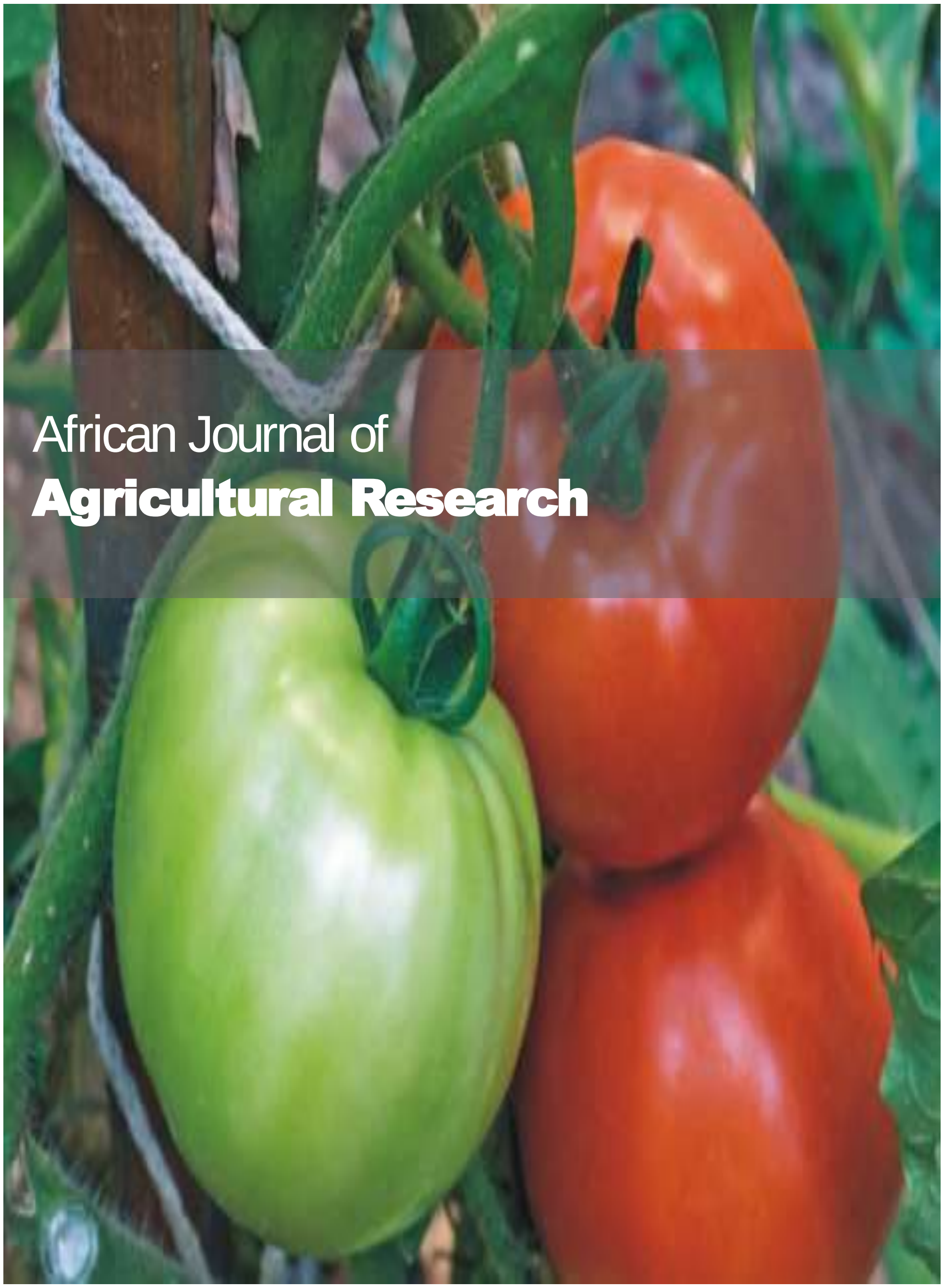
OPEN ACCESS



African Journal of
Agricultural Research

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

ACADEMIC
JOURNALS
expand your knowledge

ABOUT AJAR

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

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

Contact Us

Editorial Office: ajar@academicjournals.org

Help Desk: helpdesk@academicjournals.org

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

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

Editors

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Editorial Board

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

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

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

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

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

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

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

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

Dr. Mohamed A. Dawoud

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

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

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

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

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

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

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

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

African Journal of Agricultural Research

Table of Contents: Volume 13 Number 23, 7 June, 2018

ARTICLES

academicJournals

Vol. 13(23), pp. 1163-1169, 7 June, 2018
DOI: 10.5897/AJAR2017.12205
Article Number: CEE57A957306
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Review

