. viridiflorum* very highly nectariferous and slightly polliniferous. During its foraging activity, workers improved the pollination possibilities of plant species. By planting or protecting these plant species, a bee-friendly garden can be preserve for providing nectar flow and pollen availability for beekeeping purpose.

Key words: Apiary, apicultural value, beekeeping, bee plant, foraging behaviour, sugar content.

INTRODUCTION

Beekeeping is one of the most important cultural and economic activities in the Adamawa region of Cameroon (Ingram, 2011). The highest quantity of honey consumed or marketed in this country is from this region which has a suitable climatic condition for the proliferation of honeybees (INADES, 2000). Despite the favorable agro-ecology of honey production and the high number of bee colonies this region is endowed with, the honey production and productivity level in Cameroon is still very low (Dongock et al., 2017). Yet, sustainable beekeeping can be improved through the understanding and conservation of plants producing nutrient for the honeybees mainly in terms of nectar and pollen (El-Nebir and Talaat, 2013).

Apis mellifera is one of the bees raised on a large scale in beekeeping to produce honey and for pollination. This species comprises 28 subspecies including *Apis mellifera adansonii*, which has its origin from Africa (Fletcher, 1978). Honeybee workers are attracted commonly to plants that produce nectar and pollen. Nectar is a sweet substance that attracts bees which also need pollen in their diet (Louveaux, 1984). These food sources provide the nutritional requirements of the bee colonies. Nectar as a source of honey provides heat and energy while pollen provides protein, vitamins and fatty substances (Amsalu et al., 2003). During floral visits for nectar harvesting and pollen gathering, honeybees, in turn, pollinate plants; thus they can help in boosting fruit and seed yields of the host plant and then propagate their species (Klein et al., 2007; Allsopp et al., 2008).

The honey and other products of honeybees depend on the availability of floral resources in a given area (Amsalu et al., 2003). Intending to improve the level of honey production both in quantity and quality in the Adamawa region of Cameroon, several findings are available in enhancing beekeeping practice regarding the inventory of bee plants in some sites like Ngaoundere (Tchuenguem et al., 2010; Ingram, 2011; Djonwangwé et al., 2011; Egono et al., 2018; Wékéré et al., 2018) and Ngaoundal (Dongock et al., 2017).

Nyambaka is a small locality in the Adamawa region of Cameroon where beekeeping is still done on a small-scale. In this area, beekeeping practice appears like a commercial enterprise; it offers not only diverse hive products which can be sold in local markets and become an important source of regular income for farmer families, but also provide complementary services, such as plant pollination. Moreover, locally, bee products improve farm family nutrition and can provide traditional health care remedies. There are many plant species that produce a large amount of nectar and pollen for bees to be collected in the locality. Some of these plants are important as they provide bees with a surplus of honey. Small-scale beekeeping is considered as an important occupation that contributes significantly to livelihood security in that region. Yet, most of the honey is produced with traditional hives consisting of bast and grass; besides, bee plants are not yet well known by beekeepers in this area. It is, therefore, an important practice to help bees in their survival by adding to the shrinking inventory of flower-rich habitat in the study locality.

The United Nations World Health Organization estimates that as many as 5.6 billion people, 80% of the world population, utilize herbal medicine for primary health care (Shen et al., 2012). *Bidens steppia* (Steetz) Sherff (Asteraceae), *Cordia africana* Lam. (Boraginaceae), *Pittosporum viridiflorum* Sims (Pittosporaceae), and *Psychotria mahonii* C.H. Wright (Rubiaceae) are four multipurpose plant species which are often harvested for local use as food and medicine in Nyambaka. In the locality, different preparations of parts of *B*. *steppia* plant are commonly purported to treat several categories of illnesses such as diabetes and malaria. In the literature, extracts of *B*. *steppia* have antitumor (Sundararajan et al., 2006), anti-inflammatory, antimicrobial (Pereira et al., 1999), antidiabetic, antimalarial (Tobinaga et al., 2009) properties. *C*. *africana* is used as firewood. The fruit pulp of this plant is edible and is added as a sweetener to food. The leaves serve as fodder for livestock. Leaf decoctions are administered to treat headache, nose bleeding, dizziness and vomiting during pregnancy, wounds and worms while root decoctions are drunk to treat jaundice (Obeng, 2010). The categories to which *P*. *viridiflorum* is used in traditional medicine include wounds, treatment of veterinary ailments, gastrointestinal tract and sexually transmitted diseases, circulatory and inflammatory disorders, as well as diseases such as cancer, tuberculosis, and malaria (Madikizela and McGaw, 2017). As for *P*. *mahonii*, fresh rhizomes are chewed and the juice swallowed to treat intestinal tract diseases and worms.

In addition to their medicinal importance, all four plant species studied have flowers that produce nectar and pollen available for bee species. It is well known in the literature that the productivity of the honeybee colonies is proportional both to the abundance and attractiveness of the nectariferous and polliniferous plants present in the environment of the apiary (Williams and Carreck, 1994; Van't et al., 2005). Thus, sustainable beekeeping in a given region requires detailed knowledge of the apicultural value of plant species that grow there for their optimal management (Dongock et al., 2017). Moreover, honeybee being a bio-indicator species (Porrini et al., 2003), medicinal plants are an interesting source for the production of honey with medicinal biological activity very close to their floral origin (Liberato et al., 2011). That is why it is interesting to associate a crop of medicinal

*Corresponding author. E-mail: nentchersembere@gmail.com. Tel. (+237) 699 91 11 08.

plants with beekeeping. However, there is no available data published on the relationships between African honeybees and many local and medicinal plant species including *B. steppia*, *C. africana*, *P. viridiflorum* and *P. mahonii* in Cameroon. The main objective of the present research work was to determine the apicultural status of these plant species in Nyambaka, to improve the beekeeping potential and enhance the value of the plants studied in this locality. For each plant species, we recorded the foraging activity of *A. mellifera* on flowers and estimated its apicultural value.

MATERIALS AND METHODS

Study site and biological material

The present study was carried out from March 2017 to November 2018 in Nyambaka, a village located in the South of Ngaoundere, the capital of the Adamawa region of Cameroon. This region is located between the 6th and 8th degrees of latitude north and between the 11th and 15th degrees of longitude east; it belongs to the high-altitude Guinean Savannah agro-ecological zone (Djoufack et al., 2012). The climate is characterized by a rainy season (April to October) and a dry season (November to March), with an annual rainfall of approximately 1500 mm, a mean annual temperature of 22°C, and a mean annual relative humidity of 70% (Amougou et al., 2015) which are suitable climatic conditions for the beekeeping practice. Plants chosen for observations were located in an area of 1.5 km in diameter, centered on a Kenyan top-bar hive of *A. mellifera* colony. The hive was located at the following coordinates: 6°89'62'943'N, 14°09'28'038'E, 1136 m a.s.l.

The animal material included many insect species naturally present in the environment. The number of honeybee colonies located in the area varied from 60 in March 2017 to 69 in November 2017 and from 42 in March 2018 to 72 in November 2018. Apart from the honeybee colonies located in the experimental site, other colonies around the experimental site have not been inventoried since the radius action of foragers may exceed 12 km around the hive (Louveaux, 1984). The vegetation was represented in the study site by crops, ornamental plants, hedge plants and native plants of savannah and gallery forests.

Study of the foraging activity of *A. mellifera* on flowers

From March 2017 to November 2018, the foraging behaviour of *A. mellifera* workers was recorded on flowers of different plant species. Data were registered twice a week, between 07:00 a.m. and 06:00 p.m., at three-time intervals per day: 07:00-11:00 a.m., 11:00 a.m.-03:00 pm and 03:00-06:00 p.m. For any plant species visited by the honeybee browsers and for each investigation date, the following parameters were registered for each time frame and, whenever possible: the number of effective visits (the bee came into contact with the stigma) (Jacob-Remacle, 1989; Freitas, 1997), the mean duration of visits using a stopwatch (Tchuenguem et al., 2004). The density of foragers (highest number of individuals foraging simultaneously on a flower or 1000 flowers) was also assessed. The density of foragers was recorded following the direct counting on the same dates and daily periods as for the registration of the duration of individual flower visits; for this purpose, some foragers were counted on a known number of flowers. The density of foragers per 1000 flowers (A_{1000}) was then calculated using the following formula: $A_{1000} = ((Ax/Fx)*1000)$ where *Fx* and *Ax* are the numbers of opened flowers and the number of foragers effectively counted on these flowers at a given time *x* (Tchuenguem et al., 2004). The disruption of the activity of foragers by competitors and the attractiveness exerted by other plant species on *A. mellifera* was assessed by direct observations.

Evaluation of the sugar content of the nectar of different plant species

The concentration in total sugar of the nectar is an important parameter for the attractiveness of the honeybee concerning many flowers (Philippe, 1991). This parameter was determined with a handheld refractometer (0-90% Brix) and a thermometer that gave the ambient temperature, from March 2017 to November 2018. *A. mellifera* workers in full activity of nectar harvesting were captured on flowers and anesthetized by introducing them in a small jar containing cotton moistened with chloroform. The nectar was then removed from honeybee crop by exerting pressure on the bee abdomen placed between the thumb and the forefinger of the experiment; the nectar in the mouth was then expelled and its concentration in total sugars measured in g/100 dry matter (Tchuenguem et al., 2007). The registered values obtained were corrected according to the ambient temperature, using a table provided by the device leaflet (Cruden and Hermann, 1983).

Evaluation of the apicultural value of different plant species

As for other plant species, the apicultural value of each plant species studied was assessed using data on the flowering intensity, the degree of attractiveness of *A. mellifera* workers to nectar and/or pollen (Villières, 1987; Népidé et al., 2016).

Evaluation of the influence of *Apis mellifera* on pollination

To evaluate the ability of *A. mellifera* to act as a pollinator of each plant species during the nectar harvesting, the number of time a forager came into contact with the stigma of the visited flower was noted (Freitas, 1997). This approach allows highlighting the involvement of *A. mellifera* in self-pollination and cross-pollination (Zumba et al., 2013; Potts et al., 2015).

Statistical analysis

Data were subjected to descriptive statistics using SPSS 16. The Student's *t-test* was used for the comparison of means between two samples and Chi-square ($\chi 2$) for the comparison of two percentages. The analysis of variance (ANOVA) was used for multi-comparison of means.

RESULTS

Characteristics of the plant species studied

Tables 1 and 2 described plant species studied and the relative abundance of opened flowers per month for each of these plant species during both observation years. It is indicated from these tables that apart from *C. africana* which is mainly cultivated in the locality for the fruit production and shady purposes, *B. steppia*, *P. viridiflorum* and *P. mahonii* are respectively a shrub and small trees which grow spontaneously in the savannah.

Table 1. Scientific name, botanic family, biotope, some characteristics and strength of different plants studied.

Scientific name and status	Family	Biotope	Flowering period	DCOF	Number of plants	
					2017	2018
Bidens steppia (++; sh)	Asteraceae	Savannah	June-November	Yellow-orange	3634	4275
Cordia africana (+; tr)	Boraginaceae	Garden	June-September	White	23	25
Pittosporum viridiflorum (++; tr)	Pittosporaceae	Savannah	March-June	Greenish-white	764	716
Psychotria mahonii (++; tr)	Rubiaceae	Savannah	March-July	White	527	585

+: cultivated plant; ++: spontaneous plant; tr: tree; sh: shrub; DCOF: dominant colour of flowers.

Table 2. Relative abundance of opened flowers on each plant species per month during the two investigation periods.

Plant species	March 2017 to November 2017									March 2018 to November 2018								
	M	A	Ma	J	Ju	Au	S	O	N	M	A	Ma	J	Ju	Au	S	O	N
Bidens steppia					*	**	****	****	**				*	**	**	***	****	**
Cordia africana				**	****	****	**	*					*	****	***	**	*	
Pittosporum viridiflorum	*	***	****	**						*	***	****	**					
Psychotria mahonii	**	****	***	**	*					**	***	****	**	*				

M : March ; A : April ; Ma : May ; J : June ; Ju : July ; Au : August ; S : September ; O : October **;** N : November ; *: ≤100 flowers = rare; ** : >100 and ≤500 flowers = little abundant; ***: >500 and ≤1000 flowers = abundant; ****: >1000 flowers = very abundant.

The color of the flowers of these plant species varied from orange-yellow, greenish-white and white respectively for *B*. *steppia*, *P*. *viridiflorum*, *C*. *africana* and *P. mahonii*. Furthermore, the number of these plant species varied from about 25 for *C*. *africana* to about 4275 for *B*. *steppia*. These important numbers of plant species in the studied area enabled the availability of a large amount of floral mass during their blossoming.

A. mellifera foraging activity on flowers

Floral products harvested, intensity and frequency of collection of different products

The identity of the food harvested by *A*. *mellifera* workers from the flowers of each plant species investigated and the intensity and frequency of the collection of different food resources are presented in Table 3. The main results from this table indicated that: (a) *B*. *steppia* was weakly visited for nectar gathering while its pollen was highly attractive for *A. mellifera* workers (b) *P. viridiflorum* was slightly visited for its pollen while its nectar was abundantly harvested by honeybee foragers; (c) *C*. *africana* and *P*. *mahonii* were only visited for supplying nectar needs of *A*. *mellifera* as their pollen was scarcely collected. In general, the intensity of nectar or pollen collection varied with plant species and for a given plant species with the time.

The distribution of nutritive substances harvested by *A. mellifera* on flowers in terms of nectar and/or pollen of a given plant species according to each observation time interval is reported in Table 4. *A*. *mellifera* workers foraged nectar and/or pollen of *B. steppia*, *C. africana*, *P. viridiflorum* and *P. mahonii* almost during the whole daily period, from 06:00 a.m. till 06:00 p.m. and during all the blooming period of each plant species studied. This is an illustration that these plant species are important and abundant sources of nutrients for *A*. *mellifera*.

Density of foragers

The values of the density of foragers are reported

Table 3. Floral products harvested by *A. mellifera* from the flowers of plants according to period, harvesting intensity and abundance of food.

Plant species	*Variation of food harvesting according to the time period*																						
	March to November 2017									**March to November 2018**									**Seasonal frequency of food harvesting**				
	M	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**	**M**	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**	**TD**	**nDN**	**pDN**	**nDP**	**pDP**
B. steppia					P^1	N^1P^2	N^2P^4	N^2P^4	P^2				P^1	P^2	N^1P^2	N^2P^4	N^2P^4	P^2	96	32	33%	100	100%
C. africana				N^1	N^4	N^3	N^2	N^1					N^1	N^4	N^3	N^3	N^1		64	64	100%	-	-
P. viridiflorum	N^2	N^3	N^4P^1	N^4P^1						N^1	N^3P^1	N^4P^2	N^4P^1						64	64	100%	32	40%
P. mahonii	N^2	N^4	N^3	N^2	N^1					N^1	N^3	N^4	N^2	N^1					80	80	100%	-	-

M: March; A: April; Ma: May; J: June; Ju: July; Au: August; S: September; O: October; **N**: November; TD: Total number of observation days; nDN: number of days where the collection of nectar was effective; pDN: percentage of days were the collection of nectar was effective; nDP: number of days where the collection of pollen was effective; pDP: percentage of days where the collection of pollen was effective; N: Nectar; P: Pollen; 1, 2, 3 and 4 given as superscripts indicate the harvesting intensity which was very low, low, high and very high respectively.

Table 4. Products harvested by *Apis mellifera* from the flowers of the four plants species according to daily time interval.

Plant species	Daily time interval		
	07.00 - 11.00 am	**11.00 am - 3.00 pm**	**3.00 - 6.00 pm**
Bidens steppia	Pollen and nectar	pollen	Pollen and nectar
Cordia africana	Nectar	Nectar	Nectar
Pittosporum viridiflorum	Nectar and pollen	Nectar	Nectar and pollen
Psychotria mahonii	Nectar	Nectar	Nectar

Table 5. Abundance of *Apis mellifera* workers per 1000 flowers according to plant species and months.

Plant species	**March 2017 to November 2017**									**March 2018 to November 2018**								
	M	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**	**M**	**A**	**Ma**	**J**	**Ju**	**Au**	**S**	**O**	**N**
Bidens steppia					4	69	413	571	26				1	13	102	541	552	13
Cordia africana				18	504	724	107	7					6	430	643	132	13	
Pittosporum viridiflorum	5	462	607	26						17	362	702	10					
Psychotria mahonii	13	521	193	94	17					7	123	684	231	21				

M : March ; A : April ; Ma : May ; J : June ; Ju: July ; Au : august ; S : September ; O : October ; N : November.

in Table 5. The highest number of *A. mellifera* workers foraging simultaneously per flower was one for each plant species. The mean abundance per 1000 flowers in 2017 was 216 (n = 240; s = 122; maximum = 517) on *B. steppia*, 272 (n = 197; s = 143; maximum = 727) on *C. africana*,

Table 6. Duration of *Apis mellifera* visits on flowers of the four plants species according to the study periods and harvested products.

Plant species	March-November 2017 Mean duration of visit (sec)				March-November 2018 Mean duration of visit (sec)				Comparison of means of the two study periods		
	n	*m ± sd*	*mini*	*maxi*	*n*	*m ± sd*	*mini*	*maxi*	*t- value*	*df*	*p- value*
Bidens steppia (N)	205	5.27 ± 2.73[a]	1	16	241	5.14 ± 2.53[a]	1	12	0.52	444	> 0.05[NS]
Bidens steppia (P)	245	6.42 ± 3.86[b]	2	21	451	6.14 ± 5.24[b]	1	13	0.73	694	> 0.05[NS]
Cordia africana (N)	253	5.03 ± 2.21[a]	2	15	306	5.28 ± 2.04[a]	2	14	1.39	557	> 0.05[NS]
Pittosporum viridiflorum (N)	234	3.92 ± 2.66[c]	1	15	237	3.88 ± 2.49[c]	1	12	0.17	469	> 0.05[NS]
Pittosporum viridiflorum (P)	97	3.54 ± 2.48[c]	1	12	106	4.10 ± 2.16[c]	1	11	1.72	201	> 0.01[NS]
Psychotria mahonii (N)	552	4.48 ± 1.92[ac]	1	11	172	4.55 ±1.91[ac]	2	12	0.42	722	> 0.05[NS]

n: sample size; m: mean; mini: minimum; maxi: maximum; N: Nectar collection visits; P: Pollen collection visits; sd = standard deviation ; NS = Non significant. Mean values in the same column (mean duration of a bee visit for nectar or pollen harvesting as a function of a given plant species) or in the same line (for a given plant species as function of the floral product harvested and the year) but with different letters vary significantly (P < 0.05).

271 (n = 146; s = 131; maximum = 643) on *P. viridiflorum* and 167 (n = 205; s = 94; maximum = 727) on *P. mahonii*. In 2018, the corresponding figures was 203 (n = 268; s = 118; maximum = 552) on *B. steppia*, 244 (n = 217; s = 128; maximum = 643) on *C. africana*, 272 (n = 116; s = 142; maximum = 702) on *P. viridiflorum* and 213 (n = 189; s = 121; maximum = 684) on *P. mahonii*. The optimal value of the density of *A. mellifera* workers corresponded with the month of the peak of blossoming of each plant species studied which are: September and October for *B. steppia*, July to August for *C. africana*, April and May for *P. viridiflorum* and *P. mahonii* respectively. The difference of the mean density of foragers was not significant for each plant species according to the year.

Duration of visits

Results from Table 6 highlighted the variation of the mean duration of *A. mellifera* visit as a function of the floral product harvested and for a given plant species according to the year. As pollen grains of *C. africana* and *P. mahonii* were not so interesting for foragers, only the mean duration of a visit for pollen collection by *A. mellifera* on *B. steppia* and *P. viridiflorum* were registered in both years. Overall, the duration of a forager visit varied with the floral product searched for and for a given product with the host plant species studied. The difference was significant between pollen and nectar gathering on *B. steppia* in 2017 ($t = 5.23$; $df = 448$; $P < 0.05$) and 2018 ($t = 3.97$; $df = 690$; $P < 0.05$), between nectar collection among plant species in 2017 ($F = 6.52$; $df = 3, 1240$; $P < 0.05$) and 2018 ($F = 5.93$; $df = 3, 952$; $P < 0.05$) and between pollen collection on *B. steppia* and *P. viridiflorum* in 2017 ($t = 7.63$; $df = 340$; $P < 0.05$) and 2018 ($t = 6.57$; $df = 555$; $P < 0.05$). Workers of *A. mellifera* were disturbed during their foraging activity by other flower-visiting insects or abiotic parameters such as the wind and the rainfall. Some disturbances have resulted in the interruption of some honeybee visits and consequently reduced the time spend on the corresponding flower, thus obliged foragers to move swiftly from flower to flower.

Influence of neighboring flora

During the observation periods of each of the four plant species under investigation, flowers of many other plant species growing in the study area were visited by *A. mellifera* for nectar (ne) and/or pollen (po). Among these plants were, *Manihot esculenta* (Euphorbiaceae: ne), *Tithonia diversifolia* (Asteraceae: ne), *Bidens pilosa* (Asteraceae: ne + po), *Stylosanthes guianensis* (Fabaceae: ne + po), *Hibiscus rosa-sinensis* (Malvaceae: ne + po), *Sida rhombifolia* (Malvaceae: ne + po), *Terminalia schimperiana* (Combretaceae: ne + po), *Terminalia macroptera* (Combretaceae: ne + po), *Sesbania pachycarpa* (Fabaceae : ne + po), *Mimosa invisa* (Mimosaceae: po), *Mimosa pudica* (Mimosaceae: po), *Senna mimosoides* (Fabaceae: po), and *Zea mays* (Poaceae: po). During one foraging trip, a forager was not observed moving from the flowers of a given plant

Table 7. Concentration in total sugar of the nectar of plant species studied.

Plant species	Concentration in total sugar of the nectar (%)										
	March 2017 to November 2017				March 2018 to November 2018				Comparison of means of the two study periods		
	n	m ± s	mini	maxi	n	m ± s	mini	maxi	t	ddl	P
Bidens steppia	62	38.07 ± 9.60[a]	22	47	45	36.29 ± 9.69[a]	23	46	0.94	105	> 0.05[NS]
Cordia africana	60	19.43 ± 3.42[b]	10	21	73	19.05 ± 3.25[b]	10	22	0.65	131	> 0.05[NS]
Pittosporum viridiflorum	46	29.54 ± 6.63[c]	21	36	69	28.84 ± 6.14[c]	21	34	0.58	113	> 0.05[NS]
Psychotria mahonii	37	26.03 ± 1.03[c]	23	27	43	25.97 ± 0.96[c]	23	27	0.26	78	> 0.05[NS]

Mean values in the same column (plant species) or in the same line (for a given parameter as function of the year) but with different letters vary significantly (P < 0.05).

species studied to the neighboring plant species and conversely.

Concentration in total sugar of the nectar of plant species studied

Results from Table 7 reported the mean concentration in total sugar of *B. steppia* nectar was 38.07% (n = 62; s = 9.60) in 2017 and 36.29% (n = 45; s = 9.69) in 2018. The difference between these means is not significant (t = 0.94; df = 105; P > 0.05). The mean concentration in total sugar of the *C. africana* nectar was 19.43% (n = 60; s = 3.42) in 2017 and 19.05% (n = 73; s = 3.25) in 2018. The difference between these two means is not significant (t = 0.65; df = 131; P > 0.05). The mean concentration in total sugars of *P. viridiflorum* nectar was 29.54% (n = 46; s = 6.63) in 2017 and 28.84% (n = 69; s = 6.14) in 2018. The difference between these means is not significant (t = 0.58; df = 113; P > 0.05). The mean concentration in total sugar of *P. mahonii* nectar was 26.03% (n = 37; s = 1.03) in 2017 and 25.97% (n = 43; s = 0.96) in 2018. The difference between these means is not significant (t = 0.26; df = 78; P > 0.05). The difference was significant between the four plant species concerning this parameter in 2017 (F = 7.14; df = 3, 201; P < 0.05) and in 2018 (F =5.31; df = 3, 226; P < 0.05). Overall, the concentration in total sugar of the nectar varies following plant species.

Apicultural value of the plant species

During the flowering period of each plant species studied, we recorded distinct levels of activity of *A. mellifera* workers on the flowers. There were a high availability of flowers, a high density of workers per tree or shrub, a good nectar collection on all plant species and high pollen harvest on *B. steppia* but a low pollen collection on *P. viridiflorum*. Moreover, in the dry season, which is the main period of honey flow, individual tree of *P. viridiflorum* and *P. mahonii* investigated could produce more than 70.000 flowers. On the other hand, during the rainy season (period of the food shortage within honeybee colonies), individual tree of *B. steppia* and *C. africana* could averagely produce up to 15.000 flowers. Considering these data, the plant species studied can be classified based on their apicultural value as follows: (a) very highly nectariferous: *C. africana, and P. mahonii*; (b) very highly polliniferous and slightly nectariferous: *B. steppia* (c) very highly nectariferous and slightly polliniferous: *P. viridiflorum*. Table 8 summarizes the appropriate period for the optimal nectar and/or pollen availability in Nyambaka in 2017 and 2018. Thus, in this study area, the nutritional requirements of honeybees are provided by *B. steppia* from August to September, *C. africana* from June to August while *P. viridiflorum* and *P. mahonii* were important suppliers of nectar to foragers from April to May.

Impact of A. mellifera activity on the pollination of the plant species

During the collection of pollen or nectar on the flowers of the four plant species studied, foragers regularly contacted anthers and carried pollen. With this pollen, they flew frequently from flower to flower. The percentage of the total number of visits during which worker bees came into contact with the stigma of the visited flower was 100% for

Table 8. Apicultural value of plant species studied and the most favorable period for bees to harvest nectar and/or pollen.

Plant species	Floral product harvested		
	Nectar	Pollen	Intense blooming period
Bidens steppia	**	****	September-October
Cordia africana	****	-	July-August
Pittosporum viridiflorum	****	**	April-May
Psychotria mahonii	****	-	April-May

**** = very high nectariferous or polliniferous; ** = slightly nectariferous or polliniferous.

Table 9. Number and frequency of contacts between *Apis mellifera* and the stigma during the floral visits to three plant species.

Plant species	March-November 2017			March-November 2018			Total		
	Number of studied visits	Visits with stigmatic contact		Number of studied visits	Visits with stigmatic contact		Number of visits studied	Visits with stigmatic contact	
		Number	%		Number	%		Number	%
Bidens steppia	450	450	100.00	692	692	100.00	1142	1142	100.00
Cordia africana	253	253	100.00	306	306	100.00	559	559	100.00
Pittosporum viridiflorum	331	331	100.00	343	343	100.00	674	674	100.00
Psychotria mahonii	552	552	100.00	172	172	100.00	724	724	100.00

Number and frequency of contacts comparison: (*Bidens steppia*) : χ2 2017/2018 = 0.00 ; *df* = 1; $P > 0.05^{NS}$; (*Cordia africana*) : χ^2 2017/2018 = 0.00 ; *df* = 1 ; $P > 0.05^{NS}$; (*Pittosporum viridiflorum*) : χ^2 2017/2018 = 0.00 ; *df* = 1 ; $P > 0.05^{NS}$; (*Psychotria mahonii*) : χ^2 2017/2018 = 0.00 ; *df* = 1 ; $P > 0.05^{NS}$; (*B. steppia*, *C. africana*, *P. viridiflorum, Ps. mahonii*) : χ^2 2017 = 0.00 ; *df* = 3; $P > 0.05^{NS}$; (*B. steppia*, *C. africana*, *P. viridiflorum, P. mahonii*) : χ^2 2018 = 0.00; *df* = 3 ; $P > 0.05^{NS}$.

B. steppia, *C. africana P. viridiflorum* and *P. mahonii* during the 2017 as well as the 2018 investigation period (Table 9). Consequently, *A. mellifera* workers strongly increase the pollination possibilities of *B. steppia*, *C. africana*, *P. viridiflorum* and *P. mahonii.*

DISCUSSION

In Nyambaka, an important area for beekeeping practice in the Adamawa region of Cameroon, the four plant species studied have shown their importance as sources of pollen and nectar for African honeybees. Previous works have already been done in other countries which have shown the immense potential that some of these plant species abounded in the local beekeeping practice. That is the case for *C. africana* which was mentioned in the Western Amhara region of Ethiopia as a major honeybee plant (Tesfa et al., 2013); moreover, the pollen of this plant species was identified as the secondary pollen source in four honey samples collected from Salika village in Ethiopia (Tewelde, 2006). The collection of the nectar of *P. psychotroides* by *A. mellifera*, another plant species belonging to the genus *Psychotria*, has already been reported in previous investigations in the Adamawa Region (Dongock et al., 2017). In Benin, Yédomonhan et al. (2009) found that, on the flowers of *Psychotria* spp., *A. mellifera* harvested both pollen and nectar widely. In the southern highland of Tanzania, the flowers of *B. steppia* and *P. viridiflorum* were mentioned as an important source for both pollen and nectar collection all day long and during the whole flowering period (Latham, 2015). In Bujumbura (Burundi), *B. steppia* flowers were mainly visited by the honeybee (Ndayikeza et al., 2014) for both nectar and pollen collection. Overall, the substance harvested by *A. mellifera* from flowers (nectar or pollen) on a given plant species can vary with regions. The variations observed in this study could be explained mainly by the real needs of the colonies from which originated honeybee workers (Segeren et al., 1996). The good nectar collection observed in the four plant species is the fact that, bees can collect nectar with sugar concentrations below 15-85% under natural conditions (Roubik and Buchmann, 1984).

From our fieldwork, the colors of the flowers of the studied plant species are among the most attractive for honeybee foragers. According to Bergström (1982), the bright colors are the most attractive for the flower-visiting insects in general and honeybees in particular because those are among the colors they can easily perceive. Indeed, bees have a much broader range of color vision. Their ability to see ultraviolet light gives them an advantage when seeking nectar and pollen (Dyer and Garcia, 2014). Thus, to identify the most profitable flowers, and avoid non-rewarding flowers like mimics (Dafni, 1984), bees make use of several cues including color (Hempel et al., 2001) information. Furthermore, several other parameters such as the accessibility of nectar and/or pollen, the availability of both products, the floral mass or number of flowers or inflorescences bearded by a plant species are important for the good practice of beekeeping elsewhere (Segeren et al., 1996).

Another important aspect from the present study is the possibility of the mastery of the period when the blossoming of each plant species studied is effective and optimal yearly. Indeed, the knowledge of these time intervals makes it possible to establish the apicultural calendar in avoiding pollen and nectar scarcity and shortage (Chigere et al., 2014). For this purpose, the supply of *A*. *mellifera* foragers with nectar and/or pollen in a well-known period of the year is already possible for *B*. *steppia*, *C*. *africana*, *P. viridiflorum* and *P. mahonii* in the study site.

The observed high abundance of foragers per 1000 flowers recorded in this study could be attributed to the ability of honeybees to recruit a great number of workers for the exploitation of high-yield food sources (Frisch, 1969; Kajobe, 2006). Honeybees can smell or detect pollen or nectar odor (Free, 1970) using sensory receptors located on the flagellum of their antennae. Worker honeybees dance inside the nest after a successful foraging trip to communicate with their congeners, information about the food odor, the distance and the direction from the hive to the food source (Frisch, 1967). The round dance is performed when the resource is within 100 meters from the hive, while the wagging dance takes place for the resource 100 meters away from the hive (Frisch, 1967).

Significant differences observed between the duration of pollen harvesting visit and that of nectar harvesting on the flowers of *B. steppia* could be explained by the accessibility of each of these floral products. On the flower of *B. steppia*, pollen is a product in great quantity and is easily accessible to bees. In these conditions, honey bee workers can obtain their pollen load by visiting a few flowers during a foraging trip. That is why *A. mellifera* spent more time on a flower for pollen harvesting than for nectar in *B. steppia.* Therefore, on each of the four plant species, *A. mellifera* spent more time on a flower for nectar collection of *C. africana, B. steppia, P. mahonii* and *P. viridiflorum* respectively. The fact that *A. mellifera* spent significantly different time on a flower of different species for nectar and pollen collection could be explained by the abundance and/or the accessibility to each of these floral products.

The disruptions of visits by other insects reduced the duration of certain *A. mellifera* visits. This obliged some workers to visit more flowers during a foraging trip, to maximize their pollen or nectar loads. Similar observations were made for *A. mellifera* workers foraging on flowers of *Entada africana* (Fabaceae), *Eucalyptus camaldulensis* (Myrtaceae), *Psidium guajava* (Myrtaceae) and *Trichillia emetica* (Meliaceae) (Tchuenguem et al., 2007), *Combretum nigricans* (Combretaceae), *Erythrina sigmoidea* (Fabaceae), *Lannea kerstingii* (Anacardiaceae), *Vernonia amygdalina* (Asteraceae) (Tchuenguem et al., 2010), *Jatropha curcas* (Euphorbiaceae), *Senegalia polyacantha* (Mimosaceae) and *Terminalia schimperiana* (Combretaceae) (Wékéré et al., 2018)

The present study shows that during one foraging trip, an individual bee foraging on a given plant species scarcely visited another plant species. This result indicates that *A. mellifera* shows flower constancy (Louveaux, 1984) for the flowers of each of the four plant species studied. This floral constancy in honeybees exists because an individual forager is generally capable of memorizing and recognizing the shape, color, and odor of the flowers visited during previous foraging trips (Hill et al., 1997; Wright et al., 2002). The flower constancy of *A. mellifera* has been demonstrated on flowers of several other plant species among which are *Jatropha curcas* (Euphorbiaceae), *Senegalia polyacantha* (Mimosaceae) and *Terminalia schimperiana* (Combretaceae) (Wékéré et al., 2018), *Lannea kerstingii* (Anacardiaceae) and *Ximenia americana*. (Olacaceae) (Djonwangwé et al., 2011), and *Callistemon rigidus* (Myrtaceae) (Fameni et al., 2012). The faithfulness of the honeybee to the flowers of the plant species studied can also be explained, in part, by the fact that their nectar is rich in sugars; Philippe (1991) suggested that foragers could not allow their colony to record a net energy gain if the sugar concentration of the harvested nectar is less than 20%.

Considering this minimum limit, browsers can allow their colony to gain a lot of energy when they collect nectar from plant species studied.

During the collection of nectar and/or pollen on each flower, *A. mellifera* workers regularly come into contact with the stigma and anthers. They could thus enhance self-pollination, which has been demonstrated for other plant species in the past (Anderson and Symon, 1988; Lewis et al., 1999; Otiobo et al., 2015). *A. mellifera* could induce cross-pollination through carrying of pollen with their furs, legs and mouth accessories, which is subsequently deposited on another flower belonging to different plants of the same species (Abrol, 2012).

Conclusion

At Nyambaka, *A. mellifera* workers harvested intensely and regularly the nectar and pollen of *B*. *steppia, C*. *africana, P*. *viridiflorum* and *P*. *mahonii* flowers. These results suggest that these plants are the highly nectariferous and polliniferous floral plant able to substantially contribute to maintaining the nutritional needs of the honeybee colony. All these plant species contributed more or less to the feeding and therefore to the strengthening of the honeybee colonies. *A*. *mellifera* workers increased the pollination possibilities of each plant species. Based on our results, we recommend: (a) the installation of *A. mellifera* colonies in environments where one or more of the studied plant species occur abundantly and (b) the plantation and/or protection of each plant species in the surrounding of *A. mellifera* apiaries. These precautions will allow, in addition to improving the production of honey in the study location, its enrichment in various therapeutic properties for the well-being of the local populations. The impact of *A. mellifera* on fruit or grain yields of each plant species studied via its pollination efficiency will be looked at in future works.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abrol DP (2012). Pollination biology: biodiversity conservation and agricultural production. Springer Dordrecht Heidelberg, London, UK 792 p.

Allsopp MH, de Lange WJ, Veldtman R (2008). Valuing insect pollination services with cost of replacement. PLoS ONE 3(9):3128.

Amougou JA, Abossolo SA, Tchindjang M (2015). Variability of precipitations at Koundja and Ngaoundere based on temperature changes of Atlantic Ocean and El NINO. Ivory Coast Review of Science and Technology 25:110-124.

Amsalu B, Nuru A, Radloff H (2003). Multivariate morphometric analysis of honeybees in the Ethiopian region. Apidologie 35:71-81.

Anderson GJ, Symon D (1988). Insect foragers on Solanum flowers in Australia. Annals of Missouri Botanic Garden 75(3):842-852.

Bergström G (1982). Relations chimiques entre les Orchidées et les pollinisateurs. Bulletin de la Société Entomologique de France 90 (5-6 /7-8):1223-1228).

Chigere M, Machingauta P, Chiororo L (2014). Threats to the African bees and beekeeping in Zimbabwe. HICC, Harare, Zimbabwe 15 p.

Cruden RW, Hermann SM (1983). Studying nectar: Some observations on the art. In: Bentley & Elias Ed., The biology of nectarines. Columbia University press, New York pp. 223-242.

Dafni A (1984). Mimicry and deception in pollination. Annual Review of Ecology and Systematics 15:259–278

Djonwangwé D, Tchuenguem FFN, Messi J (2011). Foraging and pollination activities of *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae) on *Ximenia americana* (Olacaceae) flowers at Ngaoundéré (Cameroon). International Research Journal of Plant Sciences 2(6):170-178.

Djoufack V, Fontaine B, Martiny N, Tsalefac M (2012). Climatic and demographic determinants of vegetation cover in northern Cameroon. International Journal of Remote Sensing 21:6904-6926.

Dongock ND, Zra E, Tchuenguem FFN (2017). Bee plant potentials and characteristics in the Ngaoundal subdivision, Adamawa-Cameroon. Agricultural Science Research Journal 7(9):285-296.

Egono NCC, Kingha TMB, Fameni ST, Dounia, Tchuenguem FFN (2018). Pollination efficiency of *Apis mellifera* (Hymenoptera: Apidae) on *Helianthus annuus* (Asteraceae) flowers at Dang (Ngaoundéré, Cameroon). International Journal of Biosciences 13(3):314-328.

El-Nebir MA, Talaat DAM (2013). Identification of botanical origin and potential importance of vegetation types for honey production in the Sudan. Journal of Natural Resources and Environmental Studies 1(2):13-18.

Fameni TS, Tchuenguem FFN, Brückner D (2012). Pollination efficiency of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Callistemon rigidus* (Myrtaceae) flowers at Dang (Ngaoundéré, Cameroon). International Journal of Tropical Insect Sciences 32(1):2-11.

Fletcher DJC (1978). The African Bee, *Apis mellifera adansonii*, in Africa. Annual Review of Entomology 23 (1):151–171.

Free JB (1970). Insect pollination of crops. Academic press, London, UK 506 p.

Freitas BM (1997). Number and distribution of cashew (*Anacardium occidentale*) pollen grains on the bodies of its pollinators, *Apis mellifera* and *Centris tarsata*. Journal of Apicultural Research 36(1):15-22.

Frisch KV (1967). The dance language and orientation of bees. The Belknap Press of Harvard University Press, Cambridge, UK 235 p.

Frisch KV (1969). Vie et mœurs des abeilles. A. Michel (Ed.), Paris, France 556 p.

Hempel DIN, Giurfa M, Vorobyev M (2001). Detection of colored patterns by honeybees through chromatic and achromatic cues. Journal of Comparative Physiology 187:215-224

Hill PM, Wells PH, Wells H (1997). Spontaneous flower constancy and learning in honey bees as a function of colour. Animal Behaviour 54(3):615-627.

INADES (2000). Rapport des ateliers avec les Apiculteurs de l'Adamaoua, Cameroun. INADES-Formation, Antenne de Maroua (Ed.), Maroua, Cameroun 29 p.

Ingram V (2011). Bee plants for Cameroon highlands and Adamawa plateau honey. Center for International Forestry Research (CIFOR) pp. 1-22.

Jacob-Remacle A (1989). Comportement de butinage de l'abeille domestique et des abeilles sauvages dans des vergers de pommiers en Belgique. Apidologie 20:271-285.

Kajobe R (2006). Pollen foraging by *Apis mellifera* and stingless bees *Meliponula bocandei* and *Meliponula nebulata* in Bwindi Impenetrable National Park, Uganda. African Journal of Ecology 45:265-274.

Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T (2007). Importance of pollinators in changing landscapes for world crops. Proceeding of the Royal Society B 274:303-313.

Latham P (2015). Plants visited by bees and other useful plants of the Southern Highlands Tanzania. Croft Cottage, Forneth, Blairgowrie, Perthshire, PH10 6SW, UK 303 p.

Lewis DH, Considine JA (1999). Pollination and fruit set in the tamarillo (*Cyphomandra betacea*) (Cav.) Sendt.) floral biology. New Zealand Journal of Crop Horticulture 27(2):101-112.

Liberato MCTC, De Morais SM, Siqueira SMC, De Menezes JESA, Ramos DN, Machado LKA, Magalhaes IL (2011). Phenolic Content and Antioxidant and Antiacetylcholinesterase Properties of Honeys from Different Floral Origins. Journal of Medicinal Food 14 (6):658-663.

Louveaux J (1984). Domestic bee and their relation with grown plants. In. Pesson P. & Louveaux J. Ed., Pollination and plant production, INRA, Paris, France pp. 527-555.

Madikizela B, McGaw LI (2017). *Pittosporum viridiflorum* Sims (Pittosporaceae): A review on a useful medicinal plant native to South Africa and tropical Africa. Journal of Ethnopharmacology 205:217-230.

Ndayikeza L, Nzigidahera B, Mpawenimana A, Théodore M (2014). Dominance d'*Apis mellifera* L. (Hymenoptera, Apoïdea) dans les écosystèmes naturels et les agro-écosystèmes du Burundi: risque d'érosion de la faune des abeilles sauvage. Bulletin scientifique de l'Institut national pour l'environnement et la conservation de la nature 13:72-83.

Népidé NC, Tchuenguem FFN (2016). Pollination efficiency of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Croton macrostachyus* (Euphorbiaceae) flowers at Dang, Ngaoundéré, Cameroon. International Journal of Biosciences 3(9):75-88.

Obeng EA (2010). *Cordia africana* Lam. [Internet] Record from PROTA4U. Lemmens, R.H.M.J., Louppe, D. & Oteng-Amoako, A.A. Ed. PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands 24 p.

Otiobo ENA, Tchuenguem FFN, Djiéto-Lordon C (2015). Foraging and pollination behavior of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Physalis micrantha* (Solanales: Solanaceae) flowers at Bambui (Nord West, Cameroon). Journal of Entomology and Zoology Studies 3(6):250-256.

Pereira RLC, Ibrahim T, Lucchetti L, Da Silva AJR, De Moraes VLG (1999). Immunosuppressive and anti-inflammatory effects of methanolic extract and the polyacetylene isolated from *Bidens pilosa* L. Immunopharmacology 43 (1):31-37.

Philippe JM (1991). La pollinisation par les abeilles: pose des colonies dans les cultures en floraison en vue d'accroître les rendements des productions végétales. EDISUD, La Calade, Aix-en-Provence, France 179 p.

Porrini C, Sabatini AG, Girotti S, Ghini S, Medrzycki P, Grillenzoni F, Bortolot-ti L, Gattavecchia E, Celli G (2003). Honey Bees and Bee Products as Monitors of the Environmental Contamination. Apiacta 38:63-70.

Potts S, Biesmeijer K, Bommarco R, Breeze T, Carvalheiro L, Franzén M (2015). Status and trends of European pollinators, Key findings of the STEP project. Pensoft Publishers, Sofia, Bulgaria 72 p.

Roubik DW, Buchmann SL (1984). Nectar selection by *Melipona* and *Apis mellifera* (Hymenoptera: Apidae) and the ecology of nectar intake by bee colonies in a tropical forest. Oecologia 61(1):1-10.

Segeren P, Mulder V, Beetsma J, Sommeijer R (1996). Apiculture sous les tropiques. Agrodok 32, 5ème Ed., Agromisa, Wageningen, Netherlands 88 p.

Shen T, Li GH, Wang XN, Lou HX (2012). The genus Commiphora: a review of its traditional uses, phytochemistry and pharmacology. Journal of Ethnopharmacology 142(2):319-330.

Sundararajan P, Dey A, Smith A, Doss AG, Rajappan M, Natarajan S (2006). Studies of anticancer and antipyretic activity of *Bidens pilosa* whole plant. African Health Sciences 6(1):27-30.

Tchuenguem FFN, Messi J, Brückner D, Bouba B, Mbofung G, Hentchoya HJ (2004). Foraging and pollination behavior of the African honey bee (*Apis mellifera adansonii*) on *Callistemon rigidus* flowers at Ngaoundéré (Cameroon). Journal of the Cameroon Academy of Sciences 4:133-140.

Tchuenguem FFN, Djonwangwé D, Messi J, Brückner D (2007). Exploitation des fleurs de *Entada africana*, *Eucalyptus camaldulensis*, *Psidium guajava* et *Trichillia emetica* par *Apis mellifera adansonii* à Dang (Ngaoundéré, Cameroun). Cameroon Journal of Experimental Biology 3(2):50-60.

Tchuenguem FFN, Fameni TS, Pharaon MA, Messi J, Brückner D (2010). Foraging behaviour of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Combretum nigricans, Eryhrina sigmoidea, Lannea kerstingii* and *Vernonia amygdalina* flowers at Dang (Ngaoundéré, Cameroon). International Journal of Tropical Insect Sciences 30(1):40-47.

Tesfa A, Ejigu K, Kebede A (2013). Assessment of current beekeeping management practice and honey bee flora of Western Amhara, Ethiopia. International Journal of Agriculture and Biosciences 2(5):196-201.

Tewelde G (2006). Study on identification and establishment of floral calendar of honey bee plants in Atakilty Kebele, gray, Ethiopia. PhD thesis, Addis Ababa University, Ethiopia 72 p.

Tobinaga S, Sharma MK, Aalbersbergetal WGL (2009). Isolation and identification of a potent antimalarial and antibacterial polyacetylene from *Bidens pilosa*. Planta Medica 75(6):624-628.

Van't LL, Boot WJ, Mutsaers M, Segeren P, Velthuis H (2005). L'apiculture dans les zones tropicales. Agrodok 32, 6ème Ed., Agromisa, Wageningen, Netherlands 95 p.

Villières B (1987). L'apiculture en Afrique Tropicale. Dossier «Le point sur» n°11, GRET, Paris, France 220 p.

Wékéré C, Kingha TBM, Dongock ND, Djakbe JD, Faïbawa E, Tchuenguem FFN (2018). Exploitation of *Jatropha curcas, Senegalia polyacantha* and *Terminalia schimperiana* flowers by *Apis mellifera* (Hymenoptera: Apidae) at Dang (Ngaoundéré, Cameroun). Journal of Entomology and Zoological Studies 6(2):2072-2078.

Williams IH, Carreck NL (1994). Land use changes and honey bee forage plants. In. Matheson A (ed.), Forage for bees in an agricultural landscape. IBRA, Cardiff, UK pp. 7-20.

Wright GA, Skinner BD, Smith BH (2002). Ability of honeybee, *Apis mellifera*, to detect and discriminate odors of varieties of canola (*Brassica rapa* and *Brassica napus*) and snapgragon flowers (*Antirrhinum majus*). Journal of Chemical Ecology 28:721-740.

Yédomonhan H, Tossou MG, Akoègninou A, Demènou BB, Traoré D (2009). Diversité des plantes mellifères de la zone soudano-guinéenne: cas de l'arrondissement de Manigri (Centre-Ouest du Bénin). International Journal of Biological and Chemical Sciences 3(2):55-366.

Zumba JX, Myers GO, Clawson EL, Miller DK, Danka RG, Blanche SB (2013). Developing hybrid cotton (*Gossypium* spp.) using honeybees as pollinators and the roundup ready phenotype as the selection trait. Journal of Cotton Sciences 17:293-301.

Vol. 16(9), pp. 1289-1297, September, 2020
DOI: 10.5897/AJAR2020.14832
Article Number: D5BC5AB64839
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Spatiotemporal hotspot patterns of wheat rust incidence and severity in Ethiopia

Abu Tolcha[1*], Olika Dessalegn[2], Almaz Nigussie[1] and Degefie Tibebe[3]

[1]Kulumsa Research Center, Ethiopian Institute of Agricultural Research, Ethiopia.
[2]Melkassa Research Center, Ethiopian Institute of Agricultural Research, Ethiopia.
[3]Head Quarter, Ethiopian Institute of Agricultural Research, Ethiopia

Received 4 March, 2020; Accepted 13 August, 2020

Wheat rusts, stem rust, leaf rust, and stripe or yellow rust are the major biotic constraints in all wheat-growing regions of Ethiopia. Therefore, the main objective of this study is to identify the temporal-spatial hot spot pattern of wheat rust incidence and severity in Ethiopia. A GIS-based hotspot analysis tool was employed to identify the spatial distribution of hot spot patterns and temporal trends using survey data collected by the International Maize and Wheat Improvement Center and the Ethiopian Institute of Agricultural Research from the fields of smallholder farmers in Ethiopia. The analysis identified seven hot spot pattern categories; no trend detected, new hot spot, consecutive hot spot, diminishing hot spot, oscillating hot spot, persistent hot spot and a sporadic hot spot for yellow and stem rusts distributed in different parts of the country. For instance, the persistent hot spot is observed in west Arsi and Bale zones, which are the potential wheat-growing areas of the country while new hot spots are emerging in central and northern parts of the country. Generally, areas where these two hot spot patterns occurred, are requiring special attention to minimize yield loss due to rust and tackle food insecurity.

Key words: Emerging hotspot, stem rust, yellow rust, leaf rust.

INTRODUCTION

Wheat is cultivated on over 1.6 million hectares of land, with an annual production of 4.64 million tons, contributing about 15.17% of the total grain production in Ethiopia (CSA, 2017). The area under wheat has increased from 0.77 million ha in 1997 to 1.69 million ha in 2017 during the last 20 years (CSA, 1998, 2017). It ranked fourth after tef (*Eragrostis tef*), maize (*Zea mays* L) and Sorghum (*Sorghum bicolor* L) in land-coverage and total production (CSA, 2017). Following maize, wheat ranks second in terms of productivity with the average yield of 2.73 t/ha at the national level.

Despite the large area coverage of wheat in Ethiopia, the national average yield is 2.7 t/ha (CSA, 2017), which is much lower than the average of African and world yield productivity. There are several factors including biotic (diseases, insect pest, and weeds) and abiotic (moisture,

*Corresponding author. E-mail: tolchabu@gmail.com. Tel: 0000-0002-1613-4826.

soil fertility, etc.), and adoption of new agricultural technologies contributed to this low productivity (Zegeye et al., 2001; DRRW, 2010; Nelson, 2013).

The major biotic constraints in all wheat-growing regions of Ethiopia are wheat rusts, stem rust (*Puccinia graminis* Pers. f.sp. tritici), leaf rust (*Puccinia triticina* Eriks) and stripe rust (*Puccinia striiformis* Westend. f. sp. tritici). Among these, wheat stem rust has been the most devastating disease of all wheat rusts in Ethiopia causing up to the total damage of wheat crops over wide areas during the epidemic years. It is widespread in the wheat-growing regions, particularly in Central, South-East and North-West Ethiopia (Admasu and Fikadu, 2005; Admasu et al., 2010).

Leaf or stripe (yellow) rust can cause up to 60% of yield loss and 61 to 100% loss for stem rust (Admasu et al., 2009; Park, 2007). The specific characteristics of the rust fungi make rusts persistently significant disease in wheat. These characteristics include the ability to change genetically, thus producing new races that can overcome previously resistant wheat cultivars and a capacity to produce a large number of spores that can be wind-disseminated over wide areas and infect wheat under favorable environmental conditions.

Because of emerging and re-emerging of virulent races that break previous resistance of cultivars, several epidemics have been reported at different times. Therefore, to give a clear picture of the distribution and importance of wheat rusts, it is usually suggested that continuous and exhaustive surveys need to be carried out. Disease monitoring and surveillance are very important for sustainable wheat production and assure food security. The measurement and quantification of plant diseases are therefore of essential importance in the study and analysis of plant disease epidemics. Therefore, the main objective of this study is to identify the spatial-temporal hot spot pattern of wheat stem, leaf, and stripe (yellow) rust incidence and severity in Ethiopia to give an insight to decision-makers and end-users for better livelihood.

MATERIALS

Eleven years (2007- 2017) wheat rust incidence and severity data from a panel survey conducted on smallholder farmers' field in Ethiopia were used. The data was collected annually by the International Maize and Wheat Improvement Center (CIMMYT) and the Ethiopian Institute of Agricultural Research (EIAR) from the known wheat-growing areas of the country using a random sampling method for the development of early warning system. The rust severity was computed using the "Modified Cobb scale" method.

The data was transformed into a Network Common Data Form (NetCDF) data cube structure before running the statistical analysis. The GIS-based "create space-time cube" tool was used to transform data by aggregating rust disease points in each location into space-time 'bins' with a spatial resolution of 10 km and a one-year time-step interval based on the available survey data and survey design. The NetCDF structure stores space as latitude and longitude coordinates (x, y) and time (t) (that is, the year the disease was observed) as another dimension (Figure 1). Each bin represents a fixed position in space (x, y) and in time (t) that collectively create a three-dimensional cube (Figure 1). The value of each bin was assigned as the count of rust incidence and severity in the bin for a given year. The ESRI ArcGIS Emerging Hot Spot Analysis geoprocessing tool was used for statistical analysis and ArcGIS software was used for map symbolization.

METHODS

A GIS-based hotspot analysis tool was employed to identify the temporal trends and spatial distribution of hot spot patterns of wheat rust incidence and severity. Different hot or cold spot trends such as new, consecutive, intensifying, persistent, diminishing, sporadic, oscillating and historical can be detected by this tool. This tool uses a space-time implementation of the Getis-Ord-Gi* statistic to measure the intensity of feature clustering which considers the value for each bin within the context of the values for neighboring bins. Emerging Hot Spot Analysis tool evaluates the spatiotemporal patterns in rust incidence and severity in the country using a combination of two statistical measures: the Getis-Ord Gi statistic (Ord and Getis, 1995) to identify the location and degree of spatial clustering of the disease, and Mann-Kendall non-parametric trend test (Mann, 1945; Kendall and Gibbons, 1990) to evaluate temporal trends of the time series.

First, the Getis-OrdGi* statistic measures the intensity of clustering of high or low values (that is counts of rust incidence and severity) in a bin relative to its neighboring bins in the data cube. The sum for a bin and its neighbors is compared proportionally to the sum of all bins. The Getis-Ord-Gi* statistic generates z-scores (standard deviations) and P values (statistical probabilities) for each bin. This value indicates whether rust incidence and severity in a given bin is statistically clustered compared to incidence and severity in neighboring bins, as well as incidence and severity across the entire analysis domain. A z-score above 1.96 or below -1.96 means that there is a statistically significant hot spot or a statistically significant cold spot of the disease incidence and severity at a significance level of P <0.05. The larger a bin's z-score, the more intense the clustering of values (hot spot). The Getis-Ord_Gi* local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} x_j - \bar{X} \sum_{j=1}^{n} w \ldots}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w \ldots \right.\right.}{n-1}}} \quad (1)$$

where G_i^* is the local *G* statistic for a feature (*i*), W_{ij} represents the spatial weight for the target-neighbor *i* and *j* pair (Peeters et al., 2015), X_j is the attribute value for feature *j*, *n* is the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (3)$$

The G_i^* statistic is a z-score so no further calculations are required. The output of the G_i^* statistic is a map indicating the location of the spatial clusters in the study area. The degree of clustering and its statistical significance is evaluated based on a confidence level and

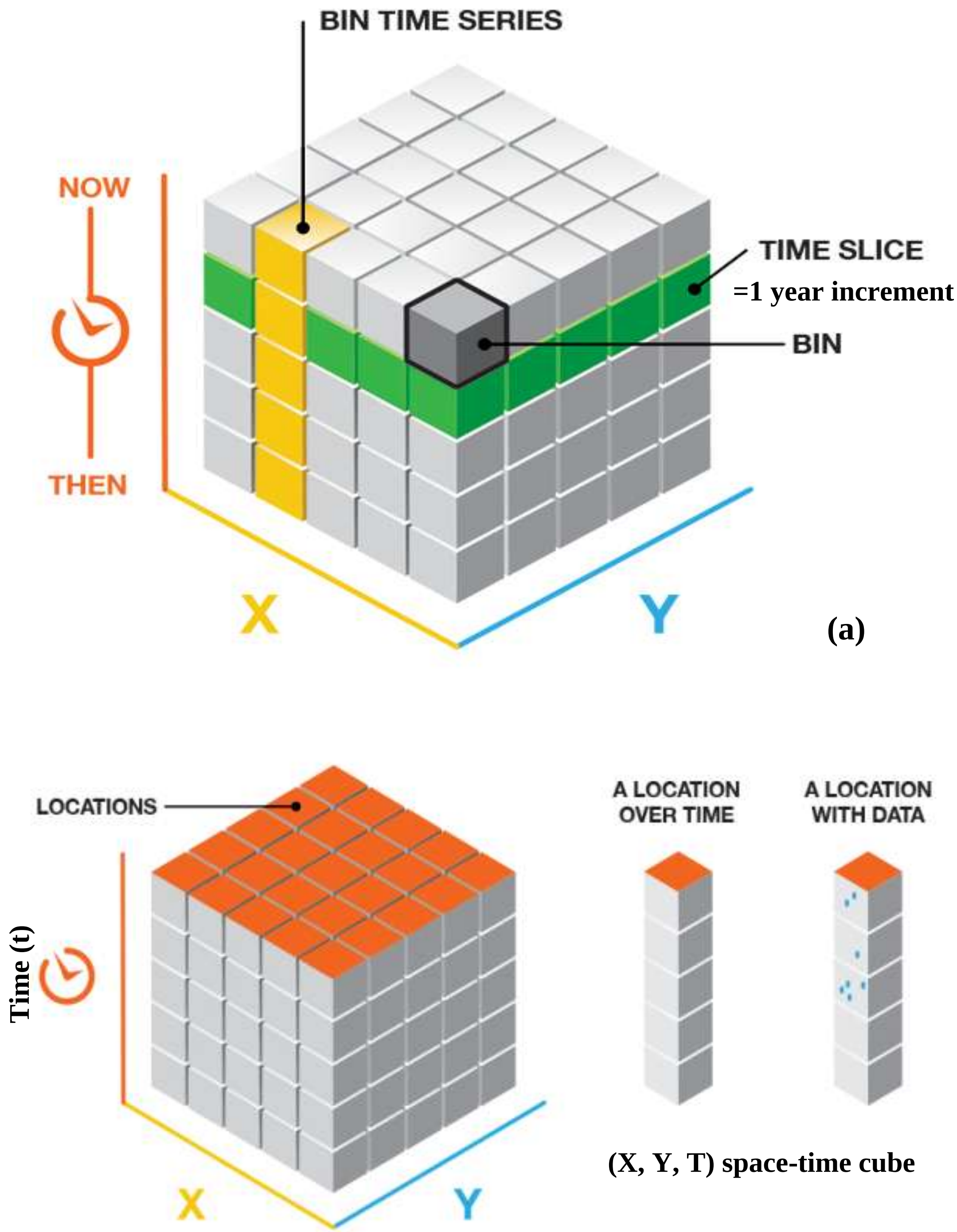


Figure 1. Space-time cube.
Source: Modified from http://desktop.arcgis.com/en/arcmap/10.3 /tools/space-time-pattern-mining-toolbox/emerginghotspots.htm.

the output*z*-scores. If z-score is positive and significant, it shows that one location and its neighboring locations have a relatively high frequency of rust incidence and severity, that is, is a spatial cluster of high data values(hotspot); while conversely, if *z-score* is negative and significant, it points to a cold spot (spatial cluster of low data values).

Second, the Emerging Hot Spot Analysis tool uses the Mann-Kendall statistic (Mann, 1945; Kendall and Gibbons, 1990) to test whether a statistically significant temporal trend exists through each bin's 11-year time series of z-scores resulting from the Getis-Ord-Gi

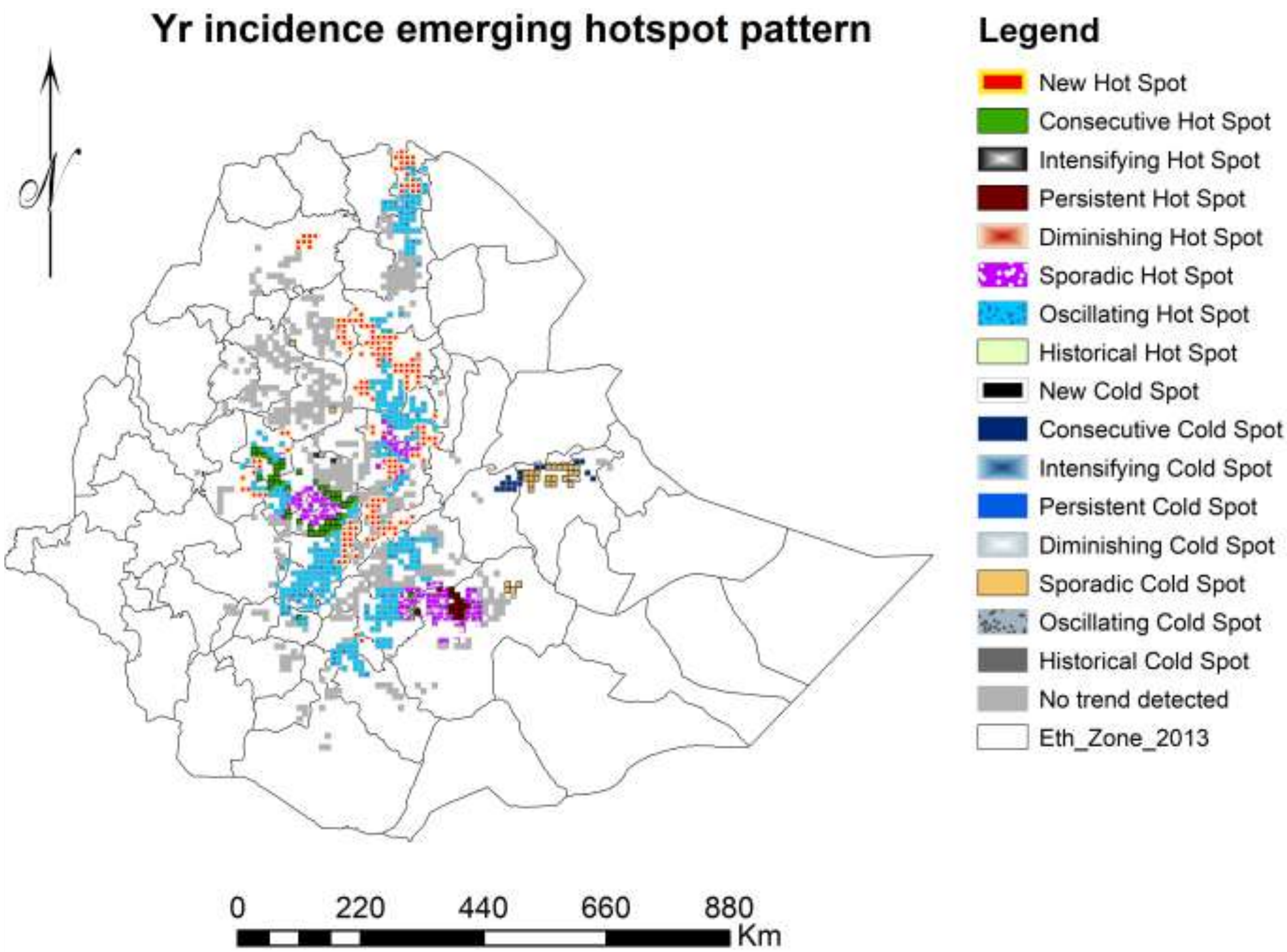


Figure 2. Space-time hot spot patterns of yellow (stripe) rust incidence in wheat-growing areas of Ethiopia during 2007-2017.

statistic. The neighborhood distance and time step parameters were considered when calculating the statistic for a specific bin and define how many surrounding bins, in both space and time. Therefore, the hot and cold spot trends detected by the Getis-OrdGi* hot spot analysis were evaluated with the Mann-Kendall test to determine whether trends are persistent, increasing, or decreasing over time.