What factors influence performance of farmer groups? A review of literature on parameters that measure group performance

Sheilla Jeruto Tallam

Department of Sociology, Moi University, P. O. Box 3900, Eldoret, Kenya.

Received 6 February, 2017; Accepted 11 April, 2017

Farmers form and participate in groups in order to benefit socially and economically through collective activities. However, membership in groups alone is not enough to facilitate improvement of livelihoods, owing to the fact that only successful groups would be able to fully exploit their potential and meet the interests of their members. Understanding group performance is therefore a pertinent issue among social researchers and development practitioners working with farmers groups. Findings from literature indicate that scholars have measured performance of group differently, and this can be divided into three broad areas: Group performance measured by level of cohesion/ group characteristics, group performance measured by outputs/benefits and group performance measured by both level of cohesion/group characteristics and outputs/benefits. The measurement of performance of groups engaging in the same activities has been much easier, however; for the groups that engage in diverse activities the measurement of their performance becomes even more complicated. This study concludes that group performance can be measured in various ways depending with what researchers and development practitioners want to investigate and achieve.

Key words: Small holder farmers, farmer groups, group cohesion, group performance.

INTRODUCTION

Agriculture is the mainstay of the economy in sub-Saharan countries. It is the main contributor of GDP in the region, a major source of subsistence crops and provides livelihood for a large proportion of the population (e.g., UNEP, 2003). Majority of the residents of sub Saharan Africa live in rural areas and are dependent on agriculture as a source of food and income (Salifu et al., 2010).

Ironically three out of four poor people in Africa depend directly or indirectly on agriculture for their livelihoods (Dorward et al., 2009). This is a result of an array of challenges that farmers face, such as; lack of access to water for irrigation, in ability to access markets, illiteracy and lack of access to quality agricultural inputs, technical training and inability to control pests and diseases (Khalid, 2011). Because of these challenges smallholder

E-mail: sjtallam@gmail.com. Tel: +254722779260.

farmer groups are highly vulnerable to poverty (Curtis, 2013).

Farmer groups are increasingly recognized as a transformative force for improving rural livelihoods in Sub Saharan Africa (Place et al., 2004), these groups have been used as important avenues for reaching the very poor at the grassroots level (Bernard et al., 2008; Develtere et al., 2008). Therefore farmer groups provide an essential entry point for improving agricultural production and income in this region (Nyang et al., 2010).

Membership in farmer groups however, is not sufficient in enhancing sustainable development, these groups should have the capacity to meet their objectives and serve the needs of members (Abaru et al., 2006). For a group to be effective, farmers need to be well organized (Bosc et al., 2001). Groups should have the capacity to deliver relevant services which allows smallholder farmers to participate actively in collective action at the grass root level (Mukindia, 2012).

Measurement of groups' performance is an effective way of understanding the level of development of farmer groups. Understanding group performance is essential in identifying the kind of support farmer groups need to enable them to improve on their service deliver. The categorization of groups according to their performance also facilitates effective monitoring of the changes that takes place as the groups develop over a period of time. Understanding group performance has been a key subject of research by institutions and social researchers. However, identifying the parameters for the measurement of group performance have been a great challenge through the years. Thus stakeholders in this field face constraints in understanding group performance. This study reviews literature on how scholars have measured group performance; this would shed more light on how to go about identifying group level of performance and guide stakeholders in this field on how best to support groups based on their level of advancement.

RESULTS AND DISCUSSION

Literature review show that the measurement of group performance by social researches can be divided into three broad areas:

1. Group performance measured by level of cohesion/ group characteristics;
2. Group performance measured by outputs/benefits;
3. Group performance measured by both the level of cohesion/ group characteristics and outputs/benefits.