RESULTS AND DISCUSSION

Wheat rust incidence

The map in Figures 2 to 4 presents the emerging hot spots of wheat yellow rust, stem rust and leaf rust incidence, respectively. The analysis identified eight hot spot pattern categories; no trend detected, new hot spot, consecutive hot spot, diminishing hot spot, oscillating hot spot, persistent hot spot, historical hotspot and sporadic hotspot for all rust types.

Out of the detected hot spot pattern categories, the areas where persistent hot spot, consecutive hot spot and new hot spot were identified are of particular interest to pathologists as they indicate areas where require special attention. Sporadic hot spots and oscillating hot spots are relatively less significant and difficult to manage since they are irregular and variable. These detected hot spot pattern categories occurred in different parts of Ethiopia. Persistent hot spot is identified in west Arsi and Bale zones for yellow and stem rusts and in the West Arsi zone for leaf rust. Consecutive hot spot pattern is identified in Hadiya zone of Southern Nation Nationalities and Peoples Region (SNNPR) and west Shewa, west Wellega, southwest Shewa, and HoroGuduru zones of Oromia regional state for all the three rust types and expanded to west Arsi zone for yellow and leaf rusts (Figures 2 to 4). Vast areas of new hot spot are present in Gurage, Selti, east Shewa, west Shewa, southwest Shewa, west Wellega, HoroGuduru, north Shewa of Amhara region, south Wollo, North Wollo, and eastern Tigrai zones of the country for all rust types during the

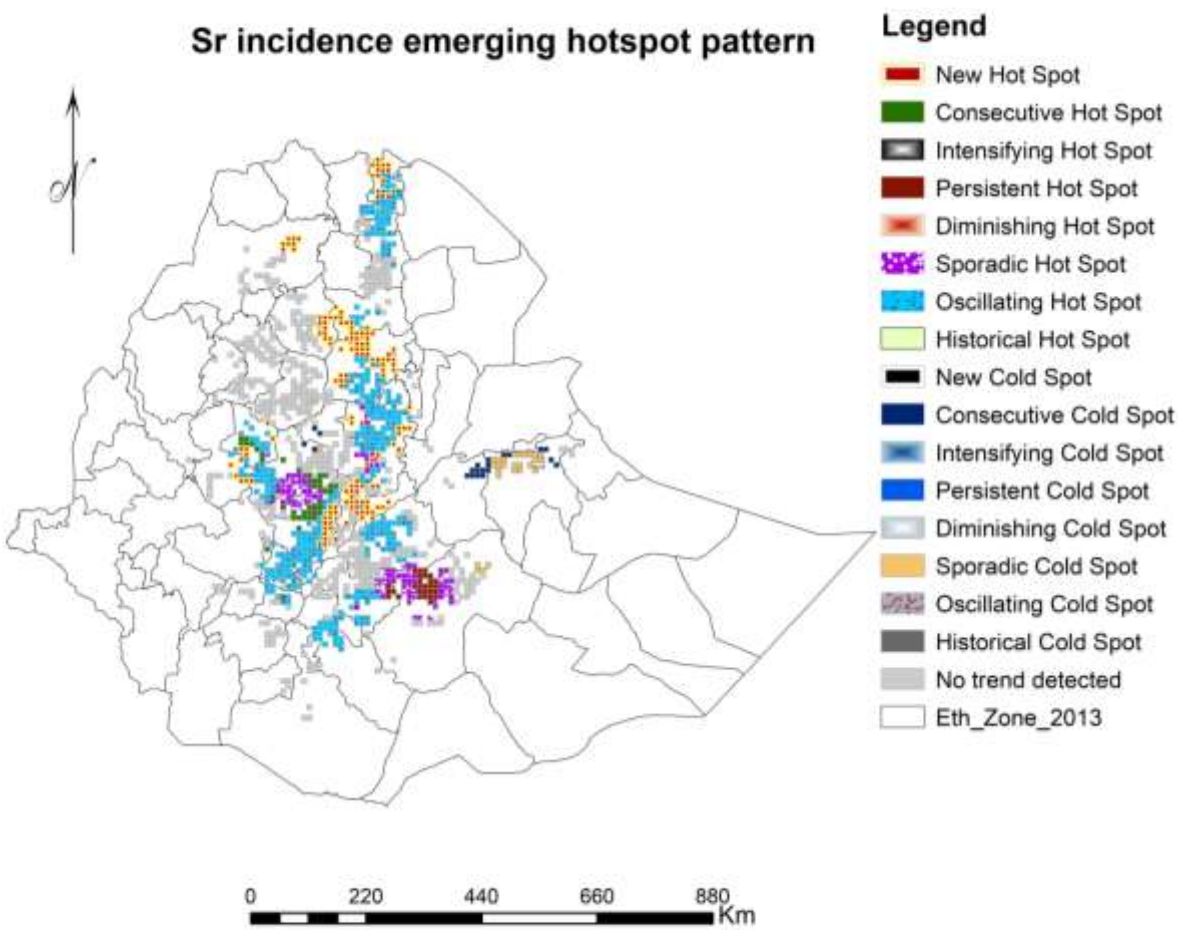


Figure 3. Space-time hot spot patterns of stem rust incidence in wheat-growing areas of Ethiopia during 2007-2017.

last eleven years (2007-2017) (Figure 2 to 4). This indicates that they are expanded to the areas that are less affected before. The sporadic hot spot widely occurs in Arsi, West Arsi, Bale, HoroGuduru, West, and southwest Shewa zones of Oromia region and North Shewa and north Wollo zones of Amhara region for all rusts (Figures 2 to 4).

Overall, the detected hot spot pattern categories occurred in different parts of the surveyed areas and similarly distributed for all rust types. Meaning that the same hot spot pattern has appeared in similar parts of the country for all rust types. For instance, the persistent hot spot is observed in southeastern highlands (Arsi, West Arsi, and Bale) for all the three rust types (Figures 2 to 4). This might be due to the weather condition of the area as favorable environmental condition is required for wheat rust to occur. Changes in atmospheric composition and the physical climate including temperature, rainfall and humidity will no doubt affect the economic importance, geographical distribution, and management of rusts of wheat ultimately affecting wheat production and food security (Chakraborty et al., 2011). For example, a change in weather too warm and humid may lead to more rapid development of a plant disease, a loss in yield of a crop, and consequent financial adversity for individual farmers and for the people of the region. The existing environmental conditions will favour stem rust infection in most wheat-growing regions of the world which leads to epidemic buildup (Singh et al., 2011). The situation is worsened by the fact that a large proportion of current breeding materials are susceptible to wheat rust races and susceptible wheat varieties are distributed to large areas.

Wheat rust severity

Like the incidence, different hot spot pattern categories are identified for the severity of wheat yellow (stripe), stem and leaf rusts in Ethiopia (Figures 5 to 7). Consecutive hot spot is observed in Arsi, West Arsi, Hadiya, West Shewa, South-west Shewa, and Horo-Guduru Wellega zones of the country for all rust types and expanded to Gurage and Selti zones for stem rust. It covers wide areas of west and southwest Shewa zones for leaf rust. Persistent severity hot spot is identified in

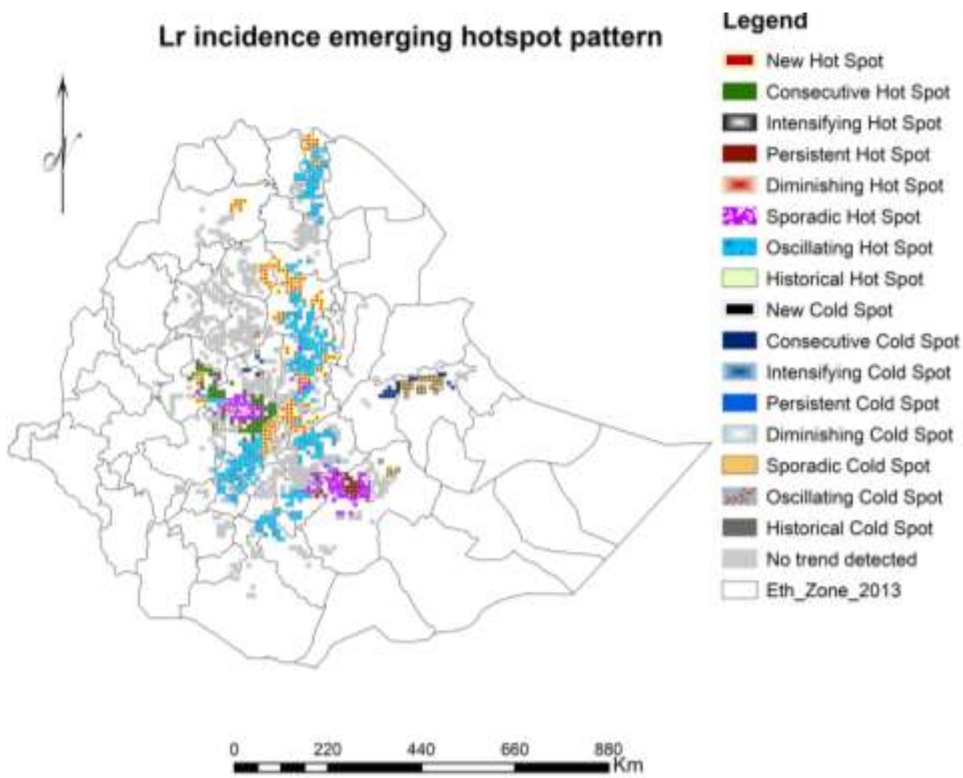


Figure 4. Space-time hot spot patterns of leaf rust incidence in wheat-growing areas of Ethiopia during 2007-2017.

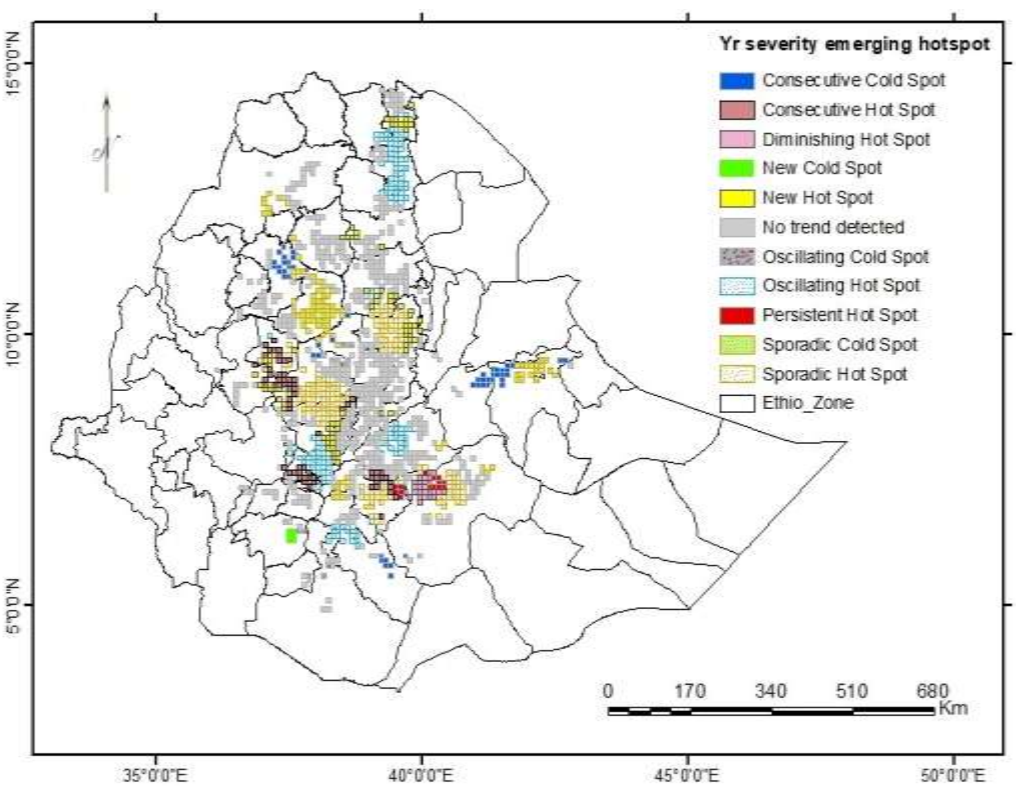


Figure 5. Space-time hot spot patterns of yellow (stripe) rust severity inWheat-growing areas of Ethiopia during 2007-2017.

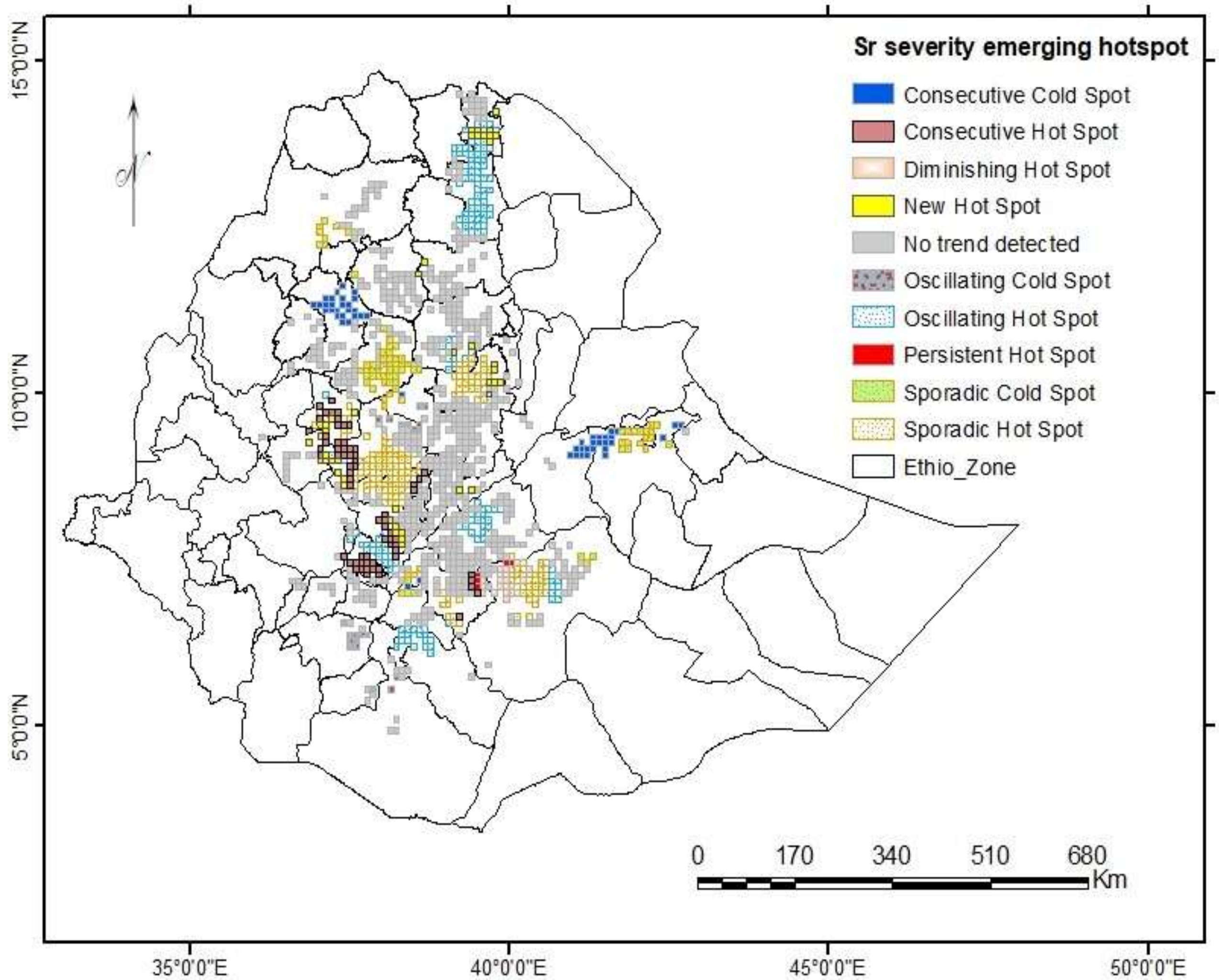


Figure 6. Space-time hot spot patterns of stem rust severity in wheat-growing areas of Ethiopia during 2007-2017.

west Arsi and Bale zones for yellow and stem rusts and in the West Arsi zone for leaf rust during the last ten years (Figures 5 to 7). This could result in high wheat yield reduction which in turn can affect the wheat supply of the country as these zones are the major wheat-growing areas in the country. New hot spots have emerged in different parts of the country such as Gurage, Selti, West Shewa, Horo Guduru, West Wellega, North Shewa of Amhara region, South Wollo, North Wollo, and Eastern Tigrai zones for all rust types (Figures 5 to 7). Overall, new severity is observed in the northern and western parts of wheat-growing areas of the country for all rust types. Meaning that they become sever over the areas where they were not or fewer sever before. Moreover, sporadic hot spots have occurred in Bale, West Arsi, southwest Shewa and West Shewa zones of Oromia region for all the three rust types while expanded to North Shewa and South Wollo of Amhara region for yellow and stem rusts (Figures 5 to 7).

Conclusions

Wheat rusts, stem rust, leaf rust, and stripe or yellow rust are the major biotic constraints in all wheat-growing regions of Ethiopia. It is usually suggested that continuous and exhaustive surveys need to be carried out to give a clear picture of the distribution and importance of wheat rusts. Therefore, the emerging hot spot analysis tool was applied to show the spatial distribution and temporal trends of wheat rust incidence and severity in wheat-growing areas of the country using wheat rust survey data. Thus, the space-time analysis revealed that similar hot spot patterns of wheat rust incidence and severity occurred in different parts of the country for all rust types. For instance, persistent hot spot occurs in Bale and West Arsi zones while new hot spot emerges in the northern and western parts of the country for all the three rust types. Similarly, persistent and new severity hot spots are observed in the northern and

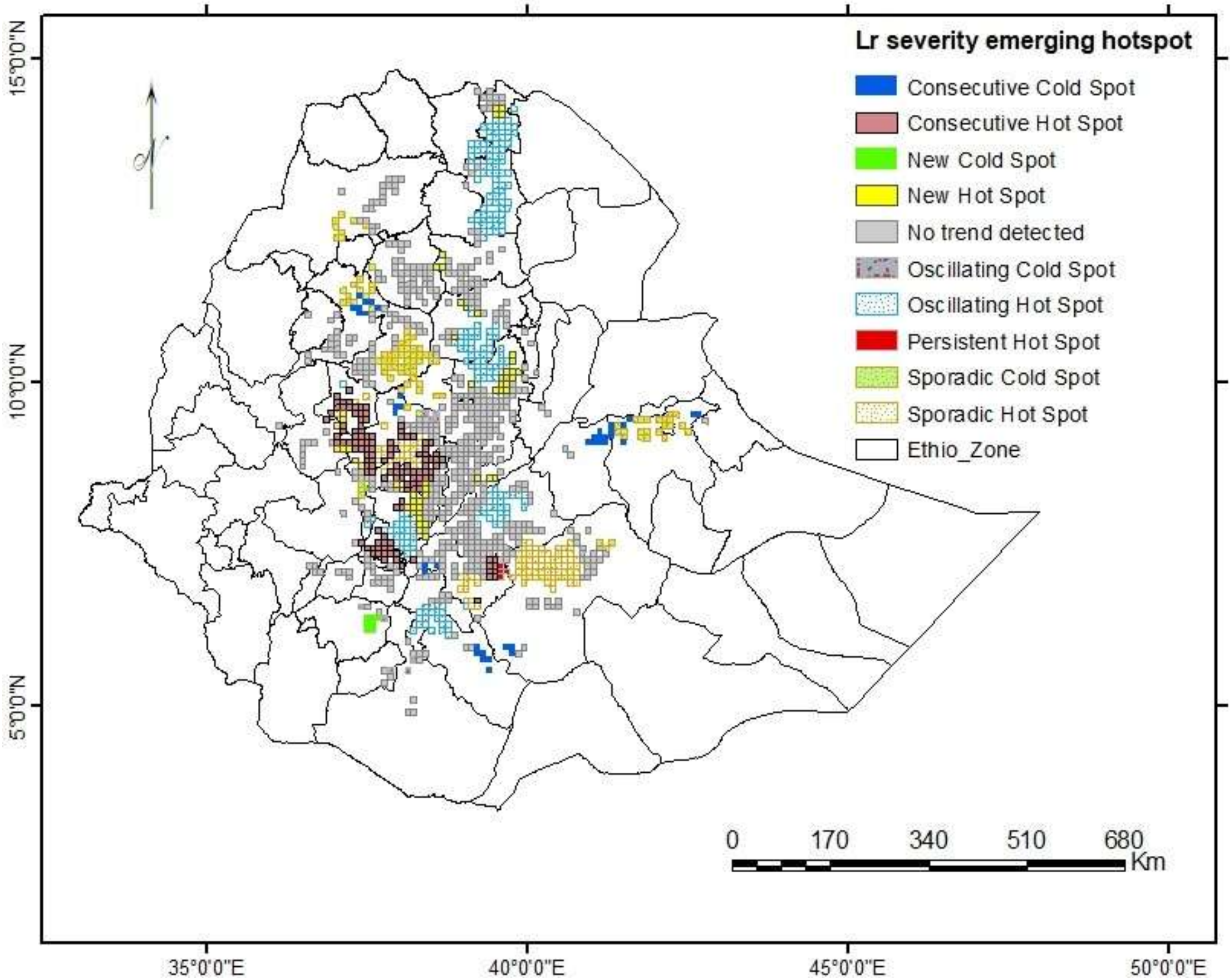


Figure 7. Space-time hot spot patterns of leaf rust severity in wheat-growing areas of Ethiopia during 2007-2017.

western parts of wheat-growing areas of the country for all rust types. Both of these hot spot pattern categories require special attention.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors would thank the Ethiopian Institute of Agricultural Research (EIAR) and the International Maiz and Wheat Improvement Center (CIMMYT) for providing the required rust disease survey data used in this study. They thank all colleagues who have contributed a lot to the success of this work. This study was funded by the Ethiopian Government (Project code 44-06).

REFERENCES

Admasu B, Fikadu E (2005). Physiological races and virulence diversity of *P. graminis*f.sp.*tritici*on wheat in Ethiopia. Phytopathology Mediterranea 44(3):313-318.

Admasu B, Lind V, Friedt W, Ordon F (2009). Virulence analysis of *Pucciniagraminis* f.sp. *tritici* populations in Ethiopia with special consideration of Ug 99. Plant Pathology 58:362-369.

Admasu B, Wolfgang, Friedt W, Ordon F (2010). Genetic Characterization of Pucciniagraminisf.sp.tritici Populations from Ethiopia by SSRs. Journal of Phytopathology 158:806-812.

Chakraborty S, Luck J, Hollaway G, Fitzgerald G, White N (2011). Rust-proofing wheat for a changing climate. Euphytica 179(1):19-32.

Central Statistical Agency (CSA) (1998). Report on Area and Crop Production Forecast for Major Grain Crops. Addis Ababa, Ethiopia.

Central Statistical Agency (CSA) (2017). Report on area and crop production forecast for major crops (for private peasant holdings, meher season). Statistical bulletin, Addis Ababa, Ethiopia

DRRW (2010). Phase II. Proposal for Bill and Melinda Gates Foundation.Office of International Programs, College of Agriculture and Life Sciences, Cornell University. USA.

Kendall MG, Gibbons JD (1990). Rank Correlation Methods. London: Griffin.

Mann HB (1945). Nonparametric tests against trend. Econometrica:

Journal of the Econometric Society, pp. 245-259.
Nelson KM (2013). Analysis of Farmer Preferences for Wheat Variety Traits in Ethiopia: A Gender-Responsive Study. MSc Thesis, Cornell University. USA.
Ord K, Getis A (1995). Local spatial autocorrelation statistics: distributional issues and an application. Geographical Analysis 27:286-306.
Park RF (2007). Stem rust of wheat in Australia. Australian Journal of Agricultural Research *58*(6):558-566.
Peeters A, Zude M, Käthner J, Ünlü M, Kanber R, Hetzroni A, (2015). Getis-ord's hot- and cold-spot statistics as a basis for multivariate spatial clustering of orchard tree data. Computers and Electronics in Agriculture 111:140-150.
Singh PR, Hodson PD, Huerta- Espino J, Jin Y, Bhavani S, Njau P, Herrera-Foessel S, Singh S, Govindan V (2011). The emergence of Ug99 races of stem rust fungus is a threat to world wheat production. Annual Review of Phytopathology 4:465-481.
Zegeye T, Taye G, Tanner D, Verkuijl H, Agidie A, Mwangi W (2001). Adoption of improved bread wheat varieties and inorganic fertilizer by small-scale farmers in YelmanaDensa and Farta districts of Northwestern Ethiopia.EARO and CIMMYT. Mexico City, Mexico.

Vol. 16(9), pp. 1298-1306, September, 2020
DOI: 10.5897/AJAR2020.14758
Article Number: DB7F9AE64854
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Impact of native arbuscular mycorrhizal fungi based fertilizers on to increase maize productivity in North Benin

Abdel D. KODA[1], Gustave DAGBENONBAKIN[2], Françoise ASSOGBA[3], Nadège A. AGBODJATO[1], Christine N'TCHA[1], Sylvestre ASSOGBA[1], Ricardos M. AGUEGUE[1], Aude E. KELOMEY[1], Adolphe ADJANOHOUN[2] and Lamine BABA-MOUSSA[1*]

[1]Laboratoire de Biologie et de Typage Moléculaire en Microbiologie, Département de Biochimie et de Biologie Cellulaire, Faculté des Sciences et Techniques, Université d'Abomey-Calavi, 05 BP 1604 Cotonou, Bénin.
[2]Centre de Recherches Agricoles Sud, Institut National des Recherches Agricoles du Benin, BP 884 Attogon, Benin.
[3]Centre de Recherches Agricoles Plantes Pérennes (CRA-PP) / Institut National des Recherches Agricoles du Bénin (INRAB).

Received 3 February, 2020; Accepted 1 September, 2020

Mycorrhizae are symbiotic associations between fungi and host plants, which confer several advantages, including good mineral nutrition. Arbuscular mycorrhizal fungi (AMF) then present an effective alternative in order to develop a sustainable agriculture that is less dependent on mineral fertilizers. The objective of this study was to assess the impact of organic fertilizers based on native arbuscular mycorrhizal fungi on increasing maize productivity and improving soil health in North Benin. For this study, three mycorrhizal fungi strains (*Glomeraceae* sp., *Acaulosporaceae sp*. and *Diversisporaceae* sp.) were used with or without mineral fertilizers. The corn variety 2000 SYN EE-W was used. The experimental design is a randomized complete block of nine treatments with three replicates. After 65 days, the endomycorrhizal infection was evaluated. The results showed that mycorhizal fungi had a positive impact on the different plant growth parameters (height, leaf area, and yield). At the height level, Acaulospora + ½ dose of $N_{15}P_{15}K_{15}$ recommended + urea produced good results compared to the control, an increase of 24.9%. The same observations were made for leaf area and yield, an increase of 70.4 and 39.04%, respectively. However, the results show that the rate of endomycorrhizal infection is high with *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + urea followed by *Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + urea and *Acaulosporeacea* sp.+ 50% of recommended $N_{15}P_{15}K_{15}$ + urea. In terms of spore number, the treatment *Glomeraceae* sp. gave the best result.

Key words: Mycorrhizal fungi, organic fertilizer, corn, Benin.

INTRODUCTION

In West Africa, corn is used for human and animal food and is used as a raw material in industries including brewing, soap and oil (Boone et al., 2008; Naitormmbaide et al., 2015). This cereal represents a significant source of income for producers and traders. However, there is low productivity of maize mainly due to the decline in soil fertility (Balogoun, 2012). The main solution to this problem is the use of mineral manures to increase the yield of maize production. This solution seems not to help an efficient in long term because several studies have shown that long-term fertilizer use leads to acidification of the land (Therond et al., 2017). However, for quality plant production implies high-end finished products and the use of technologies that best protect the environment, any realistic approach aimed at reducing the use of pesticides and chemical fertilizers and protecting crops and the quality of the soil deserves to be exploited (Assogba et al., 2017).

The relationships between soil microorganisms and the functioning of ecosystems have for some years been among the main objects of research in ecology. Those soil microorganisms are considered as a “key” microbial group in the functioning of terrestrial ecosystems, in particular for their ability to promote the development of plants in degraded environments (Abbas, 2014). Previous studies have shown that these mycorrhizae can be beneficial in agricultural ecosystems (Zhang et al., 2016).

It was reported that mycorrhizae are widespread in the main ecosystems and are found in 95% of plants (Diallo et al., 2016; Kouadio et al., 2017). Mycorrhizae are observed on most of the cultivated plants that are used for human and animal foods (Leake et al., 2004). Thus according to Tchabi et al. (2016), it would be possible to promote healthier farming systems using mycorrhizal fungi. This solution can reduce the use of chemical inputs (pesticides and fertilizers) while ensuring the profitability of crops and quality environment and long-term preservation of soil fertility and ecosystem stability. Indeed, mycorrhizae play a key role in the mineral nutrition of many plant species, especially those that thrive in marginal soil fertility conditions (Assogba et al., 2017). The objective of this study was to assess the impact of organic fertilizers based on native arbuscular mycorrhizal fungi to increase the productivity of corn and improve soil health in Benin.

MATERIALS AND METHODS

Variety of corn

For this study, the 2000 SYN EE-W corn variety was used. It is an 80-day extra-early variety developed by the International Institute of Tropical Agriculture (IITA) and the National Institute of Agricultural Research in Benin (INRAB). The grain yield in rural areas is 2.5 $t.ha^{-1}$. A variety has good resistance to breakage, streaking, american rust and helminthosporiasis. In addition, it tolerates pests and drought (MAEP, 2016).

Microorganisms

The inoculum used were native arbuscular mycorrhizal fungi (*Glomeraceae sp., Acaulosporaceae* sp. and *Diversisporaceae* sp.), these strains were isolated and characterized from North Benin rhizospheric soils and then kept at the Laboratory of Biology and Molecular Typing in Microbiology (LBTMM) of the University of Abomey-Calavi (UAC).

Characteristics of the experimental site

This study was carried out in Ina, at an altitude of 358 m between a latitude 9˚58'N and a longitude 2˚44'E at the North Benin Agricultural Research Center located in the town of Bembèrèkè (Figure 1). The experimental site is characterized by tropical ferruginous soil with very variable characteristics, very sensitive to leaching and a rainy season between May and September CRA-Nord (2007). The soil content of our experiment site was organic matter (1.92%), nitrogen (0.092%, pH 5.7), phosphorus (58 ppm) and potassium (0.49 meq/100 g of soil). The sum of the bases and the cation exchange capacity are average (Igué et al., 2015).