Group performance measured by level of cohesion/group characteristics

Kifanyi et al. (2013) explored the performance of community-based organizations in managing sustainable urban water supply and sanitation projects, guided by the following factors; community participation, appropriate technologies and institutional arrangements. The findings signify that overall performance of community-based organizations will depend on full involvement of communities in all stages of project development, implementation and management.

Joy et al. (2008) examined the factors that determine group performance of women-led Agro-processing self-help groups in Kerala India, guided by the following indicators; category of the self-help group (fish processing, copra processing, powder making and groups dealing with ready to eat items), group cohesion (degree in which members are connected to the group and are motivated to remain in the group), group leadership (ability of team members to interact freely without any formal inhibition), team spirit (willingness of the group members to work together in devotion), group decision making (the process of arriving at decisions by the group members through either consensus or a majority vote) and record keeping (regularity in keeping records and their verification which is also an indicator of transparency in group activities). The results indicate that the poor performing groups had very low scores in these indicators, the above factors were therefore found to influence group performance. In order to determine the relationship between the group performance indicators above and socio-economic characteristics of the members, a number of indicators of socio-economic characteristics were explored; education of respondent and spouse, age, market perception, economic motivation, attitude towards self-employment, management-orientation, knowledge about processing, risk orientation, innovativeness and information seeking behavior. The findings indicate that the socio-economic characteristics that contributed towards group performance were; management orientation, information seeking behavior, knowledge about processing, market perception and economic motivation. The least influential factors were; age, education, attitude towards self-employment and innovativeness. Education of the respondent and/or spouse and innovativeness were found to have a significant relationship with group cohesion. Management orientation, knowledge about processing and attitude towards self-employment had a positive and significant relationship with group leadership. The variables on education of the respondent and age showed a negative but significant relationship with group leadership and as educational status increases, participation in self-help group activity reduces. Economic motivation, information-seeking behavior, management orientation and market participation had a significant and positive relationship with team spirit. Increase in team spirit enhanced the market perception of a group, whereas information-seeking behavior, knowledge about processing, management orientation, market perception, risk orientation and economic motivation were significantly and positively related to group decision making. Finally, market perception, economic motivation, knowledge about processing, risk orientation and information seeking behavior influences the regularity in maintenance of records.

Chamala and Shingi (1997) identified three categories of factors that influence the performance of community groups;

Internal factors

Group composition, group structure and size, group atmosphere, cohesion, group standards and norms, leadership styles, balance between group maintenance needs, individual needs and task needs, development phase of a group, group culture (empowering, controlling),level of group " think" characteristics.

Government and non-governmental agencies

Technical capabilities of extension staff, skills in managing groups, staff attitude and commitments to groups, types of planning method (directive or participative, top down or bottom up or a balance of method, support for field extension officers and formation process of groups).

Community factors

Groups are part of the community in which they exist hence the community influences the success of a group.

Salifu et al. (2012) assessed the influence of leadership and management on the performance of farmer-based organizations (FBOs) in Ghana, results indicate that despite the majority of FBOs claiming to practice democratic principles in selecting leaders, on the contrary the basis of selecting a chairperson has been the age, socio-economic status and the role that individual played during the group formation process. The role of secretary was often left for a member with the highest level of education, whereas the position of a treasurer was often reserved for a female member of the group unless it's a purely male group. Findings further show that the leadership and group members were not aware of what is contained in the constitution and the bylaws. Despite these, the groups organized themselves to suit to their specific collective action activity. It was observed that farmer-based organizations that come up with rules and management styles that uniquely suit them are able to successfully manage themselves. It was evident from the study that the group formation process did not influence the performance of groups. Whether the group was formed by members or external actors could not be easily distinguished because members organized themselves into groups' in order to obtain benefits from the government or other sources. The motivation behind the formation of an FBO was found to be a better indicator of performance and not the individuals behind its formation.

McCarthy et al. (2002) conceptualized collective action to mean cooperation. Further, the success of collective action was found to be a function of individuals' motivation to contribute to maintenance and abide by rules and regulations of the institution. Collective action involves the capacity of a community as a whole to cooperate and it's influenced by the overall policy environment in which these institutions operate. In a study of collective action in Natural Resource Management (NRM) groups in Burkina Faso, two indicators of collective action were identified; organizational performance and networks. The proxies for networks comprised of density of organizations and density of household participation.