Experimental design

The experimental design was a randomized complete block of nine treatments with three repetitions. Each treatment covered an elementary plot of 12.8 m² made up of four lines of 4 m. The sowing was done at a spacing of 0.80 m × 0.40 m (a density of 31.250 plants/ha). The aisles between plots and rehearsals were 1.8 and 2 m, respectively. The growth and yield data were collected on the useful plot (6.4 m^2) represented by the two central lines. The different treatments evaluated were T1 (Control), T2 (*Glomeraceae sp.*), T3 (*Acaulospora*), T4 (*Diversisporaceae* sp.), T5 (50% of recommended $N_{15}P_{15}K_{15}$ + Urea), T6 (*Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea), T7 (*Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea), T8 (*Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea) and T9 (100% of recommended $N_{15}P_{15}K_{15}$ + Urea). Mineral fertilizer dose recommended in Benin is 200 kg/ha of NPK to sowing and 100 kg/ha of urea 45 days after sowing $N_{15}P_{15}K_{15}$ (INRAB, 1995).

Evaluation of growth parameters

The height, the diameter at the collars and the number of leaves of the selected plants were taken every 15 days after sowing until the 60^{Th} day when the leaf surface was taken. The product of the length and width of the leaves affected by the coefficient 0.75 estimated the leaf area (Ruget et al., 1996).

Evaluation of the yield parameters

Per elementary plot, 12 plants were harvested at 85 DAS on the two central lines of each elementary plot. After the deseeding and ginning of the corncobs, the total weight of the corn kernels in each plot was taken using an electronic scale (Highland HCB 3001 Max 3000 g × 0.1 g). After this operation, the relative humidity (LDS-1F) of the corn kernels was taken for each treatment.

The average grain yield of corn plants was determined according

*Corresponding author. E-mail: laminesaid@Yahoo.fr.

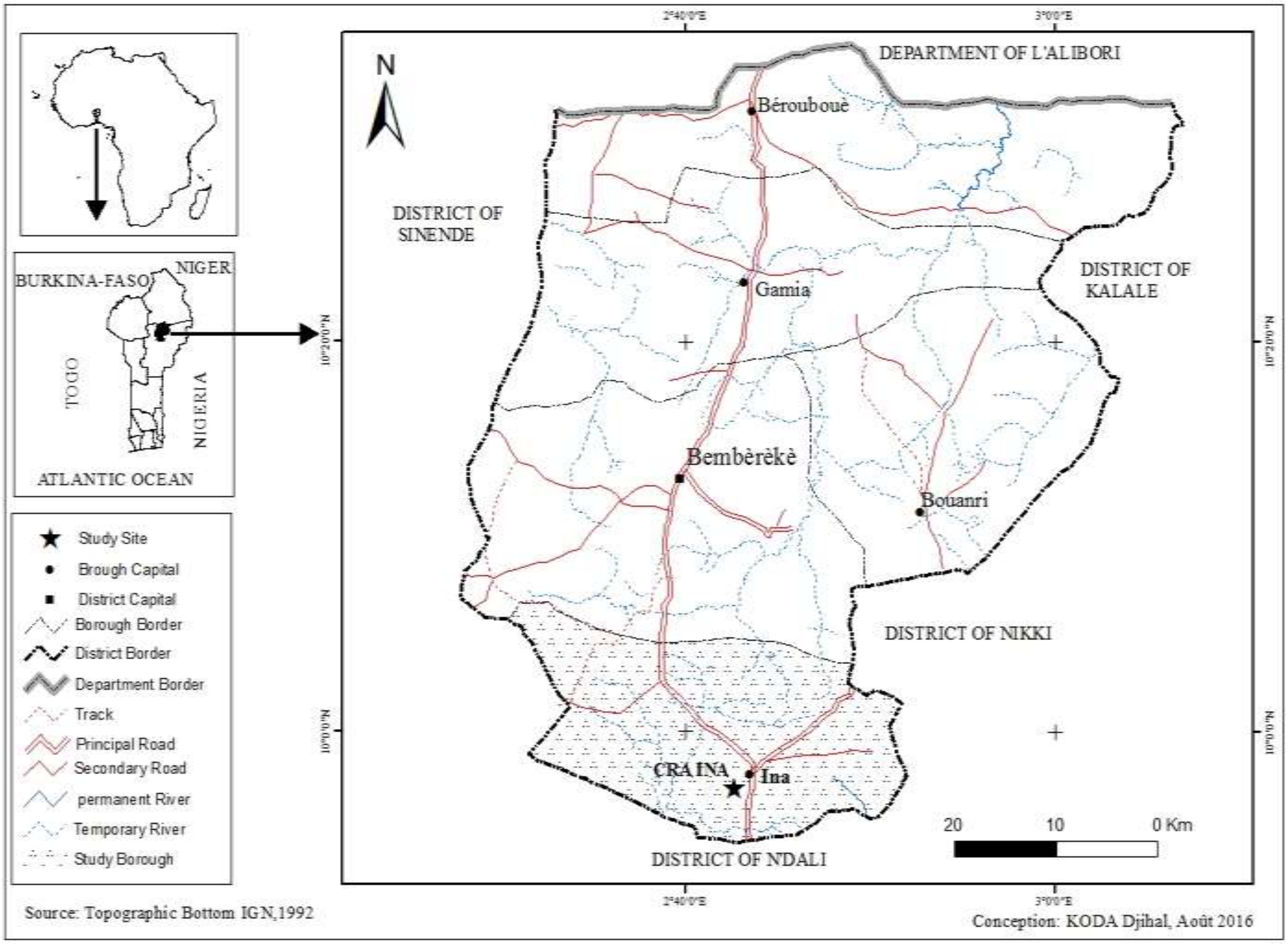


Figure 1. Geographical location of the experimental station.

to the formula developed by Kjeldahl (1883).

$$Y = \frac{P \times 10{,}000}{S \times 1{,}000} \times \frac{14}{\%\,H}$$

With: Y is the average yield of corn kernels expressed in $t.ha^{-1}$, P is the weight of the corn kernels expressed in kilograms (kg), 10,000 is the conversion from m^2 to ha, S is the harvest area in m², 1000 conversion from kg to ton (t), 14 is the initial humidity value and % H is the percentage of grain moisture, expressed as %.

Sampling and evaluation of endomycorrhizal root infection

The more root soil samples from each plot were taken with an auger at the level of a few feet of corn at a depth of 0-20 cm. Once collected, sample was put in a sterile labeled plastic bag, transported in coolers to the laboratory, and stored at 4°C until treatment.

The technique of Phillips and Haymann (1970) was used for the determination of endomycorrhizal infection. The roots are cut into 1 cm long pieces to 0.2 g; of these, to the roots were added 10% KOH, before incubation at 90°C for 1 h. After the incubation time, samples were rinsed thoroughly with water; the 0.05% trypan blue solution was added to the root and then the whole leaked back into the oven at 70°C for 15 min. After this operation, the roots are washed with cleaned water and then observed with microscope (Motic, S/N S 219031590).

Mycorrhization frequency and intensity were evaluated using the method described by Trouvelot et al. (1986):

$$F(\%) = \frac{(N - n0)}{N} \times 100$$

With: F reflecting the degree of infection of the root system; N corresponds to the number of fragments observed and n0 the number of fragments without trace of mycorrhization.

I (%) = (95n5 + 70 n4 + 30 n3 + 5 n2 + n1) / N-no

With: I is the intensity of mycorrhization; N is number of fragments observed; no is number of fragment without trace of mycorrhization; n5, n4, n3, n2 and n1 are respectively the five classes of infection marking the importance of mycorrhization namely: 5 = more than 95%, 4 = from 50 to 95%, 3 = 30 to 50%, 2 = 1 to 30% and 1 = 1%.

The determination of the number of spores was made using an adaptation of the protocol described by Rivera et al. (2003) and the formula used is as follows:

$S = n_0 \times 1g / N$

With: S is number of spores, n_0 is number of spores observed and N is amount of soil

Statistical analysis

By fitting a linear model with mixed effects on longitudinal data, the impact of mycorrhizal fungi on plant growth parameters (height and diameter at the collar) was evaluated. Treatments were considered to be fixed factors and time was considered a random factor. The adjusted means were also calculated in order to represent the evolutionary trends of each growth parameter at the level of each treatment. These analyzes were done with R 3.6.0 software (R Core Team, 2019) using the packages nlme (for fitting the model), lsmeans (for calculating adjusted means), and ggplot2 (for representing curves). The performance of the plants (leaf area and grain yield) was assessed using an analysis of variance. The tests of Ryan-Joiner and Levene (Glèlè Kakaï et al., 2006) were carried out in order to verify the conditions of normality and homoscedasticity of the data essential for the realization of ANOVA. The Dunnett test (post-hoc or multiple comparisons) was carried out in order to assess the statistical differences in the means when the results of the ANOVA are significant. The adjusted means were also calculated in order to represent the means of each growth parameter according to each treatment. The packages car, lsmeans and ggplot2 were respectively used to perform the ANOVA, the calculation of adjusted averages and the editing of graphs.

RESULTS

Plant height

The results of the linear mixed effects model have shown that time has a significant effect on the plant height ($p < 0.0001$). Also, the processing ($p = 0.031$) and then the interaction between time and processing ($p = 0.034$) are not significant. We deduce that the variations observed over time depend on the treatment. In this study, the *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ and 100% of recommended $N_{15}P_{15}K_{15}$ treatments have a significant effect on plant growth regardless of the duration of the treatment (Table 1). The recommended full dose of P and *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea better affects plant growth.

Collar diameter

The variations observed in plant growth in terms of collar diameter over time depend on the treatments ($p = 0.0002$). Treatments supplying 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, *Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea and full dose of recommended $N_{15}P_{15}K_{15}$ + Urea have a significant effect over time on the collar diameter of the plants (Table 2). Those treatments have a significant impact on corn plants.

Impact of mycorrhizal fungi on leaf area and grain yield

The results of the analysis of variance (Table 3) show a significant difference in the effects of the treatments on the leaf surfaces of the plants ($p = 0.003$).

The leaf area of plants subjected to the *Acaulosporaceae sp.*+ 50% of recommended $N_{15}P_{15}K_{15}$ and full dose of recommended $N_{15}P_{15}K_{15}$ + urea treatments had a different statistical effect on the leaf area of the plants subjected to the control (Figure 2).

It should be noted that the other treatments do not have statistically different effects from that of the control treatment. However, treatments did not have statistically different effects on plant yields (Figure 3).

Field infestation settings

The analysis of variance shows a significant difference with the treatment of *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea compared to the control. However, the plants that received the *Glomeraceae* sp. inoculum induced the best frequency of mycorrhization (Table 4).

Number of spores

The analysis of variance results showed (Table 5) a significant difference in the treatment that receives *Glomeraceae sp.*, *Diversisporaceae sp.*, *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea. The number of spores is high with these same strains.

DISCUSSION

Mycorrhizal fungi are generally described as essential components of soil-plant systems. Representing a key interface between host plants and soil (macro- and micro-) nutrients, the benefits of mycorrhizal symbiosis also include increased plant resistance to pathogens and other environmental stresses (that is, organic and metallic pollution, salinity and acidity) and an improvement in the water nutrition of host plants in exchange for photosynthetes (Lambers et al., 2008). Statistical analyzes have shown that of the three strains only treatment with Acaulospora + ½ dose of recommended $N_{15}P_{15}K_{15}$ + Urea induced good results

Table 1. Effects of treatments on corn plant height.

Parameter	t-Value	p-Value
(Intercept)	-2.884910	0.0049
Time	8.775380	0.0000
Glomeraceae sp. (T2)	0.227477	0.8206
Acaulosporaceae sp (T3)	0.832007	0.4077
Diversisporaceae sp (T4)	1.186087	0.2388
50% of $N_{15}P_{15}K_{15}$ + Urea (T5)	0.506738	0.6136
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	0.930430	0.3547
Acaulosporaceae sp+ 50% $N_{15}P_{15}K_{15}$ + Urea **(T7)**	**2.135818**	**0.0355 ***
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	1.947296	0.0547
100% $N_{15}P_{15}K_{15}$ + Urea (**T9)**	**3.152591**	**0.0022 ***
Time: T2	0.830792	0.4083
Time: T3	-0.454600	0.6505
Time: T4	-0.651631	0.5163
Time: T5	0.149723	0.8813
Time: T6	-0262951	0.7932
Time**: T7**	**-2.113554**	**0.0374 ***
Time: T8	-1.161590	0.2485
Time**: T9**	**-2.219381**	**0.0290 ***

T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = *Glomeraceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, * significant values, Time: T = interaction time and treatment

Table 2. Effects of the treatments on the growth in diameter at the collar of the plants.

Parameter	t-Value	p-Value
(Intercept)	2.702686	0.0083
Time	1.894991	0.0614
Glomeraceae sp. (T2)	0.203106	0.8395
Acaulosporaceae sp (T3)	-0.524080	0.6015
Diversisporaceae sp (T4)	-0.476715	0.6347
50% of $N_{15}P_{15}K_{15}$ + Urea (T5)	**-2.146334**	**0.0346 *****
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	-1.790805	0.0768
Acaulosporaceae sp+ 50% $N_{15}P_{15}K_{15}$ + Urea **(T7)**	**-3.166270**	**0.0021 *****
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	**-2.757414**	**0.0071 *****
100% $N_{15}P_{15}K_{15}$ + Urea (**T9)**	**-2.698718**	**0.0083 *****
Time: T2	0.253567	0.8004
Time: T3	0.856038	0.3943
Time: T4	1.298533	0.1975
Time: T5	**3.527295**	**0.0007 *****
Time: T6	**2.880950**	**0.0050 *****
Time: T7	**4.133472**	**0.0001 *****
Time: T8	**4.425512**	**0.0000 *****
Time: T9	**4.479283**	**0.0000 *****

T1 = *Glomeraceae* sp. Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae sp.*, T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, * significant values, ** highly significant, *** very highly significant, Time: T = Interaction time and treatment.

with regard to the height growth of the plants (Table 2) compared to the control. Other authors observed similar

Table 3. Effects of treatments on yield parameters.

Parameter	Leaf area (cm^2)	Yield (kg/ha)
	Moy ± sd	**Moy ± sd**
Absolute control (T1)	119.25 ± 25.62	1.46 ± 0.18
Glomeraceae sp. (T2)	123.29 ± 57.75	1.13 ± 0.41
Acaulosporaceae sp (T3)	95.59 ± 19.03	1.37 ± 0.35
Diversisporaceae sp. (T4)	108.04 ± 31.34	1.22 ± 0.39
50% $N_{15}P_{15}K_{15}$ + Urea (T5)	179.50 ± 3.11	1.71 ± 0.17
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	172.77 ± 19.57	1.87 ± 0.56
Acaulosporaceae sp+ 50% $N_{15}P_{15}K_{15}$ + Urea (T7)	203.21 ± 13.81	2.03 ± 0.57
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	199.09 ± 60.00	1.95 ± 0.54
100% $N_{15}P_{15}K_{15}$ + Urea (T9)	213.32 ± 23.37	1.73 ± 0.28
F value	4.936	1.76
Pr (>F)	0.003 ***	0.161

T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = Glomeraceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = Acaulospora + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = Diversisporaceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, *** significant values.

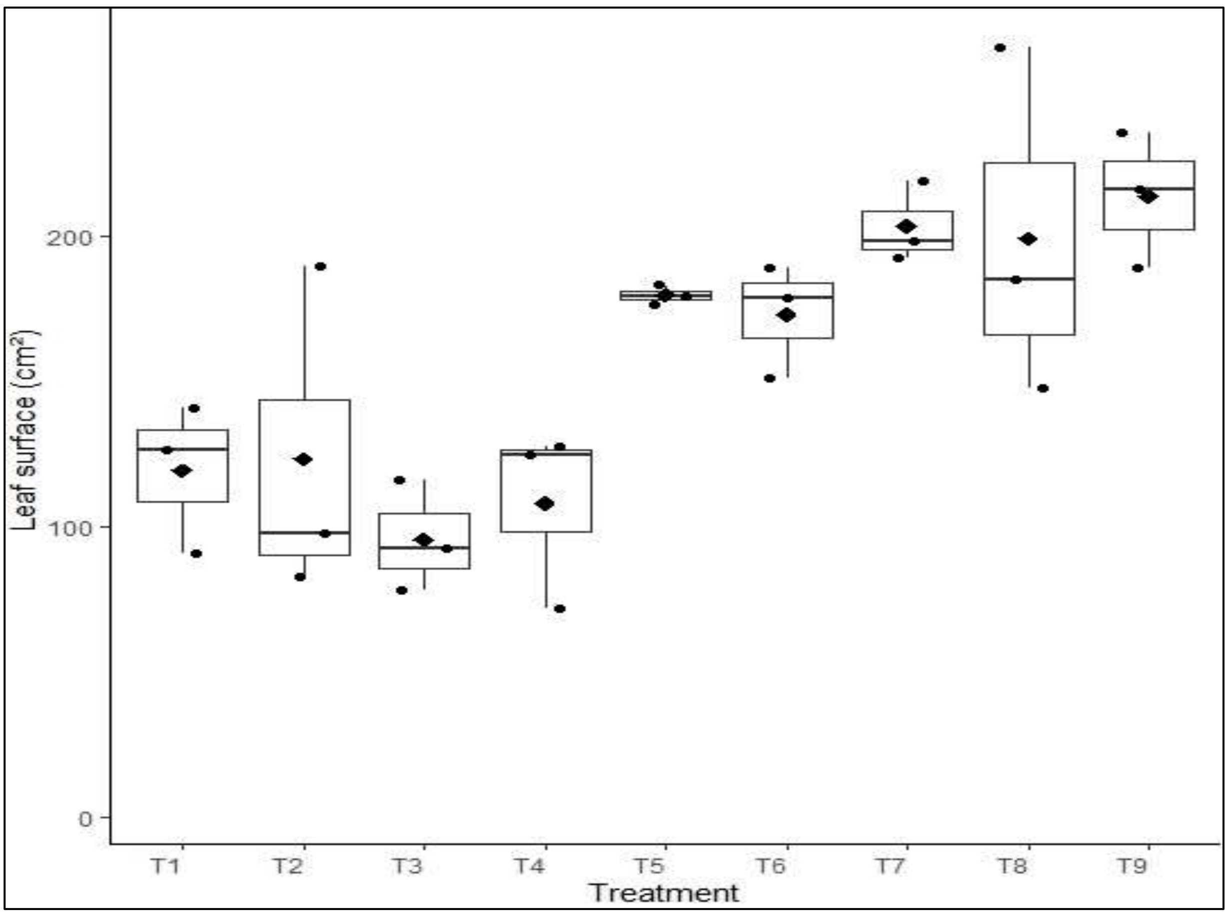


Figure 2. Average values of leaf areas per treatment. T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = Glomeraceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = Acaulospora + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = Diversisporaceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea; *** significant values.

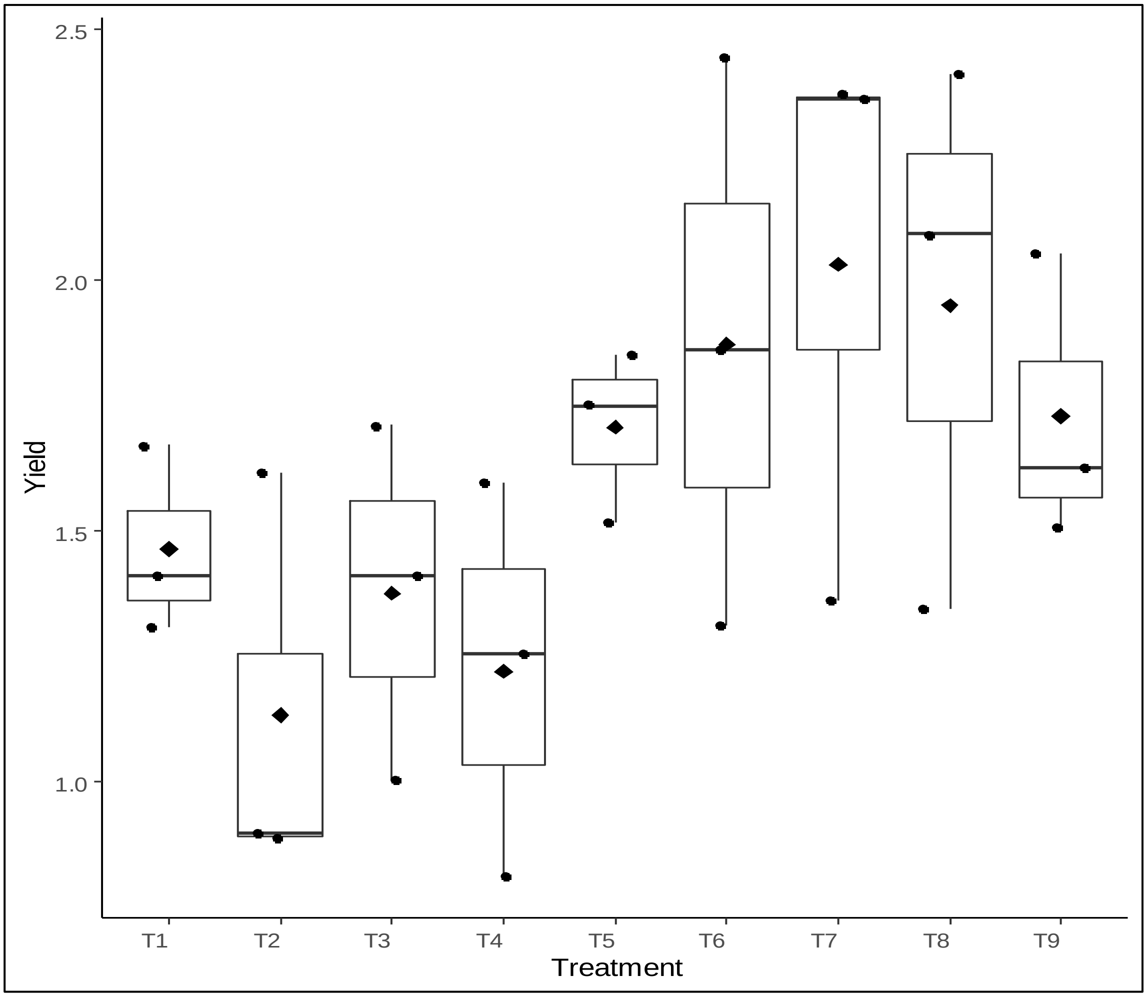


Figure 3. Average values of yields per treatment. T1 = Absolute control, T2 = *Glomeraceae sp.*, T3 = *Acaulosporaceae* sp. T4 = *Diversisporaceae sp.*, T5 = 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T6 = Glomeraceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T7 = Acaulospora + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T8 = Diversisporaceae sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea, T9 = full dose of recommended $N_{15}P_{15}K_{15}$ + Urea, *** significant values.

Table 4. Frequency of mycorrhization of corn plants.

Parameter	Estimate	Std. error	t value	Pr(>|t|)	
(Intercept)	2.73003	0.18429	14.814	4.48e-09	***
Acaulospora (T3)	0.10318	0.25416	0.406	0.69190	
Diversisporaceae sp. (T4)	-0.06744	0.26513	-0.254	0.80352	
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	0.29849	0.24323	1.227	0.24328	
Acaulospora + 50% $N_{15}P_{15}K_{15}$ + Urea (T7)	0.23180	0.24678	0.939	0.36609	
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	0.72524	0.22452	3.230	0.00722	**

results (Jesús et al., 2004). This growth increase would be the result of an improvement in the nutritional and especially phosphate status of plants by mycorrhizae (Benjelloun et al., 2004) as well as an improvement in the photosynthesis of plants (Jesús et al., 2004). Babana (2003) showed that the use of mycorrhizal fungi on wheat had a positive effect on the height growth of the plants. Contrary results have been observed by Plenchette et al. (2000) who observed that mycorrhization of millet with *Glomus aggregatum* did not stimulate its growth.

Table 5. Number of spores / 50g of soil.

Parameter	Estimate	Std. error	z value	Pr(>|z|)	
(Intercept)	4.13250	0.07313	56.511	< 2e-16	***
Acaulospora (T3)	-0.19416	0.10882	-1.784	0.074384	.
Diversisporaceae sp. (T4)	-0.46042	0.11757	-3.916	8.99e-05	***
Glomeraceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T6)	-0.34076	0.11343	-3.004	0.002663	**
Acaulospora + 50% $N_{15}P_{15}K_{15}$ + Urea (T7)	-0.14970	0.10751	-1.392	0.163787	
Diversisporaceae sp. + 50% $N_{15}P_{15}K_{15}$ + Urea (T8)	-0.44362	0.11697	-3.793	0.000149	***

However, at the level of the collar diameter, five treatments (*Glomeraceae sp.*+50% of recommended $N_{15}P_{15}K_{15}$ + urea, *Acaulospora*+50% of recommended $N_{15}P_{15}K_{15}$ + urea, *Diversisporaceae sp.*+50% of recommended $N_{15}P_{15}K_{15}$ + Urea and 100% of recommended $N_{15}P_{15}K_{15}$ + urea) produced a significant effect. These results agree with those observed by Bulakali et al. (2000), who showed in their study that mycorrhizal fungi had a beneficial effect on the growth in diameter at the collar of corn plants. The same observations were made by Aguegue et al. (2017), who showed that the inoculation of corn seeds by mycorhizal fungi had a beneficial effect on the diameter at the collar of the treated plants compared to the control.

Previous studies have shown that the presence of mycorrhizal fungi stimulate the growth of the leaf surface of corn plants (Kothari et al., 1990). These observations are in agreement with the study data, which showed that, of the three strains used, only the treatment with *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea gave the best yield in leaf area compared to the control (70.4%). This increase in leaf area in mycorrhizal plants is thought to be due to an improvement in nitrogen acquisition from the soil due to the hyphae of mycorrhizal fungi (Tobar et al., 1994).

Considering the yield grain, the treatment *Acaulosporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea gave the best result compared to the control with an increase of 39.04%. These results corroborate those of Diatta et al. (2013), who showed in their work that the *G. fasciculatum* strain induced a good grain yield (1324 kg/ha) compared to the control (1019 kg/ha).

Focusing in the endomycorrhizal infection, the highest infection frequency was obtained with *Diversisporaceae* sp. + 50% of recommended $N_{15}P_{15}K_{15}$ + Urea. Similar results have been reported by several authors, who have shown in their work that in general, the frequency of mycorrhization of inoculated plants is high, while the intensity of mycorrhization remains low (Haro, 2016; Koda et al., 2018). Indeed, according to Diagne and Ingleby (2003), the level of infection does not have to be very high to be beneficial to the plant. In addition, Hart et al. (2003) suggest that a heavily infected plant will transfer more of its carbon resources to mycorrhizal fungi, thereby reducing their beneficial effect.

Analyzes of variances have shown that the greatest number of spores is observed at the treatment with only *Glomeraceae* sp., but the number of spores decreases in the presence of mineral fertilizer. These results evolve in the same direction as those obtained by some authors who showed that the infection rate decreases when the amount of phosphorus is high. Indeed, several studies have shown that optimal or high phosphorus levels inhibit arbuscular colonization of plant roots (Koide and Li, 1990).

Conclusion

Agriculture is the biggest interface between humans and the environment; humanity will have to meet the ever-increasing food demands while facing a decrease in dependence on mineral fertilizers. In view of the results obtained, it can be retained that the native mycorrhizal fungi have given good results on growth and yield of corn. Of the three tested strains, the *Acaulospora* treatment + 50% of recommended of $N_{15}P_{15}K_{15}$ + Urea displays the best result. This result opens the gate of the possible use of those fungi not only to improve the productivity but also to restore sols.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abbas Y (2014). Microorganismes de la rhizosphère des Tétraclinaies : un outil pour optimiser la régénération assistée du *Tetraclinis articulata* Vahl. Thèse Doctorat en Ecophysiologie végétale, Université Mohamed V, Rabat P 177.

Aguegue MR, Noumavo PA, Dagbenonbakin G, Agbodjato NA, Assogba S, Koda AD, Adjanohoun A, Rivera R, de la Noval Pons BM, Baba-Moussa L (2017). Arbuscular mycorrhizal fertilization of corn (*Zea mays* L.) cultivated on ferrous soil in Southern Benin. Journal of Agricultural Studies 5(3):99-114.

Assogba S, Noumavo PA, Dagbenonbakin G, Agbodjato NA, Akpode C, Koda AD, Aguegue RM, Bade F, Adjanohoun A, Rodriguez AF, de la Noval Pons BM, Baba-Moussa L (2017). Improvement of Maize productivity (*Zea mays* L.) by Mycorrhizal Inoculation on Ferruginous Soil in Center of Benin. International Journal of Sustainable

Agricultural Research 4(3):63-76.

Babana HA (2003). Mise au point d’un inoculant biologique pour le blé irrigué du Mali. Thèse P 105.

Balogoun I (2012). Essais de validation des formules d’engrais et des périodes de semis recommandées par le modèle DSSAT pour la production de maïs (*Zea mays* L.) au Sud et Centre Bénin. Mémoire de Diplôme d’Etudes Approfondies, Faculté des Sciences Agronomiques, Université d’Abomey-Calavi, Bénin P 78.

Benjelloun S, El Ghachtouli N, Benbrahim K, Amrani JK, El Yamani J (2004). Influence de la mycorhization par le champignon *Glomus mosseae* sur la croissance et le métabolisme du maïs (*Zea mays*. L) sous des conditions de stress hydrique. Journal of Catalysis, Material and Environment pp. 31-36.

Boone PETER, Stathacos CJD, Wanzie RL (2008). Évaluation sous-régionale de la chaine de valeurs du maïs. Rapport technique ATP n 1. Bethesda, MD: projet ATP, Abt Associates Inc Accra-Ghana 73 p.

Bulakali B, Lumande K, Luyindula N, Mbaya N, Musasa T, Mwange K (2000). Effets de l’inoculation de cinq espèces de glomus sur la croissance et la nodulation en pépinière de *Racosperma auriculiforme* en République Démocratique du Congo. Tropicultura 18(2):63-67.

CRA-Nord (2007). Rapport Annuel. Institut National des Recherches Agricoles du Benin, Centre de Recherche Agricole Nord Ina, Benin.

Diagne O, Ingleby K (2003). Ecology of the AMF mycorhiziens arbusculaires infecting *Acacia raddiana*. *In* : Grouzis M, Floc'h L (Eds.) Un arbre au desert. IRD Editions: Paris pp. 205-228.

Diallo B, Samba SAN, Sane D (2016). Effets de champignons MA sur la croissance et le développement de plants de ricin élevés sous contrainte saline en conditions semicontrôlées. Revue des Energies Renouvelables 19(1):59-68.

Diatta MB, Laminou Manzo O, Macoumba Diouf PR, Diop T (2013). Effets de l’inoculation mycorhizienne sur le sesame (*Sesamum indicum* L.) en conditions naturelles. International Journal of Biological and Chemical Sciences 7(5):2050-2057.

Haro H (2016). Optimization of the symbioses rhizobienne and mycorhizienne to improve the productivity of the niébé [Vignaunguiculata (L.) Walp.] to Burkina. Doctorate (Ph. D.). University Ouaga 1 Professor Joseph Ki-Zerbo P 241.

Hart MM, Reader RJ, Klironomos JN (2003). Plant coexistence mediated by arbuscular mycorrhizal fungi. Trends in Ecology and Evolution 18:418-423.

Igué AM, Adjanohoun A, Aîhou C, Mensah GA (2015). Document Technique d’Information : Evaluation de l’état de la fertilité des sols champs des producteurs élites de maïs du Bénin. Dépôt légal N° 8116 du 09/09/2015, 3ème Trimestre, Bibliothèque Nationale (BN) du Bénin - ISBN : 978-99919-0-707-9.

INRAB (1995). Fiches Techniques Des Cultures Vivrières. In Adjanohoun, A. (2006). Nutrition du manioc sous différentes combinaisons de NPK au Sud du Bénin. Bull. Rech. Agro. Benin 52:1-6.

Jesús SB, Trinitario F, Angeles M, Asunción M, José A (2004). Variations in water status, gas exchange, and growth in *Rosmarinus officinalis* plants infected with *Glomus deserticola* under drought conditions. Plant Physiology pp. 675-682.