Organizational performance indicators comprised of:

Rules: Total number of rules observed for all NRM organizations.

Activities: Total number of activities observed for all NRM organizations,

Average meetings participation rate: The number of households that usually attends meetings; this number was used to create the percent of households attending meetings for each institution, and a variable was constructed of the average of this percent across organizations.

Average activities participation rate: The percentage of households participating was constructed, and an average was taken across organizations.

Results indicate that all the variables are significantly and positively correlated except the number of activities and membership in non –NRM organizations.

Njoku, Mathews et al. (2009), explored the factors influencing role performance of Community Based Organizations in Agricultural development, the findings indicate that role performance had a significant relationship with income, experience, type of agricultural activity, quality of leadership and membership size.

Thompson et al. (2009) presented the seven habits of highly effective farmer organizations which were described as the essentials of success in high-performing farmer organizations in Africa. The seven habits identified were; clarity of mission, sound governance, strong responsive and accountable leadership, social inclusion and rising of voice, demand driven and focused service delivery, high technical and managerial capacity and effective engagement with external actors.

Accordingly these habits offer a useful checklist of working principles and practices to assess the performance of farmer organizations in Africa and elsewhere. Organizations can be internally effective by adopting the seven habits; however, it cannot successfully represent its members in the absence of an enabling legal, regulatory and policy environment that guarantees its autonomy.

Aldana et al. (2007) in a study of 40 farmer groups in India, Uganda and Bolivia found out that the success of a group depends on the acquisition of skill sets such as; group organization and management, internal savings and lending, sustainable production, ability to access and apply new technology and market skills.

Rau (2013) in a s study of a network of Community Based Organizations in India, found out that the factors that influence effectiveness of a network of Community Based Organizations include: Enthusiasm and commitment among CBO members in support of the networks, implementing partners with creative ideas, sound technical skills, willingness to negotiate important political relationships on behalf of communities, innovation and flexibility that permit ideas to be tested and adapted to suit the circumstances of each state network. Skills in analysis, communication and problem solving, as well as having skills in organizational management and a common goal so that differences do not divide members within it.

Group performance measured by outputs/benefits

Ampaire et al. (2013) investigated the factors influencing the effectiveness of second-tier rural producer organizations (RPO) in linking their members to output markets in Uganda. Effectiveness of the RPO was measured using percentage of RPO members who used the RPO for marketing of at least some of their produce. It was found that RPO size, democratic leadership and higher proportion of women membership have a significant positive influence on the effectiveness of the RPO. Contrary to expectations, RPO leaders trained in leadership skills and involved in related business activities had a significant negative influence on the effectiveness of RPOs. Although there is no clear theoretical explanation for this result, one possible explanation was presented. Leadership trainings received by RPO management team members mainly covered group leadership skills, financial management and bookkeeping. In practice, such training results in stronger institutionalization of rules and regulations within the RPO. In spite of the fact that these rules should serve to strengthen the RPO, the rules also reduce the motivation for some members to market their produce through the organization.

According to Place et al. (2004) the measurement of group performance is a challenge because groups take on many activities over time making the analysis and comparison of performance very complicated. Therefore the measurement of groups' performance would best be done by use of the outputs generated by the group activities. Therefore the ability of groups to effectively produce achievements (performance) can be measured best by the use of direct outputs. In a study of groups in central Kenya, the common types of direct benefits included; cash or credit from merry-go-rounds or risk-coping groups, animal fodder, improved livestock breeds, household goods, knowledge and spiritual uplifting of members. Although this can be difficult to quantify therefore the proxies that reflect these benefits need to be identified.

Haque et al. (2011) measured effectiveness of Community Based Organization (CBO) micro credit programmes supported by Concern World Wide in Bangladesh based on the ability of a member to assess, use and repay loans on time. Results indicates that repayment performance of CBO microcredit programmes was highly satisfactory, the respondents' income and loan receipt amount, positively contributed to loan repayment whereas respondents age, education, family size and forced saving negatively affected loan repayment. Almost all respondents repaid their loan on time with the hope of getting loans in future. Self-consciousness and proper supervision by the CBO staff and concern worldwide field workers were the other important contributing factors for repayment performance.