Kjeldahl J (1883). Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. Z. Analytical Chemistry 22(1):366-382.

Koda AD, Dagbenonbakin G, Assogba F, Noumavo PA, Agbodjato NA, Assogba S, Aguegue MR, Adjanohoun A, Rivera R, de la Noval Pons BM, Baba-Moussa L (2018). Maize (*zea mays* l.) response to mycorrhizal fertilization on ferruginous soil of northern Benin. Journal of Experimental Biology and Agricultural Sciences 6(6):919-928.

Koide RT, Li M (1990). On host regulation of vesicular arbuscular mycorrhizal symbiosis. New Phytologist pp. 59-65.

Kothari SK, Marschner H, George E (1990). Effect of VA mycorrhizal fungi and rhizosphere microorganisms on root and shoot morphology, growth and water relations in maize. New Phytologist pp. 303-311.

Kouadio ANMS, Nandjui J, Krou SM, Séry DJM, Nelson PN, Zézé A (2017). A native arbuscular mycorrhizal fungus inoculant outcompetes an exotic commercial species under two contrasting yam field conditions. Rhizosphere 4:112-118.

Lambers H, Raven JA, Shaver GR, Smith SE (2008). Plant nutrient-acquisition strategies change with soil age. Trends in Ecology and Evolution pp. 95-103.

Leake JR, Johnson D, Donnelly DP, Muckle GE, Boddy L, Read DJ (2004). Networks of power and influence: the role of mycorrhizal mycelium in controlling plant communities and agroecosystem functioning. Canadian Journal of Botany pp. 1016-1045.

Ministère de l’Agriculture, de l’Elevage et de la Pêche (MAEP) (2016). Catalogue Béninois des Espèces et Variétés végétales (CaBEV), 2016. INRAB/DPVPPAAO/ProCAD/MAEP & CORAF/WAAPP. Dépôt légal N° 8982 du 21 octobre 2016, Bibliothèque Nationale (BN) du Bénin, 4ème trimestre. ISBN: 978-99919-2-548-6. P 339.

Naitormmbaide M, Djondang K, Mama VJ, Koussou M (2015). Criblage de quelques variétés de maïs (*Zea mays* L.) pour la résistance au Striga hermonthica (Del) Benth dans les savanes tchadiennes. Journal of Animal and Plant Sciences 24:3722-3732.

Phillips JM, Hayman DS (1970). Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Transactions of the British Mycological Society pp. 158-161.

Plenchette C, Bois JF, Duponnois R, Cadet P (2000). La mycorhization (*Glomus aggregatum*) du mil (*Pennisetum glaucum*). Etudes et Gestion des Sols 7(4):379-383.

Rivera R, Fernández F, Hernández-Jiménez A, Martín JR, Fernández K (2003). El manejo efectivo de la simbiosis micorrízica, una vía hacia la agricultura sostenible., 1- 42. Estudio de caso, el Caribe. (Rivera, R. y Fernández, K., Eds. p. 166, 2003). Ediciones Instituto Nacional de Ciencias Agrícolas, La Habana, Cuba. ISBN: 959-7023-24-5. https://www.researchgate.net/publication/299979710.

Ruget F, Bonhomme R, Chartier M (1996). Estimation simple de la surface foliaire de plantes de mais en croissance. Agronomie pp. 553-562.

Therond O, Duru M, Roger-Estrade J, Richard G (2017). A new analytical framework of farming system and agriculture model diversities. A review. Agronomy for Sustainable Development 37(3):21.

Tobar R, Azcon R, Barea JM (1994). The improvement of plant N acquisition from an ammonium-treated, drought-stressed soil by the fungal symbiot in arbuscular mycorrhizae. *Mycorrhizae* pp. 105 - 108.

Zhang H, Liu Z, Chen H, Tang M (2016). Symbiosis of arbuscular mycorrhizal fungi and Robinia pseudoacacia L. improves root tensile strength and soil aggregate stability. Plos one 11:4.

Vol. 16(9), pp. 1307-1316, September, 2020
DOI: 10.5897/AJAR2019.14678
Article Number: 5A6C2EA64862
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Effect of potassium on yield and growth of Enset (*Ensete ventricosum* (Welw.) Cheesman) in Dale District, Sidama Region, Ethiopia

Kibreselassie Daniel[1]* and Suh-Yong Chung[2]

[1]Department of Soil Resources and Watershed Management College of Forestry and Natural Resources, Hawassa University, Wondogenet, Ethiopia.
[2]Division of International Studies, Korea University, Korea.

Received 25 December, 2019; Accepted 27 February, 2020

Only limited work has been done on fertilizer requirement of *Enset* crop. An experiment was conducted in Dale district, Sidama region, Ethiopia to investigate the response of *Enset* to potassium (K) fertilizer for two years (2016-2018). The treatments were: 0, 80, 150 and 200 kg K/ha as potassium chloride (KCl), single levels of phosphorus (P) (20 kg/ha), sulfur (S) (11.15 kg/ha) and boron (B) (0.57 kg/ha) as blended NPSB and nitrogen (N) (138 kg/ha) as Urea and NPSB. Regardless of the high yield obtained at 200 kg K/ha application, the maturity of the plant was similar at all rates of K, except for control. However, application of K twice along with the recommended nutrients enabled the *Enset* to reach the second edible stage (Sidamic term: *etancho*) in two years and four months after transplanting. Thus, *Enset* matured two years earlier as compared to the farmers' experience of four years to reach this stage in the area. *Enset* crops in control plots matured at one year later stage (Sidamic term: *malancho*) than those with K application. All growth parameters, dry matter and *Enset* yields (*kocho, bulla and* fiber) were high as compared to those of control plots. In the district, application of 200 kg K/ha twice during the life of *Enset* significantly ($P \leq 0.05$) increased the growth, yields and net benefits of *Enset* production than the other treatments. Hence, application of 200 kg K/ha twice during the life of *Enset* is recommended.

Key words: Growth parameters, kocho and bula yields, maturity time, agroecology, economic analysis.

INTRODUCTION

Enset farming system is among the four major agricultural systems in Ethiopia (Amede and Diro, 2005). *Enset* (*Enseteventricosum* (Welw.) Cheesman) is a perennial horticultural plant that is cultivated from home vicinity to far fields and it is usually called "false banana". It has several hundred landraces (clones), having different characteristics and uses (Mohammed et al., 2013). According to Brandt et al. (1997), *Enset* is a staple crop for an estimated 15-20 million people in Ethiopia and a reliable food source where failure of annual crops is common (Dalbato, 2000; Mikias et al., 2010). Thus, *Enset* cultivation is one of the tremendous potentials of the

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

country to nourish the rapidly increasing part of population, particularly those below food poverty line. Moreover, *Enset* provides a range of services such as forage (Funte et al., 2010), fiber (Tsehaye and Kebebew, 2006) and traditional medicine (Nyunja et al., 2009), construction and soil protection.

Enset grows at altitudes between 1500 – 3100 m above sea level (Tsegaye and Struik, 2003). Rainfall above 1100 mm, temperature between 16 and 20°C, and fertile soils are good conditions for *Enset* production and productivity. Among these growth determinants, soil fertility is the major one (Tsegaye and Struik, 2001). Moreover, adequate moisture plays a great role for the growth and productivity of *Enset,* though *Enset* has remarkable capacity to withstand heat. Brandt et al. (1997) and Shank and Ertiro (1996) reported that it is adapted to ample rainfall areas.

Enset is distributed in the wild throughout much of central, eastern and southern Africa (Brandt et al., 1997). However, its cultivation (Taye and Feleke, 1966), domestication (Brandt, 1996) and farming system is established in Ethiopia (Ehret, 1979). CSA and MoA (1994) reported that about 183,766 ha of land is cultivated with *Enset* of which 57% is found in the southern parts of Ethiopia. In southern Ethiopia, *Enset* is cultivated among Sidama, Hadiya, Gedeo, Gurage and related groups existing side by side as a co-staple to tuber crops or cereals (Amede and Diro, 2005). The central statistical authority estimated the area coverage by *Enset* as; 37, 000, 18, 000 and 13, 000 ha in Sidama, Hadiya, and North Omo (where Wolaita is located), respectively (Tsegaye, 2002).

Enset requires application of high amount of organic fertilizers and soil amendments (household refuses, farmyard manure and compost) for desirable production and productivity (Haile and Abay, 2012). High N content was found in *Enset* indicating its high N uptake (Haile and Abay, 2012). Although *Enset* has high demand for organic residues, limitation in the number of livestock in *Enset* growing areas is causing reduction in the amount of animal dung to be added (Ayele, 1975). This situation is alarming, especially in the areas where population density is high, and calling for the use of chemical fertilizers to tackle the problem (Forsido et al*.,* 2013). A research conducted at Areka, south Ethiopia, indicated vigorous growth and prompted maturity when 138 kg N/ha and 20 kg P/ha were applied twice throughout the life of *Enset* (Ayalew and Yeshitila, 2011) revealing the importance of chemical fertilizers to prevent yield loss.

Until recently, there has been a general perception that soils of Ethiopia contain sufficient amount of potassium (K) based on the report by Murphy (1968). Thus, fertilizer extension program in Ethiopia did not include K until 2014. However, national soil fertility survey conducted by Ethiopian Soil Information System (EthioSIS) found vast areas, especially highland Vertisols and acidic soils in the country, that respond to K fertilization (EthioSIS, 2013, 2014). Furthermore, the study conducted by Haile (2009) in Sidama zone, showed significant effect of K fertilizer on the yield of Irish potato. These findings indicate the importance of K application to increase crop yield in the different agricultural areas.

This research was therefore aimed at evaluating the response of *Enset* to K application in Sidama region, Ethiopia and to determine the rate and frequency of K application to *Enset* for optimum growth and productivity.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Dale district of Sidama region, Ethiopia (Figure 1) from 2016 - 2018. Sidama region is located between 5°45'- 6°45' N latitude and 38°39° E longitude, covering a total area of 6,538 km^2 of which 98% is land and 2% is covered by water (SZPEDD, 2004). It lies in the area varying from lowland to highland (Sidama Development Corporation, 2000). The regional capital, Hawassa, is located in the northern tip of the region, at a distance of 275 km from Addis Ababa. As per traditional agro-ecological zone classification of Ethiopia, the area is characterized by mid highland and low land agro-ecology. The experimental site was located at 6°49.0'94'' N and 38^{o}23.1'83'' E (Soyama farmers' association) at an altitude of 1782 masl.

Soil sampling, preparation and analysis

A composite sample was taken from a total of twelve random soil samples (0-50 cm) collected prior to land clearing and preparation. It was air-dried and passed through 2-mm sieve to remove large particles, debris and stones.

Particle size analysis was performed using the Bouyoucous hydrometer method (Bouyoucos, 1951) and the textural classes were categorized using United States Department of Agriculture soil textural triangle.

The pH was determined in 1:2.5 soil-water suspensions using a glass electrode (Jackson, 1973). Electrical conductivity was determined from the saturation extract (1:5 soil water ratio) of soils (Gupta, 2009). Organic carbon was determined following wet oxidation method of Walkley and Black (1934). Total nitrogen (N) was determined by Kjeldhal method (Bremner and Mulvaney, 1982). Mehlich III extractant was used to extract, phosphorus (P), exchangeable potassium, calcium, magnesium, sulfur (S) and boron (B) (Mehlich, 1984). Cation exchange capacity (CEC) was determined using ammonium acetate method (Sumner and Miller, 1996).

Experimental design and field management

Field trial was conducted in three consecutive years (2016-2018). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments included: were 0, 80, 150 and 200 kg K/ha as potassium chloride (KCl). *Ganticha* clone (Sidamic term) *Enset* suckers were propagated at Hula district Halaka *kebele* and 108 seedlings of *Enset* suckers were transplanted a year after sprouting to the main field at a depth of 20 cm.

Potassium chloride (KCl) was split applied two times per year. Recommended levels of P (20 kg/ha), nitrogen (N) (138 kg/ha) (Ayalew and Yeshitila, 2011), sulfur (S) (11 kg/ha) and boron (B) (0.57 kg/ha) were also used. Application times were once for P while twice for N per year. Inter and intra row spacing was 2 × 2 m.

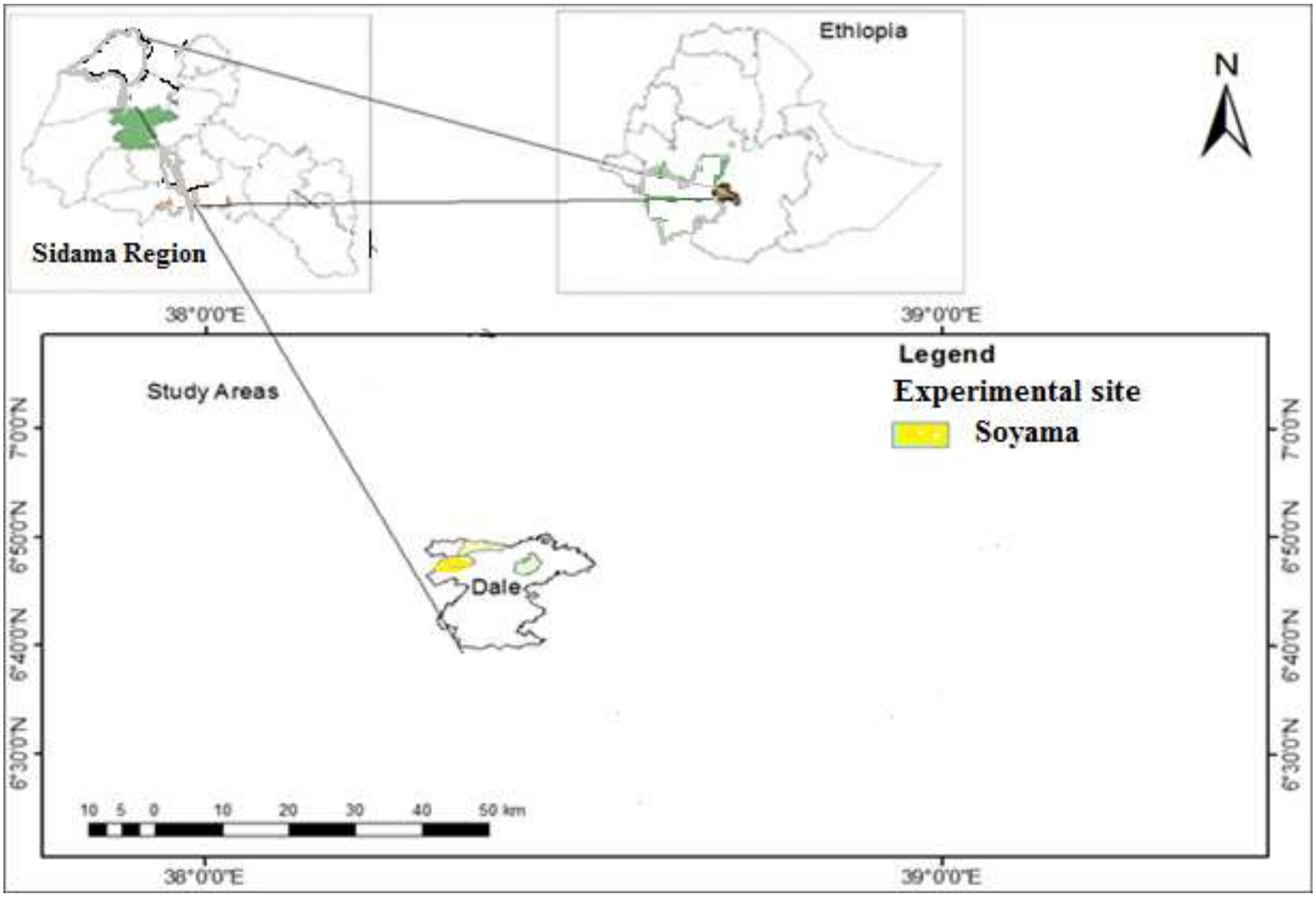


Figure 1. Map of Sidama region in Ethiopia, study district in Sidama region and experimental site 'kebele' in the study district.

Urea and NPS+B were used as sources of N while only NPS+B was used as a source of P, S and B. The fertilizers were applied in a circular band (side dress) at a depth of 3 to 5 cm after one month of planting and then yearly as per treatments as suggested by Borges et al. (2002). All the other agronomic managements (weeding, cultivation etc.,) were carried out properly and equally for all the treatments.

Plant sampling and agronomic data collection

Prior to harvesting, a total of thirty-six *Enset* plants were sampled randomly from the experimental site. Plant and pseudostem height, pseudostem circumference, leaf length and the leaf width were measured using a tape meter. Moreover, all the fully expanded and green leaves were counted starting from the emergence of new leaves until the time of harvest to determine total number of leaves while weighing corms using portable balance.

Enset sampling and *kocho*, *bula* and fiber production

After random sampling of three plants per plot, fresh weights of all leaves, midribs, central tender pseudostem and edible leaf sheaths and corm were determined. Then, 500 g samples from each were taken and packed in cellulose paper folders. Samples were dried at 105°C for 24 h in an oven (Jones, 2001). Leaf sheaths of the pseudostem were decorticated using a sharp-edged bamboo scraper while pulverizing the corm by sharp edged animal bone. The resulting pulps were thoroughly mixed with purposely decayed and pulverized corm (Sidamic term: *Gamancho*) in order to accelerate the fermentation process and put into a pit. Fermentation pits were opened, and the contents were pressed and re-arranged to enhance the fermentation process. Thereafter, the un-squeezed *kocho* was weighed, squeezed by human force to the maximum dryness and the weight was recorded.

Plant leaf sampling, preparation and analysis

A total of twelve *Enset* samples were collected from experimental site based on sampling techniques used for banana plant (Borges et al*.,* 2002) since *Enset* and banana have similar leaf morphology (Tsegaye and Struick, 2003).

After dry ashed, samples were dissolved in concentrated acid and potassium was determined by flame photometer while P was determined by Colorimetry (by Ammonium Vanadate-Ammonium Molybdate yellow color method). On the other hand, sulfur, calcium, magnesium and boron were determined by atomic absorption spectrophotometer (AAS). Lastly, total N was determined by an acid digestion following the Kjeldahl method (Kjeldahl, 1883).

Statistical analysis

The statistical analyses were conducted using the SAS package

Table 1. Selected physico-chemical characterstics of the experimental soil.

pH (H_2O)	EC (dS/m)	OC (%)	CEC (meq/100 g)	Total N (%)	Available P	Exchangeable bases					Particle size		Textural class
						K	Ca	Mg	S	B	Sand (%)	Clay	
						(mg/kg)							
6.35	0.08	2.49	23.70	0.14	4.16	450	2278	325	9.32	0.46	56	22	Sandy clay loam

Table 2. Effect of levels of potassium on % nutrient contents of *Enset* leaves.

Treatment	Nutrient content						B (mg/kg)
	N	P	K	Ca	Mg	S	
	(%)						
T1 Control (No K)	2.44^{b}	0.17^{b}	2.30^{b}	0.30^{ab}	0.20^{c}	0.10	85^{a}
T2 (80 kg K/ha)	2.66^{ab}	0.21^{a}	3.67^{a}	0.36^{a}	0.27^{a}	0.12	20^{b}
T3 (150 kg K/ha)	2.74^{ab}	0.18^{b}	3.70^{a}	0.24^{b}	0.18^{d}	0.14	7^{d}
T4 (200 kg K/ha)	3.01^{a}	0.18^{b}	3.95^{a}	0.31^{ab}	0.22^{b}	0.17	12^{c}
Minimum	2.44	0.17	2.30	0.30	0.20	0.10	7
Maximum	3.01	0.21	3.95	0.36	0.27	0.17	85
$LSD_{0.05}$	0.55	0.02	0.33	0.08	0.069	0.07^{NS}	69
SEM±	0.09	0.01	0.2	0.02	0.0096	0.01	9.5

Means within a column followed by the same letter is not significantly different at P ≤ 0.05, Total number of leaf samples was 12.

(SAS Institute, 2012). The differences in vegetative parameters and yields among treatments were analyzed using a Fisher's protected least significant difference (LSD) test at P = 0.05. One-way analysis of variance (ANOVA) was done during data analysis. Moreover, correlations among total dry matter (DM), yields (*kocho*, *bula* and fiber), potassium rates and leaf nutrient contents of selected elements were undertaken.

Economic analysis

Partial budget analysis of selected treatments was done according to CIMMYT (1988).

RESULTS AND DISCUSSION

Selected physico-chemical properties of the experimental soil

The textural class of the experimental site soil was sandy clay loam (Table 1) and it indicates the exposure of crop nutrients to leaching. The soil pH was in the moderately acid range (pH 5.6-6.5). The EC values of the soil were below 2 dS/m indicating the soils are salt free in accordance with EthioSIS (2014).

In the district, the soil available P was low, S was very low while total N was low (EthioSiS, 2014). Calcium contents of the soils were high (2000-4000 mg kg^{-1}) (Maria and Yost, 2006) while K contents were optimum (190-600 mg kg^{-1}) in accordance with EthioSIS (2014). The magnesium contents of the soils were medium (180-396 mg kg^{-1}), whereas the organic carbon was very low (Landon, 2014). According to the classification proposed by EthioSIS (2014), the B contents of the experimental sites were very low (< 0.5 mg kg^{-1}). Based on the rating by Landon (2014), the CEC of the soils in the district fall in the high range (25 – 40 cmol (+) kg^{-1}).

Nutrient contents of the *Enset* leaf

The N content increased from T1 (control) to T4 (200 kg K ha^{-1}) and varied from 2.44 to 3.01 (Table 2). Generally, the highest N content was recorded at T4 though its content in plant leaves was significantly (P ≤ 0.05) different only with that of the control treatment (Table 2). Leaf N fall in the sufficient range (2.5-4.5%) proposed by Kalra (1998), at T2, T3 and T4 while T1 (control) was below 2.5%. The low values of N in control could be due to low soil K.

The lowest and highest values of leaf P were recorded at T1 (control) and K applied (T2) treatments, respectively. The contents varied from 0.17 to 0.21% (Table 2). Leaf P was below 0.20% and the low levels of P could be due to the status of soil moisture.

Despite the optimum K status of experimental soil, *Enset* responded to the applied K levels (Table 2). This indicated the importance of further investigation to determine crop type based critical K levels for different crops. Generally, K concentrations in the leaves increased with increasing K application and the increments ranged

Table 3. Effect of different rates of potassium on vegetative parameters.

Treatment (kg/ha)	Plant height (cm)	Pseudostem height (cm)	Pseudostem circumference (cm)	3^{rd} Leaf length (cm)	3^{rd} Leaf width (cm)	Total number of leaves
T_1	520^{b}	162^{b}	118^{c}	360^{b}	73^{b}	81^{b}
T_2	577^{ab}	182^{ab}	132^{bc}	395^{ab}	77^{ab}	84^{b}
T_3	619^{a}	198^{a}	139^{ab}	421^{a}	84^{a}	84^{ab}
T_4	635^{a}	209^{a}	149^{a}	425^{a}	83^{a}	88a
Minimum	520	162	118	360	73	81
Maximum	635	209	149	425	84	88
$LSD_{0.05}$	86.4	33.9	16.2	54.3	8.6	4.7
SEM±	16.2	6.4	3.4	10	1.6	0.9
CV%	15.3	18.8	13	14.1	11.4	5.8

Means within a column followed by the same letter(s) is/are not significantly different at P ≤ 0.05. T_1= Control or no K, T_2 = 80 kg K/ha, T_3 = 150 kg K/ha, T_4 = 200 kg K/ha, Total number of plants sampled was 36.

from 2.30 to 3.95%. This could be due to the presence of higher K in a readily available form in soil solution (Anjaiah et al., 2005). Among the treatments, the lowest K was recorded at T1 (control) while the highest value was indicated by T4. Overall, leaf K falls in the sufficient range (1.50-5.50%) that was proposed by Kalra (1998).

Sulfur contents of the leaves varied from 0.10 to 0.17% (Table 2) and increased from T1 (control) to T4 (200 kg K/ha). However, the increase was not significant among the treatments (P ≥ 0.05) and the content was in the deficiency level (< 0.20%) according to Kalra (1998).

Calcium ranged from 0.30 to 0.36% while magnesium varied between 0.20 and 0.27%. The highest percent Mg was recorded at T2 (Table 2). Leaf Ca was deficient at all treatments (< 0.50%), while Mg was deficient (< 0.20%) nearly at all treatments in the district (Kalra, 1998). This could be due to the antagonistic effect of K on the uptake of Ca and Mg (IPNI, 1998).

Boron content varied from 7 to 85 mg kg^{-1} and the highest values were recorded at T1 (control). Generally, the concentrations of B in plant leaves decreased with increasing rates of K application probably due to dilution by high growth and biomass production of the plants with application of K (Mengel and Kirkby, 2001). This could be confirmed by increasing total B uptake by the plants, which increased from 0.06 to 0.12 kg ha^{-1} with increasing K rates.

Effect of applied potassium on vegetative growth parameters

Two years and four months after transplanting, the *Enset* plants were harvested to measure vegetative parameters. Generally, vegetative growth parameters increased with increasing contents of N, P and K in the leaves of plant as was also reported by Uloro and Mengel (1994) indicating the effects of N and P when K is not deficient. Among the treatments, the lowest vegetative growth was recorded at T1 (control). This indicated K deficiency in the experimental soils, although the contents were rated as optimum in accordance with EthioSIS (2014).

In general, the plant height increased with increasing level of K application and ranged from 520 to 635 cm (Table 3). Statistically significant difference (P ≤ 0.05) was observed between the control and K treated plants at T3 and T4 while T1 and T2 treatments did not significantly differ (Table 3).

The data on pseudostem height showed significant (P ≤ 0.05) variation between control and K applied plots (Table 3). Statistically significant (P ≤ 0.05) differences were observed between the control (T1) and K applied plots (T2, T3 and T4), although T1 and T2 were not different in (P ≥ 0.05). The pseudostem heights ranged from 162 to 209 cm (Table 3).

The pseudostem circumference increased with increasing levels of K application, whereby it varied from 118 to 149 cm (Table 3). The highest pseudostem circumferences were produced at T4, which were significantly different (P ≤ 0.05) from the plants at T1 (control) (Table 3).

Total leaf number increased with increasing levels of K application and ranged from 81 to 88 (Table 3). Control plants (T1) had the least number of leaves per plant while the plants at the highest K rates had the highest number.

Leaf lengths varied from 360 to 425 cm (Table 3) and increased with increasing K application. Significant differences (P ≤ 0.05) in leaf lengths were recorded between the control and K applied plots and highest and the lowest leaf lengths were recorded at T4 and T1, respectively.

Leaf widths of the plants varied from 73 to 84 cm (Table 3) and the highest leaf widths were recorded at T4. Significant differences (P ≤ 0.05) in leaf width were recorded between the control and K treated plots. The significant increase in leaf width when K was applied

Table 4. Effects of increasing rates of potassium on above and below ground dry weights.

Treatment (kg/ha)	Leaf sheaths	Corm	Leaves and midribs	Centeral tender Pseudostem	Shoot
	(kg/plant)				
T_1	7.69^c	1.73^d	1.83^d	0.15^c	9.70^c
T_2	9.39^b	2.17^c	2.26^c	0.20^b	11.90^b
T_3	9.49^b	2.39^b	2.50^b	0.20^b	12.20^b
T_4	12.44^a	3.06^a	2.78^a	0.27^a	15.50^a
$LSD_{0.05}$	0.60	0.20	0.20	0.03	0.70
SEM±	0.31	0.09	0.07	0.01	0.40
CV%	6.40	8.60	8.6	12.8	5.60

In a column, means with the same letters are not significantly different at $P \leq 0.05$. T_1 = Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha, Total number of plants sampled is 36.

suggests the inadequate K contents of the experimental soils.

Effect of increasing levels of potassium application on dry matter production

Above ground dry matter

Generally, the above ground dry matter weight increased with increasing contents of N, P and K in the leaves of plant (Table 2). This indicated the importance of K application along with N and P for an increase of the above ground dry matter weight (Uloro and Mengel, 1994). Overall, the dry matter production of *Enset* plant increased with increasing levels of applied K (Table 4). Moreover, the lowest dry matter production was recorded at T1 (control) indicating K deficiency in the experimental soils.

Significant differences ($P \leq 0.05$) in leaf and midribs dry weights were recorded among all treatments. This showed the effects of increasing levels of K.

Significant ($P \leq 0.05$) differences in dry central tender pseudostem and dry weights of leaf sheaths were recorded between T1 and K treated plots (T2, T3 and T4), although there was no significant difference ($P > 0.05$) between T2 and T3 (Table 4). The highest central tender pseudostem and leaf sheath dry weights were recorded at T4, which were significantly different from the other treatments.

With regard to shoot dry weights, significant ($P \leq 0.05$) differences were recorded between the controls and K treated plots (T2, T3 and T4) (Table 4). However, the plant dry weights at T2 and T3 were not significantly different indicating the K contents of the experimental soil was not sufficient for optimum *Enset* production.

Below ground dry matter

The corm dry matter production increased with increasing level of applied K (Table 4). Dry weights of corm of all treatments significantly ($P \leq 0.05$) differed from each other. On the other hand, the corm dry weight of control was statistically different ($P \leq 0.05$) from K treated plots. Overall, the lowest corm dry weights were recorded at T1 (control) indicating that K was deficient in the experimental soils. Conversely, the corm dry weights increased with increasing contents of N, P and K in the leaves of plant (Table 2). Thus, the results revealed the effect of K on corm dry weights when the limiting nutrients applied along with it, indicating that K promotes carbohydrate production in the state of balanced nutrition.

Maturity and yields of *Enset*

Enset crops to which K applied reached the second edible stage (Sidamic term: etancho) in two year and four months after transplanting. Thus, it matured two years earlier as compared to the farmers' experience in the area, which takes four years to reach this stage. On the other hand, *Enset* crops in control plots matured at one year later stage (Sidamic term: malancho) than those with K application.

Generally, *Enset* yields increased with increasing levels of applied K (Table 5) and the yields also increased with increasing contents of N, P and K in the leaves of plant (Table 2). Thus, the effect of potassium on *Enset* yield could be achieved when applied along with N and P (Uloro and Mengel, 1994). The result is in line with the report by Romheld and Kirkby (2010) and MoA and ATA (2012) which indicated the importance of balanced nutrient management on crop yields. Moreover, the lowest weights of *Enset* yields were recorded at T1 (control), indicating K deficiency in the experimental soils.

Among the treatments, T4 resulted in the highest weight (44 kg/plant) of fresh un-squeezed *kocho*. Moreover, significant differences ($P \leq 0.05$) in fresh un-squeezed *kocho* weights were recorded only between controls and the K applied treatments (Table 5).

Among the treatments, T4 gave the highest fermented

Table 5. Effects of increasing rates of potassium on *kocho, bula and* fiber weights.

Treatment (kg/ha)	Un-squeezed *kocho*	Squeezed *Kocho*	*Bula*	Fiber	% Increase in squeezed *kocho* yield over control	% Increase in *bula* yield over control	% Increase in fiber yield over control
	(kg/plant)						
T_1	31.0[c]	14.1c	0.8[c]	0.46[c]	-	-	-
T_2	37.0[b]	16.7[b]	0.9[bc]	0.68[b]	16	11	32
T_3	37.0[b]	16.8[b]	1.0[b]	0.71[ab]	16	20	35
T_4	44.0[a]	20.1[a]	1.2[a]	0.78[a]	30	33	41
$LSD_{0.05}$	2.5	1.2	0.1	0.08	-	-	-
SEM±	0.9	0.4	0.03	0.02	-	-	-
CV%	7.1	7.1	9.8	13.27	-	-	-

Means in a column followed by the same letter(s) is/are not significantly different at $P \leq 0.05$. T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha. Total number of plants sampled per district is 36.

Table 6. Economic analysis of squeezed *kocho* yield.