Davis et al. (2004) examined the factors that make farmer groups successful in dissemination of information and technologies in Meru, Kenya. Success in dissemination was measured using the number of buck services that took place at each group's buck station. Buck services refer to the number of female goats brought to the group for breeding with the improved buck. The "neighbor adoption index" was the dairy-goat groups' ratings of number of neighbors using dairy-goat technologies. These scores could range from 1 to 4, where 1 = none, 2 = some, 3 = many, and 4 = all. The variables considered to influence success of the groups include; size of the group, amount of member participation, homogeneity of members, jealousy within the group, group capacity, number of linkages, and type of group. Results indicate that the variables that affect the success of dairy-goat groups in disseminating information and technologies included member participation, linkages, and type of group. The size of the group, member homogeneity, degree of jealousy, and group capacity had little or no effect on group success.

Sonam and Martwanna (2012) assessed the performance of smallholder dairy farmer groups in East and central regions of Bhutan. Performance of the groups was measured using the direct benefits from the dairy groups such as; easy market for milk, timely cash income, access to credit facilities, production support, marketing support, processing efficiency, members' representation and members' capacity development opportunities. Six functional tasks associated with the dairy groups' performance were identified and evaluated; (i) production support; (ii) marketing support; (iii) processing efficiency; (iv) members' representation; (v) records and accounting and (vi) group management, using a likert-type rating scale. Limited group capacity, non-committal membership, poor sense of ownership, inactive participation by the members, heavy dependence on government support, dispersed location and complacent members' attitude were found to negatively affect performance of dairy groups, while the reverse had positive influence.

Group performance measured by both level of cohesion/group characteristics and outputs/benefits

Shiferaw et al. (2006) argues that, depending with the problem under study, certain indicators can be identified as proxies for the different levels of collective action (those that capture the level of cooperation or group action) and the degree of effectiveness of such collective action in attaining the groups' stated objectives. This kind of separation allows the assessment of the level in which such collective action can be attributed to good performance in the form of the final outcomes. According to these scholars, the level of collective action and its performance can be understood by commitment attributes of the individual members to the group activities and objectives, these include the extent to which individual members relate with other members of the group within the existing institutional mechanism, commitment and the extent to which members share a common vision to the group ideals and organizational structure. In a study of producer marketing groups in Makueni and Mbeere Districts in Eastern Kenya, Shiferaw et al. (2006) identified six indicators of collective action; number of elections held since formation of the group, number of members respecting the bylaws of the group, attendance at meetings, annual member contributions to the group, cash capital and agreed annual subscription fees. In order to assess whether high level of collective action influences performance of groups, two indicators were utilized; total assets built over a period of time and total volume of grains traded.

The results show that the number of elections held, involvement of members in decision making, initial startup capital and membership fees are positive correlates of group performance, while distance to the markets and number of villages covered by the group are negatively associated with the effectiveness of the marketing functions of the groups.

Dimelu et al. (2013) assessed the performance of faith-based grass-root, non-governmental organizations (NGOs) in Nasarawa state-Nigeria, guided by four factors; roles of the organization in rural development in the target communities, level of participation of beneficiaries in the programme, perceived effects/impacts to the beneficiaries and the beneficiaries' perception of the performance of the organization. The findings indicate that the NGO performance was rated to be good in the 11 out of the 13 programmes/activities.

Barham and Chitemi (2009) in a study of farmer groups in Tanzania examined the extent to which certain characteristics and assets owned by smallholder farmer groups facilitate improvement in group marketing performance. The study evaluated a government led program which aims at increasing smallholder farmers' income and food security through a market oriented intervention. Group Marketing Performance Rating (MPR) was developed, ranging from 0 to 2 constructed on the following basis:

Rating 0: The project intervention had little improvement to their market situation.
Rating 1: Some improvement, such groups were able to provide tangible examples on how their market situation had improved from participating in the project.
Rating 2: Huge improvement, these groups showed outstanding market improvements by initiating several collective action activities.

The variables affecting marketing performance rating were identified to include; (1) Infrastructure which is represented by the following variables, distance to markets, road conditions, staple food crops, land, reliable water source and commodity types. (2) The social structure characterized by explanatory variables such as; (i) group assets comprised of wealth rankings, education, providers/partners, membership in other groups, altruism and intra group trust (general, help and money trust); (ii) group composition/ characteristics encompassing; group maturity, group size, activity level, gender categories and leadership by gender; (iii) the group heterogeneity composed of educational level, gender and wealth.

Finally the PA (partner agency) intervention which takes into account the by partner agency and market linkage with which the farmer groups worked and whether or not the groups were actively linked to other market chain actors in an endeavor to improve their market situation. The results indicate that the variables that are strongly associated with improved marketing performance are; reliable water source, activity level and commodity types. Group maturity, partner agency and educational variables are statistically significant factors in improving marketing performance. PA linkages and leadership by gender also indicates some association with improved marketing performance.

According to Bernard et al. (2008) performance of groups is dependent on their effectiveness in providing services to their members. In order to measure performance of village organizations in Senegal and Burkina Faso, two hypothesis were tested in which none of the them was rejected; the groups had weak managerial capacity and groups lacked sufficient resources to make a difference, results indicate that the governance structure is characterized by bureaucratic procedures and the formalism of rules, groups have a control commission to look into the activities of the board of directors and utilizes the formal accounting systems.

In order to assess whether the quality of governance influences performance, performance was measured by the number of members who have benefited from the group at least once. Correlations were explored between the extent of bureaucracy and performance of groups. Due to co-linearity between variables, four of the variables were re grouped into control variables which equals to one if the organization has a control commission or a written code of conduct and zero if otherwise and a professional management variable which equals to one if the organization maintains either an accounting or registry book, zero if otherwise. Results indicate that greater management capacity is related to performance for village organizations in Senegal, in Burkina Faso greater control is a negative factor for performance. Multi-tasking whereby organizations engage in diversified services lowers the quality of each service even though it allows the organization to serve a wider clientele. In conclusion performance is negatively affected by low professional management capacity and lack of resources.

Akpabio and Aboh (2007) in an attempt to identify the significant factors affecting the success of women NGOs working with local women groups in Ibom state Nigeria found out that; ability to fulfill beneficiaries expectations, high volume of credit provision and income levels affect the success of groups. Gyau et al. (2011) studied the role of collective action in improving market access of small holder producers of agro-enterprise products in Cameroon. Results indicate that Collective action will succeed when internal factors such as; favorable group size, group norms, knowledge of market information and voluntary collaboration among members exist. These should be in the context of an enabling environment, which includes favorable policies and regulations.

Conclusion

Different scholars have measured group performance differently, others have measured group performance based on the level of cohesion/group characteristics, others have measured group performance based on the outputs and benefits members gain from the group, while other social researchers have measured group performance based on the combination of the two, which is both the output/benefits and level of cohesion/group characteristics. Measuring group performance is a great challenge especially when farmer groups engage in various activities, nevertheless understanding group performance is an important aspect for social researchers and development practioner. How they measure group performance will be dependent on what is important to them. Understanding group performance is important for the government, organizations and social researchers working with farmer groups to enable them understand the various levels of development of groups, guide them on how best to support farmer groups based on their level of performance and finally facilitate effective monitoring and evaluation of groups over time.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abaru MB, Nyakuni A, Shone G (2006). Strengthening farmers organizations.The experience of RELMA and ULAMP, Nairobi.

Akpabio IA, Aboh CC (2007). Factors Affecting women NGOs success with local women groups in Akwa Ibom state, Nigeria. The J. Int. Social Res. 1:1.

Aldana M, Burpee G, Heinrich G, Remington T, Wilson K, Ashby J, Quiros C (2007). The Organization and Development of Farmer Groups for Agroenterprise: Conclusions from a CRS and RII-CIAT Study Tour in Asia,Africa and Latin America.

Ampaire EL, Machethe CL, Birachi E (2013). The role of rural producer organizations in enhancing market participation of smallholder farmers in Uganda : Enabling and disabling factors 8(11):963-970.

Barham J, Chitemi C (2009). Collective action initiatives to improve marketing performance: Lessons from farmer groups in Tanzania. Food Policy 34(1):53-59.

Bernard T, Collion M-H, de Janvry A, Rondot P, Sadoulet E (2008). Do Village Organizations Make a Difference in African Rural Development? A Study for Senegal and Burkina Faso. World Dev. 36(11):2188-2204.