Economic variable	Dale district			
	T_1	T_2	T_3	T_4
Total yield (t/ha)	35	42	42	50
Adjusted yield (t/ha)	32	38	38	45
Value in birr	190350	225600	226800	271350
Cost of KCl applied in birr	-	2775	5203	6937
Cost that vary birr	-	2775	5203	6937
Net benefits birr	190350	222825	221597	264413

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

squeezed *kocho* dry weight, 20.1 kg/plant, whereas the lowest fermented squeezed *kocho* yields of 14.1 was recorded at T1. In general, significant ($P \leq 0.05$) differences in dry weights of fermented squeezed *kocho* were recorded between controls and the K applied treatments. The squeezed *kocho* yields at T2, T3 and T4 were higher by 16, 16 and 30%, respectively than the yields obtained from control (Table 5).

The highest *bula* weight (1.2 kg/plant) was recorded at T4, whereas the lowest *bula* yield (0.8 kg/plant) was recorded at T1. Significant difference was recorded only between control and T3 and T4. The *bula* yields at T2, T3 and T4 treatments were higher by 11, 20 and 33%, respectively than yields obtained from control (Table 5). The results also indicated the significant effect K application on the *bula* yield per plant and the need for external supply of K for optimum yield.

Among the treatments, the highest K rate (T4) resulted in the highest fiber yield, 0.78 kg/plant, whereas the lowest fiber yield, 0.46 kg/plant, was recorded at T1 indicating K deficiency in the experimental soils. In general, significant ($P \leq 0.05$) differences in fiber yields were recorded between controls and the K applied treatments. However, the fiber yield at T3 was not significantly different from those at T2 and T4. Fiber yields at T2, T3 and T4 were higher by 32, 35 and 41%, respectively than yields obtained from control (Table 5).

Economic analysis

The results of partial budget analysis pertaining to the data on fermented and squeezed *kocho* and *bula* (Tables 6 to 9) showed that the highest net benefit was obtained from K application at 200 kg/ha the experimental site in the district. Therefore, twice application of 200 kg K/ha during the life of *Enset* is recommended to increase the yield *of Enset* in the district.

A cross-correlation among total dry matter (DM), yields (*kocho, bula* and fiber), potassium rates and leaf nutrient contents of selected elements

The results of cross-correlation (Table 10) showed strong positive relationships between K rates and yield parameters such as leaf percent K contents, *kocho*, *bula*, fiber yields and total DM in both districts. Additionally, percent N and S had positive intermediate association with K rates. These associations indicated an increase of

Table 7. Partial budget analysis data of squeezed *kocho*.

Treatment	Dale district		
	Cost that vary (birr/ha)	Net Benefits (birr/ha)	Marginal rate of return (%)
T1	0	190350	-
T2	2775	222825	1170
T3	5203	221597	D
T4	6937	264413	2469

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

Table 8. Economic analysis of *bula* yield.

Economic variable	Dale district			
	T_1	T_2	T_3	T_4
Total yield	2	2	3	3
Adjusted yield	2	2	2	3
Value in birr	126000	142100	161000	189000
Cost of KCl applied in birr	-	2775.2	5203	6937
Cost that vary birr	-	2775	5203	6937
Net benefits birr	126000	139325	155797	182063

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

Table 9. Partial budget analysis data of *bula* yield.

Treatment		Dale district		
		Cost that vary (birr/ha)	Net Benefits (birr/ha)	Marginal rate of return (%)
T1	Control	0	126000	-
T2	80 kg K/ha	2775	139325	480
T3	150 kg K/ha	5203	155797	678
T4	200 kg K/ha	6937	182063	1515

T_1= Control or no K, T_2 = 80 kg K/ha, T_3 =150 kg K/ha, T_4 =200 kg K/ha.

nutrient contents in *Enset* leaves and yield with increasing K levels. Moreover, positive relationship existed among K rates and leaf percent N is convincing, since leaf N contents increase with increasing K levels (IPNI, 1998) while positive correlation with percent leaf P indicated that applied P level was low to be affected by K levels.

The strong and significant negative correlation existed between B, K rates and K indicates the dilution effect of increasing biomass production on boron (Mengel and Kirkby, 2001).

Percent K correlated positively and strongly with *kocho, bula*, fiber and total DM (Table 10) indicating positive association. Leaf N correlated positively and strongly with *kocho*, *bula* and fiber yield. The leaf percent P correlated positively and intermediately with *kocho,* fiber and total DM indicating positive proportionality. Sulfur correlated positively and intermediately with total DM. Overall, the *kocho*, *bula*, fiber yields and total DM correlated strongly and positively with each other.

CONCLUSION AND RECOMMENDATIONS

Despite the adequate K level in the experimental soils, *Enset* responded to increasing levels of K application calling for site and crop specific investigation on critical levels of available K.

An increase in above and below ground dry matter production, perceptibly rapid vegetative growth of *Enset* and increase of yield with increasing level of applied K show the effect of K when limiting nutrients are applied along with it. Noticeable increase in plant heights, pseudostem heights, leaf lengths and total number of leaves recorded show the effect of K, when applied together with other limiting nutrients. Maturity difference between controls and K applied crops could also be due

Table 10. Cross correlation among percent *Enset* leaf nutrient contents, K rates, yields and total dry matter.

Parameter	N	K	P	S	B	K rates	Kocho yield	Bula Yield	Fiber Yield	Total DM
N	1									
K	0.62*	1								
P	0.06	0.09	1							
S	0.16	0.46	-0.45	1						
B	-0.51	-0.96*****	-0.40	-0.44	1					
K rates	0.62*	0.87****	0.09	0.59*	-0.87****	1				
Kocho yield	0.82***	0.81***	0.13	0.51	-0.74**	0.87****	1			
Bula yield	0.82***	0.62*	0.01	0.49	-0.51	0.77***	0.93*****	1		
Fiber yield	0.75**	0.87****	0.34	0.40	-0.86****	0.85****	0.86****	0.76***	1	
Total DM	0.71**	0.79***	0.10	0.57*	-0.74**	0.93*****	0.96*****	0.91*****	0.82***	1

*Significant at P ≤ 0.05; ** at P ≤ 0.01; *** at P ≤ 0.005; ****at P ≤ 0.001; ***** at P ≤ 0.0001.

to the effect of K applied along with limiting nutrients.

The correlation study indicated significantly positive effects of K rates, leaves percent K and N on the yields of *kocho, bula* and fiber and DM. On the other hand, B was negatively correlated with leaf nutrient contents, yields and the dry matter. This indicates that the applied B was diluted by high biomass produced. Finally, positive relationships existed among yields and DM, indicating the direct relationships existing between them.

Finally, as findings of this study implies adequate supply of potassium (K) fertilizer to Enset crop will not only increase the production of the crop but also help avoid environmental damages to the soils. For the details on the relationship between use of potassium (K) fertilizer and sustainability of soil is the subject for further study based on the outcomes of this paper.

Generally, application of 200 kg K/ha twice throughout the life of *Enset* significantly (P ≤ 0.05) increased the growth, yields and net benefits of *Enset* production than other treatments. Hence, application of 200 kg K/ha twice during the life of *Enset* is recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

This work was supported by the Korea International Cooperation Agency (KOICA) under the title of "Strengthening the Capacity to Address Climate Change on Forestry Sector in Ethiopia" (No.2018-0004).

REFERENCES

Amede T, Diro M (2005). "Optimizing soil fertility gradients in the Enset (*Ensete ventricosum*) systems of the Ethiopian highlands: Trade-offs and Local Innovations." In: Improving Human Welfare and Environmental Conservation by Empowering Farmers to Combat Soil Fertility Degradation (Bationo et al., eds). African highlands initiative (AHI), working papers No 15.

Anjaiah T, Padmaja G, Sreenivasa Raju A (2005). Influence of levels of K and FYM on yield and K uptake by carrot (*Daucus carota* L.) grown on an Alfisol. Journal of Research, ANGRAU 33(3):82-86.

Ayalew A, Yeshitila M (2011). The Response of Enset (Ensete ventricosum (Welw) Cheesman) production to Rate and Frequency of N and P Nutrients Application at Areka, in Southern Ethiopia. Innovative Systems Design and Engineering 2:26-32.

Ayele GM (1975). The forgotten Aborigines Livestock and meat Board, Addis Ababa.

Borges AL, van Raij B, Magalhães AF, de C, Bernardi AC (2002). Nutrição e adubação da bananeira irrigada. Embrapa Mandioca e Fruticultura. Cruz das Almas, BA. (Circular Técnica, 48).

Bouyoucos GJ (1951). Recalibration of hydrometer method of mechanical analysis of soil Agronomy Journal 43(9):434-435.

Brandt AS (1996). A model for the origins and evolution of Enset food production. In: A. Tsedeke, H. Clif¬ton, B.A. Steven & S. Gebre-Mariam (eds.), Proceedings from international workshop on Enset. Enset-Based Sustainable Agriculture in Ethiopia. Edited by. Institute of Agricultural Research, Addis Ababa pp. 172-187.

Brandt, Steven A, Anita S, Clifton H, McCabe TJ, Endale T, Mulugeta D, Gizachew WM, Gebre Y, Masayoshi S, Shiferaw T (1997). The tree against hunger: Enset- Based Agricultural systems in Ethiopia. http://users.clas.ufl.edu/aspring/publications/enset.pdf

Bremner JM, Mulvaney CS (1982). Nitrogen-Total. In: Page, A.L., Ed., Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, American Society of Agronomy, Soil Science Society of America pp. 595-624.

CIMMYT (1988). From Agronomic Data to Farmer Recommendations : An Ecconomics Training Manual. Completely revised edition. Mexico, DF.

Central Statistical Authority (CSA) and Ministry of Agriculture (MOA) (1994). Area production and yield of crops, private holdings, 1993/1994 Meher season, Addis Ababa, Ethiopia.

Dalbato AL [publ. as: Lagibo A.] (2000). An overview of population and food production situation in SNNPR. Population Newsletter, Awassa–Ethiopia 4:10-13.

Ehret C (1979). On the antiquity of agriculture in Ethiopia. Journal of African History 20(2):161-177.

Ethiopia Soil Information System (Ethiosis) (2014). Soil fertility status and fertilizer recommendation atlas for Tigray regional state, Ethiopia. July 2014, Addis Ababa, Ethiopia.

Ethiopian Soil Information System (EthioSIS) (2013).Towards improved fertilizer recommendations in Ethiopia – Nutrient indices for categorization of fertilizer blends from EthioSIS woreda soil inventory data. A discussion paper. Addis Ababa, Ethiopia.

Forsido SF, Vasantha Rupasinghe HP, Tess A (2013). "Antioxidant capacity, total phenolics and nutritional content in selected ethiopian staple food ingredients." International journal of food sciences and nutrition 64(8):915-920.

Funte S, Negesse T, Legesse G (2010). Feed resources and their management system in Ethiopian highlands: the case of UmbuloWacho watershed in southern Ethiopia. Tropical and Subtropical Agroecosystems 12:47-56.

Gupta PK (2009). Soil water plant and fertilizer analysis. 2nd Edition, Agronomy and bioscience. Publishers 5(3):398-406.

Haile W (2009). Onfarm verification of potassium fertilizer effect on the yield of irish potato grown on acidic soils of Hagere selam, Southern Ethiopia. Ethiopian Journal of Natural Resources 11(2):207-221.

Haile W, Abay A (2012). Potential of Erythrinabrucei, Erythinaabyssinica and Enste venticosom, Indigenous Organic Nutrient Sources for Improving Soil Fertility in Small Holder Farming Systems in Ethiopia p. 16.

International Plant Nutrition Institute (IPNI) (1998). Potassium Availability and Uptake. Better Crops 82:3.

Jackson ML (1973). Soil analysis. Prentice Hall of India Pvt. Ltd. New Delhi. Swaminathan, M.S. (Ed.). Taylor and Francis, UK.

Jones JB Jr. (2001). Laboratory guide for conducting soil tests and plant analysis. CRC Press.

Kalra YP (1998). Handbook of Reference Methods for Plant Analysis CRC Press, Boca Rotan, FL, USA.

Kjeldahl J (1883). "Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern" (New method for the determination of nitrogen in organic substances), Zeitschrift für analytische Chemie 22(1):366-383.

Landon JR (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Routledge, Abingdon, UK. 532 p.

Maria RM, Yost R (2006). A Survey of soil fertility status of four agro ecological zones of Mozambique. Soil Science 171(11):902-914

Mehlich A (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in Soil Science & Plant Analysis 15(12):1409-1416.

Mikias Y, Handaro F, Mulugeta D, Zerihum Y, Zadik M (2010). Improved Enset production Technology, Ethiopian and SNNPR Institute of Agricultural Research (in Amharic).

Ministry of Agriculture (MoA) and Agricultural Transformation Agency (ATA) (2012). 5-year strategy for the transformation of the soil health and fertility in Ethiopia, Addis Abeba, Ethiopia. https://www.canr.msu.edu/

Mohammed B, Gabel M, Karlsson LM (2013). Nutritive values of the drought tolerant food and fodder crop Enset. African Journal of Agricultural Research 8(20):26-33.

Murphy HF (1968). A Report on Fertility Status and Other Data on Some Soils of Ethiopia. Experimental Station Bulletin No. 44. Hailesilassie College of Agriculture, Oklahoma State University.

Nyunja ARO, Onyango JC, Erwin B (2009). The Kakemaga forest medicinal plant resource and their utilization by the adjacent Luhya community. International Journal of Tropical Medicine 4(3):82-90.

Romheld V, Kirkby EA (2010). Research on Potassium in Agriculture: Needs and Prospects. Plant and Soil 335(1-2):155-180.

SAS institute (2012). User's Guide. SAS/STAT® 9.3. Statistical Procedures, Second edition. SAS institute inc, Cary, NC, USA.

Shank R, Ertiro C (1996). Enset crop assessment. United Nations World Food Programme, Bureau of Agriculture, Southern Nations, Nationalities, Peoples' Regional State UNDP Emergencies Unity for Ethiopia, Addis Ababa, Ethiopia P 56.

Sidama Development Corporation (2000). Planning and Statistics. en.m.wikipedia.org.

Sidama Zone Planning and Economic Development Department (SZPEDD) (2004). Hawassa, Ethiopia. www.oecd.org

Sumner ME, Miller WP (1996). Cation exchange capacity and exchange coefficients. In: D. L. Sparks, A. L. Page, and P. A. Helmke, editors, Methods of Soil Analysis. Part 3, Chemical Methods. Soil Science Society of America, Madison, Wisconsin, USA pp. 1201-1229.

Taye B, Feleke A (1966). The production and utilization of the genus Ensete in Ethiopia 20(1):65-70.

Tsegaye A (2002). On indigenous production, genetic diversity and crop ecology of Enset (Ensete ventricosum (Welw.) Cheesman). Ph.D. Thesis. Wageningen University, Wageningen, The Netherlands P 198.

Tsegaye A, Struik PC (2001). Enset (Ensete ventricosum (Welw.) Cheesman) kocho yield under different crop establishment methods as compared to yields of other carbohydrate rich food crops, Netherlands Journal of Agricultural Science 49(1):81-94.

Tsegaye A, Struik PC (2003). "Growth, radiation use efficiency and yield potential of Enset (Ensete ventricosum) at different sites in southern Ethiopia."Annals of applied biology 142(1):71-81.

Tsehaye Y, Kebebew F (2006). Diversity and cultural use of Enset (Ensete ventricosum (Welw.) Cheesman) in Bonga in situ conservation site, Ethiopia, Ethnobotany Research and applications 4:147-157.

Uloro Y, Mengel K (1994). Response of Ensete to mineral fertilizers in southwest Ethiopia. Fertilizer Research 37(2):107-113.

Vol. 16(9), pp. 1317-1324, September, 2020
DOI: 10.5897/AJAR2020.15031
Article Number: 41CE99A64882
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Field evaluation of introduced and local cowpea genotypes performance in Botswana

Odireleng O. Molosiwa* and Bose C. Makwala

Department of Agricultural Research, Ministry of Agricultural Development and Food Security, Private Bag 0033, Gaborone, Botswana.

Received 18 June, 2020; Accepted 11 August, 2020

A set of twenty four cowpea (*Vigna unguiculata* L. Walp) genotypes were evaluated in field conditions for three consequtive seasons based on 13 quantitative characters. A combined analysis of variance revealed a highly significant difference among the genotypes for most of the traits (P <0.001). Introduced genotypes performed better in nine of the characters, revealing the advantage of introduced genotypes. Principal Component Analysis explained a total variation of 76.16%, where the first two PCs accounted for 51%. Most variation was largely dependent from rainfall use efficiency, days to maturity, seed yield per hectare and pod width. Cluster analysis dendrogram delineated the 24 genotypes into two major clusters, with a mixture of local and introduced in both groups which indicated their potential relationship. Exceptional local genotypes B137B, with highest seed yield (866 kg/ha), and the singleton B342 with a number of desirable agronomic traits must be included in future cowpea breeding programs in Botswana.

Key words: Cluster analysis, rainfall use efficiency, SPAD reading, *Vigna unguiculata*.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp) is a crop with wide global distribution, especially in tropical regions. It is an important grain legume crop in sub-Saharan Africa, with significant production in Nigeria, Burkina Faso, Niger, Cameroon and United Republic of Tanzania (Fatokun et al., 2012; FAOSTAT, 2017). The crop is produced under rain-fed conditions in the drier regions of the world where drought is common due to low and erratic rains (Agbicodo et al., 2009). Cowpea is a high valued crop due to its high quality protein, adaptation to heat and drought, and ability to fix nitrogen. These characters make it a major crop in the context of climate change and food security (Carvalho et al., 2017).

Cowpea is an important cash crop and the main grain legume in Botswana, most production is mainly from small scale farmers under rain-fed conditions. Despite cowpea widespread cultivation, crop yield is low, with an average of 300 kg/ha, against a potential yield of 2500 kg/ha. Generally, low cowpea productivity and production is attributed to several factors such as biotic and abiotic

*Corresponding author. E-mail: odireleng.molosiwa@gmail.com.

stress, low yielding varieties, poor soils and poor crop husbandry (plant density) (Olasupo et al., 2016; Mwale et al., 2017). Additional potential constraints of cowpea production could be worsened by climate changes, drastic changes in rainfall patterns, and rise in temperature which could lead to unfavorable growing conditions thereby modifying growing seasons (Ajetomobi and Abiodun, 2010). Therefore, development and adoption of well adapted drought tolerant cowpea varieties that will cope with changing climate conditions is a priority.

International Institute of Tropical Agriculture (IITA) is integral in the development and protection of cowpea and keeps a significant amount of accessions for mining to develop superior performing cultivars (Boukar et al., 2016). The Ministry of Agricultural Development and Food Security, through cowpea breeding program has benefited significantly from this initiative as several cowpea genotypes have been evaluated in Botswana. Varieties ER7 and IT95K6352 sourced from IITA have been evaluated and released for their extra early maturing and early maturing characters, respectively. The other released varieties in the country include Inia 30, Inia 70 and Inia 71 originally from Mozambique (Chiulele, 2010). They have medium maturing characteristics and high yield potential, other varieties released in Botswana include Tswana and Botswana Blackeye. However, several efforts have been made to characterize more than 400 cowpea germplasm accessions collected from many agricultural districts of the country (Molosiwa et al., 2016) with the aim to include more genetic material into the cowpea breeding program. Therefore, the objective of this study was to compare the performance of introduced and local cowpea genotypes under the semi-arid environment of Botswana, and identify well adapted varieties with potential for release.

MATERIALS AND METHODS

Plant material

Twenty-four cowpea genotypes with early and medium maturing characteristics and high yield potential were selected for use in the study. Twelve are local lines sourced from the cowpea breeding program but originally from the National Plant Genetic Resource Centre (Botswana), while the other 12 were introduced genotypes from various countries and institutions. The characteristics of the genotypes are described in Table 1.

Study site

Field experiments were conducted for three consecutive seasons at Sebele Agricultural Research Station, 12 km north of Gaborone, in Southern Botswana (24°35'S; 25°56'E). The area has a unimodal rainfall type that falls between November and April each year. The area receives an average 30-year annual rainfall of 500 mm/year, with a semi-arid climatic condition. The rainfall received during the growing season of 2012-13 was 325.3 mm with an average temperature of 22.8°C, in 2013-14, 327.3 mm of rainfall was received with a mean temperature of 21.9°C, while in 2014-15, 180 mm rainfall was received with a mean temperature of 23.8°C**.** The soils in Sebele are shallow tropical soils consisting largely medium coarse texture and sandy loam with low water holding capacity.

Experimental design and crop management

The soil was ploughed and harrowed with a tractor for land preparation to set up the experiment. A three replicated trial with a randomized complete block design was conducted in a total area of 899 m^2. Each plot length was 4 m with a row spacing of 0.75 m and within plant spacing of 0.2 m, with a plant population estimates of 67000 plant per hectare. Two seeds were planted per hole and one seedling was left after thinning 21 days after planting. Crop management practice of weeding was adhered to, for the control of pests and disease in the experimental plots.

Agro-morphological characteristics measured

Morphological and agronomic characters selected were chosen from the International Board for Plant Genetic Resources, IBPGR (1983). Thirteen quantitative traits were recorded which include, days to 50% flowering (DFF), plant height (PH), pods per plant (PodpPlant), seeds per plant (SeedpPlant), seeds per pod (SeedpPod), pod length (PodL), pod width (PodW), 100 seed weight (100SW), rainfall use efficiency (RUE), seed yield per hectare (YDHA), Spad chlorophyll meter reading (SCMR), shoot dry weight (SDW), days to maturity (DM). At harvest, data were collected within the two middle rows. Shoot dry weight was oven dried for 48 h at 70°C and weighed. Rainfall use efficiency was estimated based on the formula, RUE = Y/R which defines RUE as dry matter accumulated/precipitation in Kg ha^{-1} mm^{-1}, a formula adopted from Wang et al. (2016). Yield (Y) is the dry matter accumulated for the cowpeas, while rainfall (R) is the accumulated rainfall for the growing season. Estimates of RUE for each genotype was computed based on the amount of rainfall received per growing season and the seed yield amount. The SCMR measurements were taken at 45 days after sowing using SPAD-502 meter (Minolta, Japan).

Statistical analysis

Data were subjected to analysis of variance and multivariate statistical analysis was performed for Principal Component and Cluster Analysis to reveal the relationship between the selected cowpea genotypes using Genstat software version 18.0

RESULTS AND DISCUSSION

Genetic variation of the 24 cowpea genotypes

A combined analysis of variance indicated a substantial amount of variation for all the 13 quantitative characters among the cowpea genotypes since most traits were highly significant (P <0.001) (Table 2). The higher genotypic variability is a great opportunity to identify best performing cultivars. The results concurred with those of Osho and Olasanmi (2018), Araméndiz-Tatis et al. (2018) and Gerrano et al. (2015), who reported statistical differences between cowpea genotypes studied. Most of the characters were not affected by genotype x

Table 1. Characteristics of the selected cowpea genotypes used in the study.

Variety	Seed colour	Growth habit[b]	Yield potential (t/ha)[c]	Origin
B097	Brown	SP	1- 2	Botswana
B137B	Reddish brown	P	1 -2	Botswana
B138	Reddish	SP	1 -2	Botswana
B342	Tan	P	1-2	Botswana
B549	Tan	P	1-2	Botswana
B629	Tan	P	1-2	Botswana
BBLACKEYE[A]	White with black-eye	SP	1.5 -2.5	Botswana
ER7[A]	Cream with brown-eye	Erect	1.5-2.5	IITA
FARMERV	Tan with brown dots	P	1-2	Botswana
INIA30[A]	Tan	SP	1.5-2.5	Mozambique
INIA70[A]	Tan	SP	1.5-2.5	Mozambique
INIA71[A]	Brown	P	1.5-2.5	Mozambique
IT95K107257	Cream with brown-eye	P	1.5-2.5	IITA
IT95K19312	Cream with brown-eye	SP	1.5-2.5	IITA
IT95K20722	Brown	SP	1.5-2.5	IITA
IT95K6352[A]	Cream with brown-eye	SP	1.5-2.5	IITA
IT97K102124	Cream with brown-eye	SP	1.5-2.5	IITA
IT97K10757	Brown	P	1.5-2.5	IITA
IT97K5641	Brown	SP	1.5-2.5	IITA
IT98K3902	Reddish brown	P	1.5-2.5	IITA
SCAM123	Tan	P	1-2	Botswana
SCAM151	Reddish brown	SP	1-2	Botswana
SCAM190	Red with black dots	P	1-2	Botswana
TSWANA[A]	Tan	P	1-2	Botswana

[A] Represent released varieties in Botswana; [b]SP= Semi-prostrate; P= prostrate.

Table 2. Combined analysis of variance for the 13 traits of 24 cowpea genotypes evaluate in the field for three seasons.

Trait	Season	Rep	Genotype	G x S	Residual	CV%	Grand mean
df	2	2	23	46	142		
Days 50% flowering	311.9**	59.4	232.8**	13.2*	8.6	6.1	49.0
Plant height	1213.9**	2712.8	278.1**	152.0**	65.8	25.4	32.0
Pods per Plant	1254.1**	1116.0	349.7**	68.6^{ns}	66.8	34.0	24.0
Seeds per Plant	285287**	227974	9451*	12274**	5922	58.0	133.0
Seed per Pod	280.6**	184.7	21.6**	5.3^{ns}	6.6	25.5	10.0
Pod Length (mm)	10320.4**	36876.9	1046.2**	305.7^{ns}	381.4	14.0	139.0
Pod Width (mm)	2.8**	5.7	4.1**	0.6^{ns}	0.5	9.3	8.0
100 Seed weight (g)	59.4**	10.4	58.3**	3.6^{ns}	6.4	17.1	15.0
Seed Yield (kg/ha)	206220^{ns}	1983266	216850*	86720^{ns}	129494	58.0	617.0
RUE (kg/ha.mm^{-1})	18.1**	7.0	7.2**	1.6^{ns}	2.5	59.4	2.7
SCMR	1150.8**	336.3	389.6**	63.6^{ns}	107.2	20.2	51.0
Shoot dry weight (g)	924.6*	18899.8	1218.2**	327.2^{ns}	369.0	37.4	51.0
Days to Maturity	496.3**	241.6	572.3**	33.3^{ns}	47.2	9.1	76.0

d.f. **=** degrees of freedom**;** **, highly significant; * significant**;** ns= non-significant; G= Genotype; S = Season; CV= coefficient of variation.

environment interaction with the exception of days to 50% flowering, plant height, and seeds per plant (Table 2), which imply that the performance of the genotypes was consistent across the three seasons, even though there were seasonal differences among most of the traits. The highest coefficient of variation was observed in rainfall use efficiency (59.4%), seed per plant and seed yield per hectare both at 58%. Similar findings with

Table 3. The performance of the 24 cowpea genotypes evaluated in the field in Sebele, Botswana based on mean and range for 13 quantitative traits.

Character	Genotypic means			
	Local	Introduced	Range	s.e
Days 50% flowering	51.0	46.0	41 -57	2.9
Plant height (cm)	33.2	31.0	24 - 43	8.1
Pods per plant	22.6	25.6	15 - 42	8.2
Seeds per plant	133.4	131.9	83-211	77
Seed per pod	9.8	10.3	8 -13	2.6
Pod length (mm)	139.5	139.1	117-160	19.2
Pod width (mm)	8.0	8.3	7-10	0.8
100 seed weight (g)	14.6	15.2	11-21	2.5
Seed yield (kg/ha)	595.1	639.3	318-866	359.9
RUE (kg/ha.mm-1)	2.7	2.8	1.3- 4.1	1.61
SCMR	49.9	52.8	38 - 67	10.4
Shoot dry weight (g)	55.7	47.0	34 -77	19.2
Days to maturity	78.2	73.0	65 -91	6.9

SCMR: Spad chlorophyll meter reading; RUE: Rainfall use efficiency; s.e: Standard error.

highest coefficient of variations among cowpeas were observed on seed yield per hectare (46.9%) and seed per plant (44.4%) by Aliyu and Makinde (2016), which reveals greater variation among these characters. Considerable genetic variability that exists among genotypes was evidenced by a highest range of seed yield (318 - 866 kg/ha), pod length (117 - 160 mm) and seed per plant (83 - 211) (Table 3). Relatively higher genotype ranges were also reported for seed yield varying from 263.76 to 2624.8 kg/ha in South Africa by Nkoana et al. (2019), while seed yield per hectare ranged 522.00 to 2807 kg/ha, pod length from 10.74 to 22.80 and seed per plant from 64.2 to 360 were reported by Aliyu et al. (2019) in Nigeria. These greater variations indicate a potential for improvement of this crop. The overall average seed yield of 617.0 kg/ha (Table 2) is much higher than the national average cowpea production, around 139 kg/ha (Statistics Botswana, 2013). However, this average is about the half crop yield of 1270.68 kg/ha recorded for cowpea in Nigeria (Aliyu et al., 2019), and much lower than 2043 kg/ha for cowpea in Zimbabwe (Matova and Gasura, 2018). Generally, there was a lower seed yield performance among the selected cowpea genotypes as indicated by the grand mean (Table 3). This can be attributed to the lower amount of rainfall than the normal amount, that is, 500 mm for a 30-year annual. However, this was the best time to conduct this research in order to compare the performance of introduced and local cowpea genotypes and identify the best performing varieties, selecting for drought adaptation (Hall, 2002).

Comparison of the performance of local and introduced cowpea genotypes

A summary of the performance of local and introduced cowpea genotypes is shown on Table 3. Comparatively, on average the local genotypes matured later (78 days), are taller (33 cm), have higher shoot biomass (56 g), but with slightly less 100 seed weight (14.6 g) and seeds per pod (10), and much less seed yield per hectare (595 kg ha^{-1}) compared to the introduced improved cowpea genotypes, except genotypes B137B (Table 4). Traits of late maturing plants with high biomass among local genotypes could have been selected by farmers who are mainly interested in the leaf vegetable of the cowpea crop, while the early maturing among introduced lines could be influenced by continued selection for earliness by breeders to reduce the drought effect. A few of introduced genotypes underperformed in some traits, such as lower seed yield (318 kg/ha) on IT95K20722 and lower pod length (117 mm) by ER7. This could be explained by a lack of adaptation to the arid conditions of Botswana. To improve the pod size of the higher yielding ER7 it would be ideal to hybridize it with those genotypes with larger pods such as B137B and Inia 71 (Table 3).

Most maximum performances were discovered in introduced genotypes such as seed per plant (211), seed per pod (13) and pod length (160 mm) in INIA71, higher pods per plant (42) in IT97K564, higher SCMR (67) and DM (91) in IT95K6352 and higher 100 seed weight (21 g) in IT95K20722. An equally higher performing of local genotypes was by B137B, which had the highest seed yield (866 kg/ha), larger pods sizes of 160 mm length and 10 mm width. IITA successfully developed cowpea cultivars with combined stable yield, tolerance to abiotic and biotic stresses with erect or determinate growth habit (Ortiz, 1998; Boukar et al., 2019), as expected would do better than local material with little crop improvement. These results provided evidence of the advantage of introduced cowpea genotypes in the country. Hence, this

Table 4. A combined summary for the 13 quantitative characters of 24 cowpeas genotypes evaluated in the field condition.

Variety	DFF[a]	PH[b] (cm)	Podpplant[c]	SeedpPlant[d]	SeedpPod[e]	PodL (mm)[f]	PodW (mm)[g]	100SW (g)[h]	YHDA (kg/ha)[j]	RUE (kg/ha.mm^{-1})[k]	SCMR[n]	SDW (g)[o]	DM[p]
B097	50	34	24	151	9	146	8	15	629	3,1	52	71	72
B137B	45	31	20	165	13	160	10	13	866	4,0	45	43	70
B138	45	31	22	105	9	143	8	14	772	4,1	44	42	68
B342	57	24	17	179	8	119	7	15	778	3,7	56	52	87
B549	54	31	26	83	10	142	8	15	451	1,7	48	57	83
B629	54	31	24	198	9	134	8	15	554	2,1	55	61	86
BLACKEYE	46	43	30	116	9	138	8	16	538	2,4	43	41	75
FARMERV	52	40	21	115	12	145	8	17	329	1,3	53	65	78
SCAM123	57	32	19	109	10	129	8	14	444	1,8	53	67	86
SCAM151	41	27	20	102	9	146	7	11	587	3,0	38	35	65
SCAM190	56	42	20	150	11	128	8	14	505	2,3	53	57	84
TSWANA	55	32	28	128	9	144	8	16	688	2,4	59	77	84
ER7	41	29	23	119	9	117	7	11	780	3,8	49	45	66
INIA30	44	27	16	137	11	148	9	12	783	3,8	51	42	68
INIA70	45	27	15	111	11	137	8	12	849	4,0	47	37	68
INIA71	43	30	26	211	13	160	9	11	743	3,1	46	44	65
IT95K107257	49	34	24	104	9	143	8	16	728	3,4	55	61	75
IT95K19312	45	31	27	159	10	142	9	19	672	2,2	61	48	72
IT95K20722	41	25	38	133	9	127	8	21	318	1,3	51	34	68
IT95K6352	49	38	27	114	8	140	9	15	499	1,9	67	50	91
IT97K102124	47	27	25	89	9	135	8	17	493	1,9	56	41	75
IT97K10757	50	43	25	124	12	136	8	14	688	2,6	54	49	73
IT97K5641	50	28	42	139	10	132	8	20	520	2,0	42	54	83
IT98K3902	48	33	19	143	13	152	9	14	598	3,1	54	59	72
Grand mean	**49**	**32**	**24**	**133**	**10**	**139**	**8**	**15**	**617**	**2,7**	**51**	**51**	**76**
LSD (0.05)	2.7	7.6	7.6	71.7	2.4	18.2	0.7	2.4	335.3	1.5	9.6	17.9	6.4

a=days to 50% flowering; b=plant height; c=pods per plant; d=seeds per plant; e=seed per pod; f=pod length; g=pod width; h=100 seed weight, j=seed yield per hectare; k=rainfall use efficiency; n=spad chlorophyll meter reading; o=shoot dry weight; p=days to maturity.

detailed analysis was able to identify certain local genotypes that could be useful in the cowpea breeding program. Relatively high values of SCMR and RUE in some cowpea genotypes reflect their capacity to photosynthesize and accumulate more dry matter as compared to those with lower values (Al-Barzinji et al., 2015; Muhammad and Massawe, 2015). The highest grain yielding genotypes B137B (866 kg/ha), INIA70 (849 kg/ha), INIA30 (783 kg/ha) and ER7 (780 kg/ha) also had higher rainfall use efficiency at 3.8- 4.0 kg/ha.mm^{-1} which explain their high yield potential (Table 4). This was consistent with the results of Nkomazana and Batlang (2018) who observed 3.67 kg/ha.mm^{-1} among other cowpea

Table 5. Principal components, eigenvalues and vectors of the 13 quantitative traits of the 24 cowpea genotypes.

Traits	PC1	PC2	PC3	PC4
Eigenvalue	4.23	2.41	2.033	1.24
% Variation	32.5	18.54	15.64	9.52
Cumulative %	32.5	51.00	66.64	76.16
Latent vectors				
DFF[a]	0.333	0.305	-0.301	-0.019
PH[b]	0.145	0.298	0.096	-0.504
Pod per plant	0.217	-0.243	0.431	0.227
Seed per Plant	-0.087	0.266	0.033	0.608
Seed per pod	-0.219	0.373	0.273	-0.182
Pod length	-0.235	0.343	0.329	-0.094
Pod width	-0.136	0.402	0.394	0.187
100SW[c]	0.329	-0.142	0.334	0.270
YHDA[d]	-0.364	0.100	-0.282	0.265
RUE[f]	-0.396	0.025	-0.317	0.123
SCMR[h]	0.250	0.255	-0.104	0.276
DM[k]	0.395	0.195	-0.196	0.097
Shoot dry weight	0.274	0.365	-0.179	-0.016

a = days to 50% flowering; b= plant height; c = 100 seed weight; d= seed yield per hectare; f = rainfall use efficiency; h = spad chlorophyll meter reading; k = days to maturity.

genotypes from Botswana. Higher values of SCMR were observed in genotypes IT95K6352 (67.0), which is in accordance to those recorded by Abed (2014) in Iran cowpea, were a highest SCMR of 65.6. The highest shoot biomass was observed in local varieties TSWANA (77 g), B097 (71 g), SCAM123 (67 g) and FARMERV (65 g) (Table 4). This indicates that these genotypes are ideal for dual purpose (leafy vegetable and seed grain) and could be further explored for developing high fodder cowpeas. Similarly, dry matter yield per plant had been hailed as a key trait used in the selection for high fodder cowpeas (Naselvakkumaran et al., 2019). The findings also concurred with previous studies that identified the genotypes TSWANA and Blackeye as suitable for leafy vegetable (Karikari and Molatlakgosi, 1999).

Genetic diversity and relatedness of the selected 24 cowpea genotypes

Principal Component Analysis was used to identify traits that account for most of the variation among the 24 genotypes. The eigenvalues >1 were selected and used to define the 13 agro-morphological traits (Table 5). The first four PCA explained a total variation of 76.16%, with the first two PCs accounting for 51% of variation. These results further support the variation observed in the analysis of variance in Table 2. Characters that contributed mostly to the variation in PC1 (32.5%) in descending order are: RUE, day to maturity, seed yield per hectare, days to 50% flowering and 100 seed weight; in PC2, accounting for 18.54% variation it was mainly pod width, seed per pod, shoot dry weight and pod length; PC3 contributing to15.64% variation was mainly influenced by pods per plant, pod width, 100 seed weight, and pod length, while seed per plant and plant height were the main contributor in the last PC4 (9.56%) (Table 5). The findings are in accordance to those by Nkoana et al. (2019) who reported a total variation of 78.20% among the first 4 PCs, where the first two PCs accounted for 50.2% of variation. They also identified influential traits such as number of seeds per pod, 100 seed weight, pod length and grain yield.

A hierarchical cluster analysis dendrogram for the 24 cowpea genotypes based on the 13 traits shows an overall similarity of 1 to 0.8 (Figure 1). The dendrogram clustered the genotypes into two main groups at 0.825 Euclidean distances. The first cluster consists of 16 genotypes ranging from genotype B097 to B342, and this include equal number of both introduced and local genotypes within the cluster excluding the B342 which is an outlier within the first group. This reveals high phenotypic similarity between the local and introduced material, and the low genetic diversity within groups. This could be influenced by the fact that cowpea is predominantly a self-pollinating crop and is expected to a certain degree of heterozygosity (Badiane et al., 2012). Cluster 2 consists eight genotypes (five introduced) which consists all the three genotypes from Mozambique and the three locals (B137B, B138, SCAM151), and these are

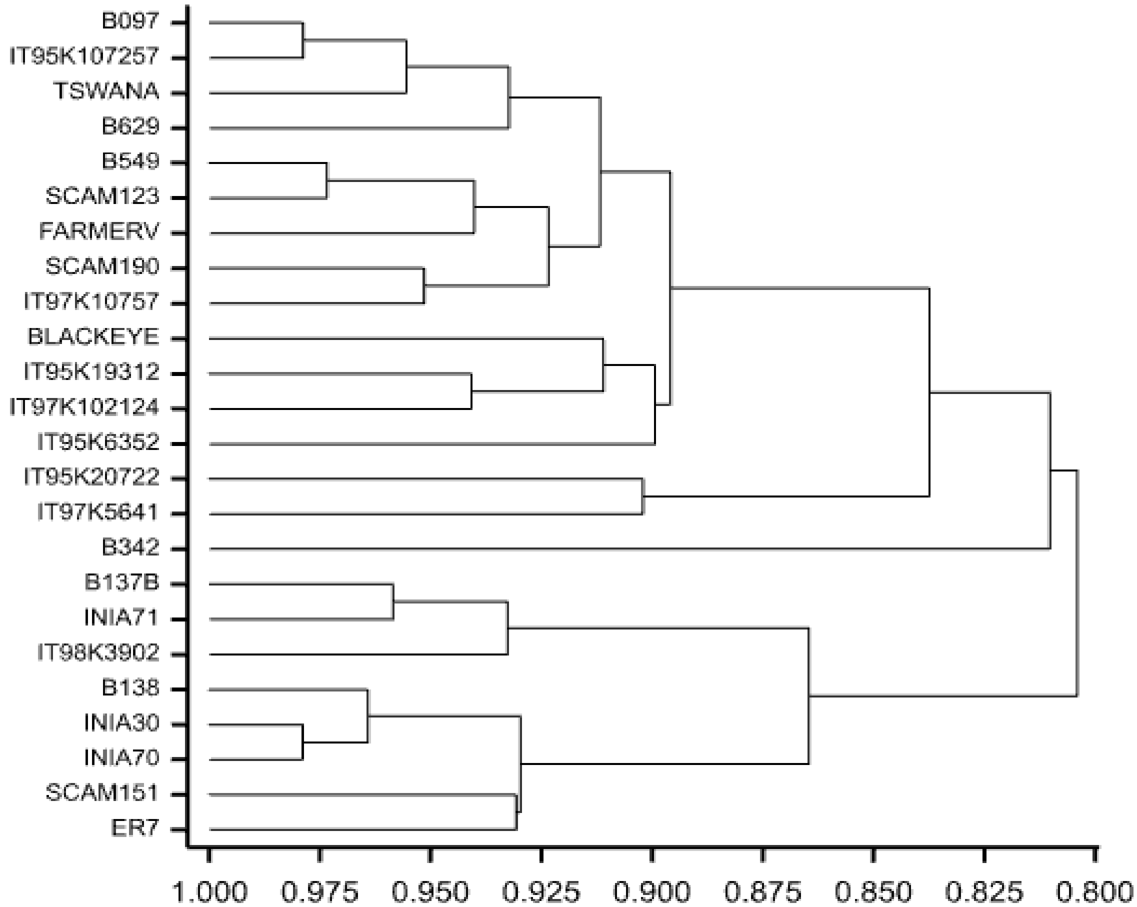


Figure 1. Dendrogram of 24 cowpea genotypes showing a similarity cluster analysis based on 13 agro-morphological traits in a field experimental condition in Sebele, Botswana.

generally high performers. The clusters have been delineated mainly based on traits with higher loadings as defined in Table 5, such as seed RUE, day to maturity and seed yield per hectare. The cluster analysis revealed some similarities between local and introduced cowpeas, such as among (B137B and INIA71), and also (B097 and IT95K107257) as shown in Figure 1. For further genetic improvement it would be ideal to conduct some hybridization between the clusters to improve cowpea genotypes in Botswana. Genotype B342 which is an outlier is more diverse and should be prioritized in selection. It was the last one to reach 50% flowering, had the lowest plant height, lowest number of seeds per pod and lowest pod width, but was among the top 5 best seed yield producers, with 778 kg/ha (Table 4). Therefore, selection of desirable traits in this genotype could assist to improve it. Farmer variety is genetically similar to other local cowpea genotypes such as SCAM123 and B549 (Figure 1), and it yield relatively low at 329 kg/ha, and flowered late, longer than 50 days for 50% flowering (Table 4). Similarly, Aliyu et al. (2019) observed that farmer varieties are well adapted to low input conditions, poor yielders, indeterminate, mature late and are susceptible to biotic and abiotic conditions. Joseph (2014) argued that farmers continue growing their low yielding varieties of cowpea because they prefer specific traits of interest such as grain quality, taste or leafy vegetables. These are some of the traits that plant breeders will have to incorporate in their breeding program to develop farmer preferred varieties.

Conclusion

In this research, based on thirteen selected traits the best performing varieties were identified. Even though the introduced cowpeas have a relatively better performance, two local genotypes, B137B and B342, were among the top five in terms of seed yield per hectare. Overall, the study revealed that the local cowpea genotypes compared well with some introduced lines. Introduced genotypes with larger seeds such as IT95K20722 will be useful sources of genes for other cowpeas and this could be useful for market acceptability This results could also have implications in selection in the local cowpea breeding program based on the performance of the best varieties such as, B137B and B342 which are not yet released to be evaluated for on-farm under participatory variety selection.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abed AZ (2014). Breeding for drought tolerance in progenies of cowpea (*Vigna unguiculata* (L.) Walp). Journal of Experimental Biology and Agriculture Sciences 2(5):490-494.

Agbicodo EM, Fatokun CA, Muranaka S,Visser RGF, Linden van der CG (2009). Breeding drought tolerant cowpea: constraints, accomplishments and future prospects. Euphytica 67:353-370.

Ajetomobi J, Abiodun A (2010). Climate change impacts on cowpea productivity in Nigeria. African Journal of Food Agriculture Nutrition and Development 10(3):2258-2271.

Al-Barzinji IM, Khudhur SA, Anwar AM (2015). Spectrophotometric method using different solvents and SPAD chlorophyll meter for determination some photosynthesis pigments of bean and cowpea plants. International Journal of Engineering Technology Management and Applied Sciences 3:108-113

Aliyu OM, Lawal OO, Wahab AA, Ibraham UY (2019). Evaluation of advanced breeding lines of cowpea (*Vigna unguiculata* L. Walp) for high yield under farmer's field conditions. Plant Breeding and Biotechnology 7(1):12-23.

Aliyu OM, Makinde BO (2016). Phenotypic analysis of seed yield and yield components in cowpea (*Vigna unguiculata* L. Walp). Plant Breeding and Biotechnology 4(2):252-261.

Araméndiz-Tatis H, Cardona-Ayala C, Espitia –Camacho M, Arrieta-Puche D, Barba AG (2018). Estimation of genetic parameters in white seed cowpea (*Vigna unguiculata* L. Walp.). Australian Journal of Crop Science 12:1016-1022.

Badiane FA, Gowda BS, Cissé N, Diouf D, Sadio O, Timko MP (2012). Genetic relationship of cowpea (*Vigna unguiculata*) varieties from Senegal based on SSR markers. Genetics and Molecular Research 11(1):292-304.

Boukar O, Belko N, Chamarthi S, Togola A, Batieno J, Owusu E, Haruna M, Diallo S, Umar ML, Olufajo O, Fatokun C (2019). Cowpea (*Vigna unguiculata*): Genetics, genomics and breeding. Plant Breeding 138:415-424.

Boukar O, Fatokun CA, Huynh BL, Roberts PA, Close TJ (2016). Genomic tools in cowpea breeding programs: status and perspectives. Frontiers in Plant Science 7:1-13.

Carvalho Muñoz –Amatriaín M, Castro I, Lino-Meto T, Matos M, Egea-Cortines M, Rosa E, Close T, Carnide V (2017). Genetic diversity and structure of Iberian Peninsula cowpeas compared to world –wide cowpea accessions using high density SNP markers. BMC Genomics pp. 18:1-9.

Chiulele RM (2010). Breeding cowpea (*Vigna unguiculata* L. (Walp.) for improved drought tolerance in Mozambique, PhD, Thesis. African Centre for Crop Improvement School of Agricultural Sciences and Agribusiness. Faculty of science and Agriculture, University of Kwazulu-Natal. Republic of South Africa.

FAOSTAT (2017). Food and Agriculture Organization. Available at: www.fao.org/faostat/en/hashtagcountry

Fatokun CA, Boukar O, Muranaka S (2012). Evaluation of cowpea (*Vigna unguiculata* (L.) Walp.) germplasm lines for tolerance to drought. Plant Genetic Resources 10(3):171-176.

Gerrano AS, Adebola PO, van Rensburg WSJ, Laurie SM (2015). Genetic variability in cowpea (*Vigna unguiculata* (L.) Walp.) genotypes. South African Journal of Plant and Soil 32(3):1-10.

Hall E (2002). Phenotyping cowpeas for adaptation to drought. Frontiers in Physiology 3(155):1-8.

International Board for Plant Genetic Resources (IBPGR) (1983). Rome, Italy, International IBPGR. *Vigna Unguiculata,* Secretariat Rome. www.biodiversityinternational.org

Joseph BTB (2014). Breeding for drought tolerance in cowpea [*Vigna unguiculata* (L.) Walp.] using marker assisted back crossing, Ph. D. thesis. West Africa Centre for Crop Improvement School of Agriculture College of Basic and Applied Sciences, University of Ghana Legon, Ghana.

Karikari SK, Molatlakgosi G (1999). Response of cowpea (*Vigna unguiculata* (L.) Walp) varieties to leaf harvesting in Botswana. UNISWA Journal of Agriculture 8:5-11.

Matova PM, Gasura E (2018). Yield and stability of new cowpea variety in Zimbabwe. African Crop Science Journal 26:277-289.

Molosiwa OO, Gwafila C, Makore J, Chite SM (2016). Phenotypic variation in cowpea (*Vigna unguiculata* [L.] Walp.) germplasm collection from Botswana. International Journal of Biodiversity and Conservation 8(7):153-163.

Muhammad YY, Massawe F (2015). Photosynthetic gas exchange and chlorophyll in bambara groundnut (*Vigna subterranea* L. Verdc.) subjected to water deficit. Bayero Journal of Pure and Applied Sciences 8(1):50-55.

Mwale SE, Ochwo-Ssemakula M, Sadik K, Achola E, Okul V, Gibson P, Edema R, Singini W, Rubaihayo P (2017). Response of cowpea genotypes to drought stress in Uganda. American Journal of Plant Sciences 8(4):720-733.

Naselvakkumaran T, Babu S, Sudhagar R, Sivakumar SD (2019). Interrelationship and Path coefficient analysis of fodder yield and yield components traits in fodder cowpea (*Vigna unguiculata* L. Walp.). Electronic Journal of Plant Breeding 10(2):720 -726.

Nkoana DK, Gerrano AS, Gwata ET (2019). Agronomic performance and genetic Variability of cowpea (*Vigna unguiculata*) accessions. Legume Research- An International Journal 42(6):757-762.

Nkomazana C, Batlang U (2018). Grain yield water use efficiency of cowpea (*Vigna unguiculata* L. Walp.) in response to planting dates in Botswana. In: Revermann R, Krewenka KM, Schmiedel U, Olwoch JM, Helmschrot J, Jürgens N (eds), Climate change and adaptive land management in southern Africa – assessments, changes, challenges, and solutions: Klaus Hess Publishers, Göttingen and Windhoek. 2018. Biodiversity and Ecology 6:282-287.

Olasupo FO, Ilori CO, Forster BP (2016). Mutagenetic effects of Gamma Radiation on eight accessions of cowpea (*Vigna unguiculata* (L.) Walp.). American Journal of Plant Sciences 7(2):331-251.

Ortiz R (1998) Cowpeas from Nigeria: A silent food revolution. Outlook on Agriculture 27(2):125-128.

Osho T, Olasanmi B (2018). Genetic variability among cowpea (*Vigna unguiculata* L. Walp.) mini core collection. Asian Journal Research in Crop Science 2(4):1-10.

Statistics Botswana (2013). Statistics Botswana. Annual agricultural survey report, Statistics Botswana, agricultural statistics unit, Ministry of Finance and Development Planning, Department of Printing and publishing, Gaborone.

Wang X, Jia Z, Liang L, Yang B, Ding R, Nie J, Wang J (2016). Impacts of manure application on soil environment, rainfall use efficiency and crop biomass under dryland farming, Scientific Reports 6(20994):1-8.

Vol. 16(9), pp. 1325-1333, September, 2020
DOI: 10.5897/AJAR2020.14904
Article Number: CF34B0A64896
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Effect of different planting techniques and sowing density rates on the development of quinoa

Abdalla Dao[1*], Jorge Alvar-Beltrán[3], Abdou Gnanda[2], Amidou Guira[2], Louis Nebie[2] and Jacob Sanou[1]

[1]Institut de l'Environnement et de Recherches Agricoles (INERA), Bobo Dioulasso BP910, Burkina Faso.
[2]Institut de Développement Rural (IDR), Université Nazi Boni, Bobo-Dioulasso, Burkina Faso.
[3]Department of Agriculture, Food, Environment and Forestry (DAGRI)-University of Florence, 50144 Florence, Italy.

Received 13 April, 2020; Accepted 21 July, 2020

Quinoa (*Chenopodium quinoa* Willd.) is a crop of increasing interest due to its agro-ecological adaptability and high nutritional properties. Few information is available on the adaptability of quinoa in the Sahel region, and on genotype's phenological, morphological and agronomical responses to different planting methods and sowing density rates. To test the effect of planting and sowing methods, two separate experiments were carried out in Burkina Faso to examine the performance of different genotypes (Titicaca, Puno, Pasankalla and Negra Collana) to multiple planting methods (ridges, dibbling, broadcasting, transplanting, traditional-pits and flat sowing) and sowing density rates (from 80,000 to 200,000 plants ha^{-1}). The results showed significant differences among genotypes in terms of growth attributes, with higher yields when sown in ridges (10.7, 8.4 and 5.7 g plant^{-1} Puno, Pasankalla and Titicaca, respectively). In addition, higher yields were observed under low density rates, with plant spacing being compensated by changes in branch system. However, higher yields were reported per unit area (Titicaca with 98.8 g m^{-2}) under high density treatments (200,000 plants ha^{-1}). As a conclusion, the use of short cycle varieties (Titicaca and Puno) sown in ridges at high density rates was recommended.

Key words: Africa, agricultural management, genotypes, phenology, physiology.

INTRODUCTION

In places where water is the main limiting factor there are multiple agronomic practices available for reducing soil erosion, increase soil moisture and improve crop yields (Belachew and Abera, 2010). Some practices are related to different sowing methods and planting density rates (Ali et al., 2020). Other strategies enhance crop's transpiration by augmenting biomass production per unit water transpired. An increase in biomass production per unit area can hold-back weed expansion and positively affect the yield performance. The harvest index (HI) can also be higher when large amounts of water are accessible by plants and used after antithesis (Van Den Boogaard, 1996). Several researchers have examined the advantages of high crop density with an adverse effect on weeds and positive impacts on crop's biomass, including yields, e.g. wheat (Kristensen et al., 2008), maize (Sharifi et al., 2009) and rice (Baloch et al., 2002). For maize, much research has been conducted on

*Corresponding author. E-mail: adao@wacci.ug.edu.gh.

Table 1. Different sowing methods applied in experiment 1.

Type of technique	Sowing depth (cm)	Row distance (cm)	Plant distance (cm)
Broadcasting	0	-	-
Dibbling	1-2	50	0
Transplanting[1]	-	50	10
Flat	3	50	10
Ridges[2]	3	50	10
Traditional-pits[3]	1-2	50	50

[1]Transplanting occurred 15 days after sowing (DAS). [2]Ridges height 15 cm and width 17 cm. [3]Pits diameter 10 cm.

Table 2. Different sowing density rates applied in experiment 2.

Indicator	Row distance (cm)	Plant distance (cm)	Total number of plants (ha^{-1})
D1	50	10	200,000
D2	50	15	133,333
D3	50	20	100,000
D4	50	25	80,000
D5	65	15	102,564
D6	75	10	133,333

different planting methods such as broadcasting, ridges, raise bed and line cropping. Some of these studies reveal that heavier grains and maximum yields are produced under ridge planting, with lowest yields under broadcasting (Bakht et al., 2011).

Quinoa (*Chenopodium quinoa* Willd.) traditionally grows in the absence of fertilizers, with a high plant density, without thinning, nor weeding or hilling (Gomez-Pando et al., 2015). Various management practices can result in different responses with respect to canopy development, time to physiological maturity and grain yield among cultivars of quinoa (González et al., 2012). Plant density models, expressing yield as a function of plant density, simulate higher yields with 327 ± 220 plants m^{-2} (equivalent to 327,000 plants ha^{-1}) (Jacobsen et al., 1994). However, high standard deviation observed in various experiments is an indication that similar yields can be obtained with different plant density rates, because quinoa can compensate the remaining spaces by modifying the architecture of its branches (Jacobsen, 2015). Studies on quinoa's agro-morphological responses have shown a diversification of the branching type when selecting different genotypes and sowing density rates (Rojas, 2015). Quinoa genotypes largely differ with respect to seed characters (size and color) and panicle type, with distinctive morphological attributes in each agro-ecological region (Planella et al., 2015; Andrews, 2017). Different quinoa growth habits are directly dependent on plant density, that is, simple, branched to bottom third, branched to second third and branched with a main panicle undefined (Rojas and Pinto, 2013). High plant densities can slow down and prevent, to some extent, the development of diseases on quinoa (e.g. mildew). This can happen in areas with a high relative humidity, where farmers are recommended to space furrows and plants by 50 cm and 15 cm, respectively (Gandarillas et al., 2015).

In this study, we therefore examine how different sowing methods and density rates affect the phenological, morphological and physiological development of multiple cultivars of quinoa in the Sahel. We then fill the gap in literature by providing insights of crop´s responses to different sowing methods and density rates in new agro-ecological zones.

MATERIALS AND METHODS

Area of study and experimental design

This study was conducted during the dry season (November-May) of 2017-2018 at Institut de l'Environnement et Recherches Agricoles (INERA) Farako-Bâ Research Station (11°05'N and 4°20´W; 405 masl), located within the Soudanian agro-climatic zone of Burkina Faso. Two parallel experimentations were conducted to evaluate the effect of different sowing methods (Table 1) and density rates (Table 2) on the development and performance of multiple genotypes of quinoa. The first study tested six different sowing methods (Table 1) with three genotypes of quinoa (Puno, Pasankalla and Titicaca). The second study examined six planting density rates (Table 2) with three genotypes of quinoa (Pasankalla, Titicaca and Negra Collana). The two experiments were set-up in a split-plot design, with experimental units sizing 4 m^2 and each unit having 3 replicates. The total amount of quinoa seeds used in both trials was equivalent to 10 kg of seeds ha^{-1}. Before sowing, the soil was amended with 5000 kg ha^{-1} of compost, 400 kg ha^{-1} of phosphate (PO_4^{3-}) and 100 kg ha^{-1} NPK (14-23-14 units). Urea

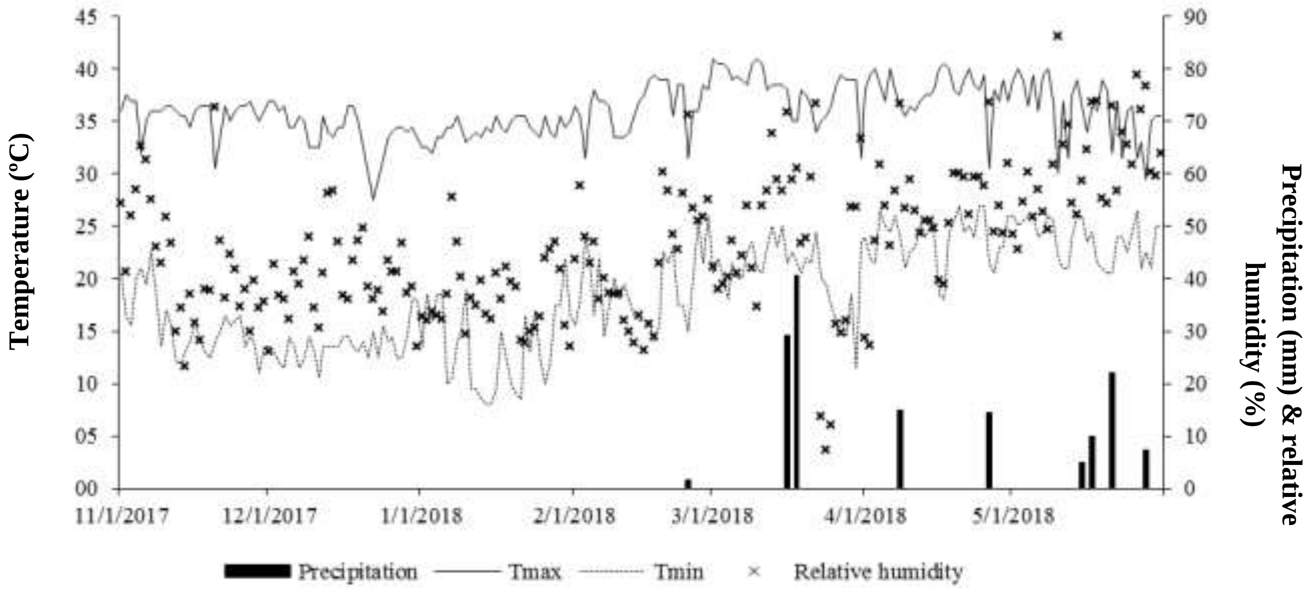


Figure 1. Meteorological conditions during the experiment.

(CH_4N_2O) was applied 30 days after sowing (DAS) at rate of 100 kg ha^{-1} (46% N).

Plant measurements and statistical analysis

For each crop parameter, plant samples were taken from the two middle lines in order to avoid side effects. Crop growth attributes such as plant height (PH in cm), branches per plant (BP in number), panicle diameter (PD in mm), stem diameter (SD in mm), and panicle length (PL in cm) were measured in 10 plants using a millimetric ruler and metric Vernier scale. Regarding plant phenology, the time to flowering was measured once 50% of the plants (Flo_{50} in days) had attained this phase. At harvest, the thousand-grain weight and volume (TGW in g, TGV in ml) was measured using an automatic seed counter machine and the grain yield per plant (GYP in g) was obtained from all the plants within the two middle lines.

The interaction between planting techniques and sowing density rates with three-genotypes of quinoa was analysed using the software Statistical Analysis System (SAS version 9.3). First, an ANOVA test was run to find out the statistical differences between treatments ($p < 0.05$); then, a Tukey HSD post-hoc test was used to compare the means and determine the differences between groups.

Agrometeorological conditions

The weather during the experimental period (November-May) was characterized by warm (Tmax average of 36°C) and dry conditions (Figure 1). Heat stress conditions were observed from March to April, with temperatures often exceeding 40°C. The extreme warm conditions during March and April were interrupted by showers, exceeding in some cases 30 mm day^{-1} in mid-March. The relative humidity was highest (62%) at the start of the rainy season (May) and lowest (38%) during the boreal winter (December-January). Extreme dry conditions, with very low relative humidity (below 20%) were observed during dust storms at the end of March. In addition, the soil in the experimental field was characterized by having a sandy-loam texture, with a low water holding capacity (72.4% sand) and slightly acidic properties (pH 4.91) (Table 3). The organic matter (OM) and nitrogen content in the soil was relatively low (less than 1%), with a C/N ratio of 10. The total amount of phosphorus and potassium in the soil remained constant at different depths (75-71 ppm total P and 1721-1770 ppm total K, respectively at 0-20 and 20-40 cm)

RESULTS

Experiment 1: Sowing methods

The findings showed significant differences ($p < 0.05$) between quinoa cultivars and different phenological (time to flowering-Flo_{50}), morphological (plant height-PH, branches per plant-BP, panicle diameter-PD, stem diameter-SD and panicle length-PL) parameters and seed yields (thousand grain volume-TGV, thousand grain weight-TGW and grain yield per plant-GYP) (Table 4). The time to flowering of Pasankalla (Flo_{50}: 45.3 days) was longer compared to that of Puno and Titicaca (Flo_{50}: 40.2 and 37.5 days, respectively). The architecture of quinoa plants was very variable at a varietal level. This was reflected in terms of BP, SD and PL. For these crop parameters (BP, SD and PL), there were significant differences between genotypes, having Pasankalla the highest values, while Titicaca the lowest. The highest seed yields were observed in Puno (GYP: 6.28 g $plant^{-1}$), while the lowest in Titicaca and Pasankalla (GYP: 4.90 and 4.07 g $plant^{-1}$, respectively). For grain quality (volume and weight), the highest values were observed in Titicaca (TGV: 4.06 ml and TGW: 2.45 g) and the lowest in Puno (TGV: 2.68 ml and TGW: 1.54 g). As foreseeable, due to the high genotype variability, the ANOVA (with the

Table 3. Physic-chemical characteristics of the soil.

Parameter	Units	Soil layer (cm)	
		0-20	20-40
Sand	%	72.4	66.5
Silt	%	16.4	12.5
Clay	%	11.2	21.0
Texture		**Sandy-loam**	**Sandy-clay-loam**
pH (H_2O)		4.91	4.77
C	%	0.24	0.29
Organic matter	%	0.41	0.50
N	%	0.024	0.026
C/N		10	11
P total	ppm	75	71
P available	ppm	1.65	1.65
K total	ppm	1721	1770
K available	ppm	70.2	57.3

Table 4. Effect of different sowing methods on multiple genotypes of quinoa in terms of time to flowering (Flo_{50}), plant height (PH), branches per plant (BP), stem diameter (SD), panicle diameter (PD), panicle length (PL), thousand grain volume (TGV), total grain weight (TGW) and grain yield per plant (GYP).

Factor		Flo_{50} (days)	PH (cm)	BP (nº)	SD (mm)	PD (mm)	PL (cm)	TGV (ml)	TGW (g)	GYP (g)
Genotype	Titicaca	37.5^{c}	52.7^{c}	9.2^{c}	5.69^{b}	28.2^{b}	17.0^{b}	4.06^{a}	2.45^{a}	4.90^{ab}
	Puno	40.2^{b}	61.8^{b}	15.8^{b}	6.27^{b}	33.2^{a}	17.1^{b}	2.68^{c}	1.54^{b}	6.28^{a}
	Pasankalla	45.3^{a}	77.9^{a}	18.4^{a}	7.55^{a}	31.6^{ab}	29.7^{a}	3.28^{b}	1.60^{b}	4.07^{b}
Sowing method	Ridges	40.1^{ab}	72.1	17.4	7.33	35.1^{a}	24.1	3.43	1.94	8.27^{a}
	Dibbling	40.3^{ab}	66.5	15.6	6.80	31.9^{ab}	24.1	3.43	1.89	4.53^{b}
	Broadcasting	40.1^{ab}	60.7	13.3	6.05	28.0^{b}	18.9	3.02	1.83	4.82^{b}
	Transplanting	44.7^{a}	62.3	14.6	6.85	31.3^{ab}	21.0	3.30	1.84	4.29^{b}
	Traditional	39.6^{b}	65.1	14.5	6.39	32.0^{ab}	20.8	3.40	1.75	5.11^{b}
	Flat	39.9^{ab}	63.4	13.3	5.81	27.6^{b}	20.1	3.38	1.91	3.54^{b}

Means that do not share a letter were significantly different, $p < 0.05$, according to Tukey HSD test.

ensemble of genotypes) did not show significant responses to planting techniques ($p > 0.05$) for PH, BP, PL, TGV and TGW. However, plants sown in ridges developed wider panicles (PD: 35.1 mm) and much higher yields (GYP: 8.3 g plant^{-1}) when compared with the rest of techniques (PD: 30.2 mm and GYP: 4.6 g plant^{-1}, average of all planting techniques except ridges). The interaction between factors (genotype and sowing method) was significant ($p < 0.05$) for all crop parameters, except for TGV and TGW (Table 5). The best sowing method varied according to the genotype. For example, ridges seemed to favor Pasankalla and Puno in terms of seed yield; but not Titicaca, without significant differences among sowing methods. However, the highest seed yields (5.75 g plant^{-1}) for Titicaca were observed under ridges, broadcasting and traditional sowing methods (Table 5). For Pasankalla, the highest values, in terms of PH, BP, PD, SD, PL and GYP, were observed under ridges, while the lowest under broadcasting and flat sowing. Significant differences ($p < 0.05$) between planting techniques were reported with respect to crop yield of Pasankalla, with four times higher values when cultivating in ridges when compared to broadcasting or flat sowing (GYP: 8.43, 2.38 and 1.61 g plant^{-1}, respectively). Similar pattern was observed in Puno, with a two-fold increase in yields when sown in ridges when compared to the rest of planting techniques. For Titicaca, most of the significant responses ($p < 0.05$) were reported in terms of PH, BP and SD, but without a clear pattern in respects to the sowing method. Overall, results showed that transplanting had a similar effect on all the three genotypes of quinoa by delaying the

Table 5. Interaction effect of different genotypes of quinoa and sowing techniques on time to flowering (Flo_{50}), plant height (PH), branches per plant (BP), stem diameter (SD), panicle diameter (PD), panicle length (PL), thousand grain volume (TGV), total grain weight (TGW) and grain yield per plant (GYP).

Genotype	Sowing method	Flo_{50} (days)	PH (cm)	BP (nº)	SD (mm)	PD (mm)	PL (cm)	TGV (ml)	TGW (g)	GYP (g)
Titicaca	Ridges	36.3^{b}	56.4^{a}	7.8^{b}	5.87^{ab}	27.6	18.4	4.07	2.41	5.73
	Dibbling	36.7^{b}	47.4^{b}	8.0^{b}	4.97^{b}	27.7	14.9	4.25	2.40	4.55
	Broadcasting	37.0^{b}	51.2^{ab}	9.6^{ab}	5.50^{ab}	27.9	16.2	3.45	2.42	5.72
	Transplanting	41.7^{a}	52.1^{ab}	12.5^{a}	6.65^{a}	26.2	17.8	3.80	2.34	4.29
	Traditional	37.0^{b}	53.8^{ab}	7.9^{b}	5.45^{b}	29.7	17.7	4.30	2.49	5.75
	Flat	36.3^{b}	52.8^{ab}	9.5^{ab}	5.42^{b}	29.4	17.3	4.35	2.76	3.87
Puno	Ridges	40.3^{ab}	69.5	20.1^{a}	7.03	36.3	20.7^{a}	2.40	1.40	10.66^{a}
	Dibbling	39.3^{b}	60.4	16.1^{ab}	6.02	31.3	18.2^{ab}	2.55	1.70	5.50^{b}
	Broadcasting	39.7^{b}	52.7	12.4^{b}	5.82	29.2	14.5^{b}	2.50	1.49	6.36^{b}
	Transplanting	43.3^{a}	55.9	15.2^{b}	6.05	36.3	14.1^{b}	3.10	1.63	4.18^{b}
	Traditional	38.0^{b}	63.8	16.3^{ab}	6.53	34.9	18.3^{ab}	2.50	1.43	6.06^{b}
	Flat	40.3^{ab}	68.5	12.1^{b}	6.55	30.8	15.7^{ab}	2.55	1.52	4.98^{b}
Pasankalla	Ridges	45.5^{ab}	98.3^{a}	22.9^{a}	9.85^{a}	39.3^{a}	34.8^{a}	3.50	1.83	8.43^{a}
	Dibbling	45.0^{ab}	85.4^{ab}	20.0^{ab}	8.80^{ab}	36.7^{a}	34.1^{a}	3.23	1.59	3.54^{bc}
	Broadcasting	43.7^{b}	72.5^{bc}	18.0^{bc}	6.67^{cd}	27.0^{c}	27.9^{bc}	3.10	1.48	2.38^{cd}
	Transplanting	49.0^{a}	73.3^{bc}	15.5^{c}	7.87^{abc}	31.4^{b}	29.6^{b}	3.16	1.54	4.40^{b}
	Traditional	43.7^{b}	77.8^{bc}	17.2^{bc}	7.20^{bcd}	30.6^{bc}	27.6^{bc}	3.40	1.58	4.06^{b}
	Flat	44.5^{ab}	67.0^{c}	18.4^{abc}	5.73^{d}	21.7^{d}	24.8^{c}	3.30	1.62	1.61^{d}

Means that do not share a letter are significantly different, $p < 0.05$, according to Tukey HSD test.

flowering time.

Experiment 2: Sowing density rates

This experiment showed that quinoa cultivars were the main factor effect, when compared to sowing density rates, in terms of crop's morphological and agronomical responses (Table 6). Large differences ($p < 0.05$) were observed between genotypes in terms of Flo_{50} and PH. Negra Collana took longer (Flo_{50}: 54.1 days) to reach the reproductive stage when compared to Pasankalla and Titicaca (Flo_{50}: 46.9 and 42.9 days, respectively); whereas Pasankalla had the highest plants (PH: 84.4 cm). Morphological parameters, such as SD, PD and PL, showed more significant responses ($p < 0.05$) in Negra Collana and Pasankalla than in Titicaca. However, not for BP, where Titicaca plants had 15.7 branches, while Negra Collana and Pasankalla 9.0 and 8.7 branches, respectively. Yield components (GYP, TGV, TGW) of different genotypes of quinoa were significantly higher in Titicaca (GYP: 7.58 g plant^{-1}) when compared to Negra Collana and Pasankalla (GYP: 0.60 and 0.15 g plant^{-1}, respectively). Due to the longer vegetative stage and late sowing date, Pasankalla and Negra Collana cultivars were affected by heat stress at flowering and during milky grain formation. As a result, extraordinary yield losses were reported in Negra Collana and Pasankalla when compared with Titicaca. For the ensemble of genotypes, significant different responses were reported with respect to PD, with wider panicles (PD: 49.8 and 48.7 mm) under low sowing density rates (D3 and D4, respectively), and vice-versa under high density rates, D1 (PD: 39.3 mm).

The interaction between factors (genotype and sowing density) provided information about the effect of sowing density rates on growth attributes for different types of cultivars (Table 7). For Titicaca, lower plant density rates (D4: 80,000 plants ha^{-1}; D3: 100,000 plants ha^{-1}; D5: 102,564 plants ha^{-1}) resulted in a wider development of the branching system (BP: 16-18) when compared with high density rates (BP: 13-16 branches plant^{-1}). As a result, higher yields were depicted under D4, D3 and D5 (GYP: 9.18, 8.95 and 8.66 g plant^{-1}, respectively). Even though higher GYP´s were observed under low density rates, the overall production per unit of area (m^{2}) was higher under high density rates (e.g. Titicaca 98.8 and 98.6 g m^{-2} under D1 and D7, respectively) when compared to low sowing density rates (73.4 g m^{-2} under D4). For Negra Collana and Pasankalla, the highest GYP (1.04 and 0.33 g plant^{-1}, respectively) was observed under D6 (133,000 plants ha^{-1}), whereas the lowest (GYP: 0.43 and 0.07 g plant^{-1}, respectively) under high

Table 6. Effect of different sowing density rates on multiple genotypes of quinoa in terms of time to flowering (Flo_{50}), plant height (PH), branches per plant (BP), stem diameter (SD), panicle diameter (PD), panicle length (PL), thousand grain volume (TGV), total grain weight (TGW) and grain yield per plant (GYP).

Factor		Flo_{50} (days)	PH (cm)	BP (nº)	SD (mm)	PD (mm)	PL (cm)	TGV (ml)	TGW (g)	GYP (g)
Genotype	Titicaca	42.9^{c}	58.7^{c}	15.7^{a}	7.5^{b}	43.2^{b}	24.1^{b}	3.54^{a}	2.23^{a}	7.58^{a}
	Negra Collana	54.1^{a}	71.0^{b}	9.0^{b}	9.6^{a}	49.8^{a}	46.2^{a}	1.69^{b}	0.92^{b}	0.60^{b}
	Pasankalla	46.9^{b}	84.4^{a}	8.7^{b}	10.3^{a}	46.1^{ab}	43.6^{a}	1.87^{b}	0.84^{b}	0.15^{b}
Density	D1 (50×10)	47.6	71.5	11.4	8.8	39.3^{b}	39.5	2.30	1.50	1.81
	D2 (50×15)	48.4	66.7	9.9	9.2	48.1^{ab}	41.0	2.17	1.34	2.47
	D3 (50×20)	46.1	75.0	12.2	8.9	49.8^{a}	36.5	2.39	1.34	3.24
	D4 (50×25)	48.8	71.0	11.1	9.3	48.7^{a}	36.2	2.36	1.20	2.78
	D5 (65×15)	49.1	68.7	12.2	8.9	44.7^{ab}	37.1	2.21	1.30	2.35
	D6 (75×10)	48.9	70.5	10.7	9.6	47.0^{ab}	36.8	2.59	1.48	2.92

Plant density rates corresponding to D1 (200,000 plants ha^{-1}), D2 (133,333 plants ha^{-1}), D3 (100,000 plants ha^{-1}), D4 (80,000 plants ha^{-1}), D5 (102,564 plants ha^{-1}) and D6 (133,333 plants ha^{-1}). Means that do not share a letter were significantly different, $p < 0.05$, according to Tukey HSD test.

Table 7. Interaction effect of different genotypes of quinoa and sowing density rates on time to flowering (Flo_{50}), plant height (PH), branches per plant (BP), stem diameter (SD), panicle diameter (PD), panicle length (PL), volume of thousand grains (VTG), total grain weight (TGW) and grain yield per plant (GYP).

Genotype	Density	Flo_{50} (days)	PH (cm)	BP (nº)	SD (mm)	PD (mm)	PL (cm)	TGV (ml)	TGW (g)	GYP (g)
Titicaca	D1 (50×10)	43.3	58.4^{ab}	15.9^{abc}	7.3^{ab}	38.9	22.8	3.45^{ab}	2.25	4.94
	D2 (50×15)	45.0	53.0^{b}	13.1^{c}	6.7^{b}	41.0	22.6	3.07^{b}	2.03	6.37
	D3 (50×20)	40.0	64.2^{a}	16.8^{ab}	8.5^{a}	49.5	25.8	3.23^{ab}	2.07	8.95
	D4 (50×25)	43.7	63.1^{ab}	17.6^{a}	7.7^{ab}	44.2	24.7	3.37^{ab}	1.90	9.18
	D5 (65×15)	45.5	59.3^{ab}	16.1^{abc}	7.6^{ab}	38.7	24.9	4.55^{a}	2.53	8.66
	D6 (75×10)	40.0	54.0^{ab}	14.3^{bc}	7.3^{ab}	43.6	23.1	4.05^{ab}	2.59	7.40
Negra Collana	D1 (50×10)	54.5	73.3^{a}	8.6	9.2	44.8	51.7^{a}	1.60^{ab}	0.95^{ab}	0.43^{ab}
	D2 (50×15)	53.7	70.0^{ab}	9.4	10.1	48.2	49.8^{ab}	1.70^{ab}	0.92^{ab}	0.83^{ab}
	D3 (50×20)	53.7	75.4^{a}	9.4	9.1	55.7	44.6^{ab}	2.05^{a}	1.03^{ab}	0.69^{ab}
	D4 (50×25)	54.7	65.3^{b}	8.9	9.6	56.9	39.8^{b}	1.43^{b}	0.77^{b}	0.38^{ab}
	D5 (65×15)	55.0	66.5^{b}	9.0	9.9	44.8	44.1^{ab}	1.57^{ab}	0.81^{b}	0.36^{b}
	D6 (75×10)	53.3	72.8^{a}	9.0	9.5	45.0	45.4^{ab}	1.90^{ab}	1.04^{a}	1.04^{a}
Pasankalla	D1 (50×10)	47.3^{ab}	74.9	9.7	9.4^{b}	36.0**d**	38.5^{b}	2.00^{ab}	1.05^{a}	0.07^{c}
	D2 (50×15)	45.5^{ab}	84.0	8.1	11.9^{a}	52.7^{a}	50.5^{a}	1.73^{ab}	0.92^{a}	0.21^{b}
	D3 (50×20)	44.0^{b}	85.3	9.3	9.3^{b}	44.6^{bc}	44.2^{ab}	1.45^{ab}	0.58^{b}	0.09^{c}
	D4 (50×25)	48.0^{ab}	84.7	6.9	10.7^{ab}	43.4^{c}	41.6^{ab}	2.27^{a}	1.02^{a}	0.10^{c}
	D5 (65×15)	44.0^{b}	85.1	9.5	9.3^{b}	50.7^{abc}	42.5^{ab}	1.30^{b}	0.55^{b}	0.13^{bc}
	D6 (75×10)	50.3^{a}	83.7	8.8	11.9^{a}	52.5^{ab}	48.6^{a}	2.30^{a}	1.01^{a}	0.33^{a}

Plant density rates corresponding to D1 (200,000 plants ha^{-1}), D2 (133,333 plants ha^{-1}), D3 (100,000 plants ha^{-1}), D4 (80,000 plants ha^{-1}), D5 (102,564 plants ha^{-1}) and D6 (133,333 plants ha^{-1}). Means that do not share a letter were significantly different, $p < 0.05$, according to Tukey HSD test.

density treatments-D1 (200,000 plants ha^{-1}). The TGV showed significant differences between D5 and D2 for Titicaca, between D3 and D4 for Negra Collana, as well as between D4 and D6 with D5 for Pasankalla. In addition, no significant differences ($p > 0.05$) were depicted in terms of crop responses when genotypes were grouped, and sowing density levels separated (Table 8).

Table 8. Main factor effect of different density levels (plant and row distance) with the ensemble of genotypes.

Density	(cm)	Flo_{50} (days)	PH (cm)	BP (nº)	SD (mm)	PD (mm)	PL (cm)	TGV (ml)	TGW (g)	GYP (g)
Plant distance	10	48.3	71.0	9.2	11.0	42.9	38.2	2.45	1.45	2.37
	15	48.7	67.7	9.0	11.0	46.5	38.7	2.19	1.31	2.40
	20	46.1	75.0	8.9	12.2	49.8	36.5	2.39	1.34	3.24
	25	48.8	71.0	9.3	11.1	48.7	36.2	2.36	1.20	2.78
Row distance	50	47.8	71.3	9.1	11.2	46.6	38.3	2.30	1.34	2.58
	65	49.1	68.7	8.9	12.2	44.7	37.1	2.21	1.30	2.35
	75	48.9	70.5	9.6	10.7	47.0	36.8	2.59	1.48	2.92

Means that do not share a letter were significantly different, $p < 0.05$, according to the Tukey HSD test.

DISCUSSION

Quinoa exhibits a different growing pattern in response to various genotypes, planting techniques and, to a lesser extent, sowing density rates. The range of variation in the morphological, phenological and agronomical characteristics of different genotypes of quinoa is the result of a high varietal variability. In the present experiment, all three genotypes display higher yields when planting in ridges (Puno: 10.7 g plant^{-1}; Pasankalla: 8.4 g plant^{-1}; Titicaca: 5.7 g plant^{-1}). The large volume of the panicle (PD × PL) when planting in ridges (≈ 422.1 cm^3) explains the high performance in terms of yield, and vice-versa under broadcasting (≈ 159.7 cm^3) and flat sowing (≈ 91.7 cm^3). In addition, increase in-depth tillage and soil aeration when preparing the ridges has supported the development of the root system. Alvar-Beltrán et al. (2019a) also report a low root development of Titicaca in sandy-loam soils, characterized by a high bulk density during the dry season. Bakht et al. (2011) report maximum yields when planting in ridges, whereas minimum yields under broadcasting. Soil aeration benefits the plant by enhancing the nutrient and water uptake from the soil to the aboveground parts of the plant (Bakht et al., 2011). For this reason, plants sown under different planting techniques perform differently. The transplanting technique shows to be prejudicial for the plant (e.g. Puno and Titicaca). For these two varieties, the transplanting shock increases the time to flowering and decreases the yield performance. There are multiple adverse effects of transplantation in tropical environments. This is because of the high evapotranspiration rates found at low-latitudes (Alvar-Beltrán et al., 2019b), besides of the mechanical injuries occurring to the root system resulting in a slow regeneration and adaptation to new soil conditions. Similar results are reported with pearl millet in Zimbabwe, with a delay in time to flowering and maturity when transplanting (Murungu et al., 2006).

In the second experiment, large distance between plants (20 and 25 cm) resulted in a differentiated architecture of the branching system, with a typically branch to second third panicle as described by Rojas and Pinto (2013). Plants develop a wider but less compacted panicles among largely spaced plants. In this case, plants are displaying an intermediate shape between glomerulate (compacted) and amarantiform (loose) panicles (Rojas, 2015). In general, a common response of plants is to grow new branches in existing gaps. This is because canopy gaps and changes in red/far-red ratios of light are reflected by neighboring plants (Marshal and Roberts, 2000). Therefore, it increases stem elongation properties besides affecting branch orientation. These results are in harmony with those reported by Risi and Galwey (1991), showing an increase in the number of branches under low density rates for Amarilla de Marangani, Blanca de Junin and Baer (Risi and Galwey, 1991). In fact, Jacobsen (2015) highlights the ability of quinoa to compensate the remaining spaces between plants by changing the agro-morphological structure of its branches. Other studies in tropical environments, show a decrease in plant height with an increase in plant density (from 100,000 to 600,000 plants ha^{-1}), and an increase of the branching system under low sowing density rates (Spehar and da Silva Roca, 2009). Similar pattern is realized in the present study, with Titicaca and Negra Collana having the highest plants under low sowing density rates (D3)

This research findings show more productive plants per unit area (e.g. Titicaca with 98.8 g m^{-2}) at high density rates (D1: 200,000 plants ha^{-1}); but not in terms of GYP, with highest GYP under low density rates. This relationship (between production per unit area and density rate) is evident for Titicaca, but not as strong for Negra Collana nor Pasankalla. However, as highlighted by Jacobsen (2015), relatively high-density rates are preferred in order to secure uniform plants and similar time to maturity. High plant density rates can also slow down and prevent the development of diseases (Gandarillas et al., 2015). Other studies confirm that the optimum sowing density rates for obtaining the highest yields is 70-140 plants m^{-2}, with 12.5 cm row spacing, and the equivalent of 8-10 kg seeds ha^{-1} (Piva et al., 2015). However, draw-backs of high-density rates emerge in those locations where sowing, harvesting, thinning and weeding is done mechanically, as the distance required for preparing the furrows is approximately 80 cm (Peralta et al., 2012). In regard to TGV, observed differences were due to due to environmental conditions (heat-stress and water availability) during the grain formation and filling grain phase, and not because of different sowing density rates. Therefore, genotypes Pasankalla and Negra Collana, with much longer cycles, were affected by extreme heat-stress conditions occurring in March and April, both in terms of GYP and TGV, with similar findings reported by Alvar-Beltrán (2019b). A positive relationship between PH and GYP is also in line with Alvar-Beltrán (2019a) who reported a strong correlation (r: 0.88) between PH and GYP for genotype Titicaca. Benlhabib et al. (2015) show a positive correlation between GYP and plant height and fresh and dry weight. While Oyoo et al. (2015) and Rojas et al. (2015) observe a positive trend between the GYP and genotype, as well as for the following agronomical parameters: time to flower, milky grain, pasty grain and physiological maturity, just like panicle length and biomass production. In addition, Pasankalla plants have a longer vegetative stage and therefore more time to build up biomass and further develop higher plants (PH: 33 and 21% higher than Titicaca and Puno).

The agronomic, environmental and genetic implications of using short cycle varieties are multiple. First, water requirements of short cycle varieties (Titicaca and Puno) are likely to be much lower to that of long cycle varieties (Negra Collana and Pasankalla). This is a key aspect giving the water constraints within the Sahel region during the dry season. In addition, increased heat-stress conditions have adverse impacts on crop yields, and these are minimized when using short cycle varieties (Lesjak and Calderini, 2017; Alvar-Beltrán et al., 2019b). However, the branching system and, in particular, the wider stem diameter of Negra Collana and Pasankalla, highlights the ability of these genotypes to withstand harmattan winds. As acknowledged by Gandarillas et al. (2015), the direction of the furrows with regards to wind and field slope is fundamental. Therefore, genetic efforts need to move towards more wind resilient but high yielding varieties (Titicaca and Puno).

Conclusion

The present study demonstrates that genotypes and sowing methods, rather than sowing density rates, are the most determining factors affecting plant growth, development and yield performance of quinoa. The overall conclusion of both experiments is that genotype Puno, planting technique ridges (sowing depth: 3 cm; ridge height and width: 15 cm and 17 cm) under high density rates (D1: row and plant distance: 50 cm × 10 cm, equivalent to 200,000 plants ha^{-1}) is the most optimal agronomic technique in terms of yield. Further research is needed to better understand the phenological, morphological and agronomical response of short cycle varieties (Puno and Titicaca) to density rates higher than 200,000 plants ha^{-1}. Other planting techniques and/or practices that favour soil aeration need to be increasingly explored. For example, by incorporating different amounts of organic matter into the soil (increasing soil porosity), diversifying the types of tillage (zero, minimum and/or reduced, and deep tillage) and reducing the soil sodicity (impeding soil infiltration).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors acknowledge Food and Agriculture Organization (FAO) for the seed and fund provision to carry out this experiment under the technical cooperation programs TCP/SFW/3404 and TCP/RAF/3602.

REFERENCES

Ali S, Chattha MU, Hassan MU, Khan I, Chattha MB, Iqbal B, Rehman M, Nawaz M, Amin MZ (2020). Growth, Biomass Production, and Yield Potential of Quinoa (Chenopodium quinoa Willd.) as Affected by Planting Techniques Under Irrigated Conditions. International Journal of Plant Production pp. 1-15.

Alvar-Beltrán J, Dao A, Saturnin C, Dalla MA, Sanou J, Orlandini S (2019a). Effect of Drought, Nitrogen Fertilization, Temperature, and Photoperiodicity on Quinoa Plant Growth and Development in the Sahel. Agronomy Journal 9(10):607.

Alvar-Beltrán J, Saturnin C, Dao A, Dalla MA, Sanou J, Orlandini S (2019b). Effect of drought and nitrogen fertilisation on quinoa (Chenopodium quinoa Willd.) under field conditions in Burkina Faso. Italian Journal of Agrometeorology 1:33-43.

Andrews D (2017). Race, Status, and Biodiversity: The social climbing of quinoa. Culture, Agriculture, Food and Environment 39(1):15-24.

Bakht J, Shafi M, Rehman H, Uddin R, Anwar S (2011). Effect of planting methods on growth, phenology and yield of maize varieties. Pakistan Journal of Botany 43(3):1629-1633.

Baloch AW, Soomro AM, Javed MA, Ahmed M, Bughio HR, Bughio MS, Mastoi N (2002). Optimum plant density for high yield in rice (*Oryza sativa* L.). Asian Journal of Plant Sciences 1(1):25-27.

Belachew T, Abera Y (2010). Response of maize (*Zea mays* L.) to tied ridges and planting methods at Goro, Southeastern Ethiopia. American-Eurasian Journal of Agronomy 3:21-24.

Benlhabib O, Jacobsen SE, Jellen EN, Maughan PJ, Choukr-Allah R (2013). Status of quinoa production and research in Morocco. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 478-491.

Gandarillas A, Saravia R, Plata G, Quispe R, Ortiz-Romero R (2015). Principle quinoa pests and diseases. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 192-215

Gomez-Pando L, Mujica A, Chura E, Canahua A, Perez A, Tejeda A, Villantoy A, Pocco M, Gonzales V, Marca S, Ccoñas W (2015). Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 378-387.

González JA, Konishi Y, Bruno M, Valoy M, Prado FE (2012). Interrelationships among seed yield, total protein and amino acid composition of ten quinoa (Chenopodium quinoa) cultivars from two different agroecological regions. Journal of the Science of Food and Agriculture *92*(6):1222-1229.

Kristensen L, Olsen J, Weiner J (2008). Crop density, sowing pattern,and nitrogen fertilization effects on weed suppression and yield in spring wheat. Weed Science 56(1):97-102.

Jacobsen SE, Jørgensen I, Stølen O (1994). Cultivation of quinoa (Chenopodium quinoa) under temperate climatic conditions in Denmark. The Journal of Agricultural Science 122(1):47-52.

Jacobsen SE (2015). Adaptation and scope for quinoa in Northern Latitudes of Europe. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 436-446

Lesjak J, Calderini DF (2017). Increased night temperature negatively affects grain yield, biomass and grain number in Chilean quinoa. Frontiers in Plant Science 8:352.

Murungu FS, Nyamudeza P, Mugabe FT, Matimati I, Mapfumo S (2006). Effects of seedling age on transplanting shock, growth and yield of pearl millet (Pennisetum glaucum L.) varieties in semi-arid Zimbabwe. Journal of Agronomy 5(2):205-211.

Oyoo M, Khaemba J, Githiri S, Ayiecho O (2015). Production and utilization of quinoa (Chenopodium quinoa Willd.) outside its traditional growing areas: a case of Kenya. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD, pp. 534-548.

Peralta E, Mazón N, Murillo A, Rivera M, Rodríguez D, Lomas L, Monar C (2012). Manual Agrícola de Granos Andinos: chocho, quinua, amaranto y ataco. Cultivos, variedades y costos de producción. Publicación miscelánea No. 69.

Piva G, Brasse C, Mehinagic E (2015). Quinoa d'Anjou: the beginning of a French quinoa sector. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 447-453.

Planella MT, López ML, Bruno MC (2015). Domestication and prehistoric distribution. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 29-41.

Risi J, Galwey NW (1991). Effects of sowing date and sowing rate on plant development and grain yield of quinoa (Chenopodium quinoa) in a temperate environment. The Journal of Agricultural Science 117(3):325-332.

Rojas W, Pinto M (2013). La diversidad genética de quinua de Bolivia. In M. Vargas, ed. Congreso Científico de la Quinua (Memorias). La Paz, Bolivia. pp. 77-92.

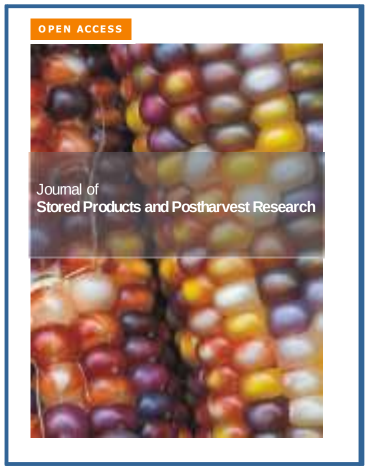
Rojas W (2015). Quinoa genetic resources and *ex situ* conservation. In: Bazile Didier (ed.), Bertero Hector Daniel (ed.), Nieto Carlos (ed.). State of the art report on quinoa around the world in 2013. Santiago du Chili: FAO, CIRAD pp. 56-82.

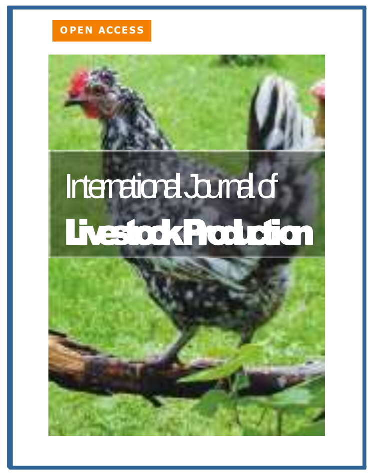
Sharifi RS, Sedghi M, Gholipouri A (2009). Effect of population density on yield and yield attributes of maize hybrids. Research Journal of Biological Sciences 4(4):375-379.

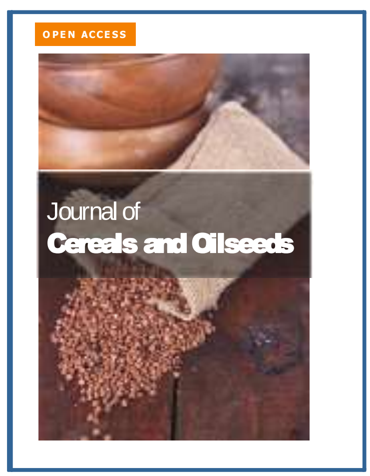
Spehar CR, da Silva Rocha JE (2009). Effect of sowing density on plant growth and development of quinoa, genotype 4.5, in the Brazilian savannah highlands. Bioscience Journal *2*5:4.

Van Den Boogaard R, Veneklaas EJ, Peacock JM, Lambers H (1996). Yield and water use of wheat (Triticum aestivum) in a Mediterranean environment: cultivar differences and sowing density effects. Plant and Soil 181(2):251-262.

Related Journals:







www.academicjournals.org