Bosc Pierre-Marie, Eychenne D, Hussein K, Losch B, Mercoiret MR, Rondot P, Macintosh-walker S (2001). The Role of Rural Producer Organizations(RPOs) in the World Bank Rural Development Strategy

Chamala S, Shingi P (1997). Establishing and strengthening farmer organizations. In B. E. Swanson, R. P. Bentz, & A. J. Sofranko, eds. Improving agricultural extension.A reference manual. Rome: Food Agricultural Organization of United Nations.

Curtis M (2013). Powering up smallholder farmers to make food fairagenda.A five point agenda, London.

Davis K, Franzel S, Hildebrand P, Irani T, Place N (2004). Extending technologies among small-scale farmers in Meru, Kenya: Ingredients for success in farmer groups, The J. Agric. Educ. Ext. 10(2):53-62.

Develtere P, Pollet I, Fredrick W (Eds) (2008). Cooperating out of poverty.The renaissance of the African Cooperative Movement, Geneva: International Labour Office.

Dimelu MU, Salua ES, Igbokwe EM (2013). Performance of faith-based grassroot non- governmental organisations in rural development in Nasarawa State , Nigeria. Int. NGO J. 8(7):146-152.

Dorward A, Kirsten Johann F, Omamo WS, Poulton C, Vink N (2009). Institutional Economics Perspectives on African Agricultural Development J. . F. Kirsten et al., eds., Washington,DC: Int. Food Policy Res. Institute. Available at: http://www.ifpri.org/pubs/books/oc61.asp.

Place F, Kariuki G, Wangila J, Kristjanson P, Makauki A, Ndubi J (2004). Assessing the factors underlying differences in achievements of farmer groups: methodological issues and empirical findings from the highlands of Central Kenya. Agric. Sys. 82(3):257-272.

Haque MS, Akter R, Laoubi K (2011). Effectiveness of community based organization (CBO) microcredit programme of concern worldwide : A case study of Bangladesh 5(24):0101-10107.

Joy L, Prema A, Krishnan S (2008). Determinants of group performance of women-led agro-processing self-help groups in Kerala . Agric. Econ. Res. Rev. 21:355-362.

Khalid S (2011). Governance of Producer Groups : A case study on Horticulture and Livestock Project , Ministry of Agriculture , Irrigation and Livestock Khulm District , Balkh Province – *Afghanistan*. Van Hall Larenstein University of Applied Science.

Kifanyi GE, Shayo BMB, Ndambuki JM (2013). Performance of community based organizations in managing sustainable urban water supply and sanitation projects. Int. J. Phys. Sci. 8(30):1558-1569.

McCarthy N, Dutilly-Dian ÈC, Drabo B (2002). Cooperation,Collective action and Natural Resource Management in Burkina Faso*:* A methodological note, Washington,DC.

Mukindia B (2012). Influence of collective action on market access among small holder banana farmers in Imenti South District,Kenya. University of Nairobi.

Nyang MN, Webo C, Roothaert RL (2010). The Power of Farmers Organisations in smallholder Agriculture in East Africa. A review of 5 project initiatives of the Maendeleo Agricultural Technology Fund, London.

Rau B (2013). Forming Networks of Community-Based Organizations: Early experiences from the Avahan India AIDS Initiative. Washington, DC: Futures Group. ISBN 978-1-59560-011-0

Salifu A, Francesconi GN, Shashidhara K (2010). A Review of Collective Action in Rural Ghana, Washington,DC.

Salifu A, Funk RL, Keefe M, Kolavalli S (2012). Perfomance of Farmer-based Organizations in Ghana., Washington DC.

Shiferaw B, Obare G, Muricho G (2006). Rural Institutions and Producer Organizations in Imperfect Markets : Experiences from Producer Marketing Groups in Semi-Arid Eastern Kenya. SAT eJournal 2:1.

Sonam T, Martwanna N (2012). Performance of smallholder dairy farmers' groups in the East and West central regions of Bhutan: Members' perspective. J. Agric. Ext. Rural Dev. 4(1):23-29.

Thompson TAJ, Hughes D, Chirwa E, Omiti J (2009). The seven habits of highly effective farmers' organisations, Future Agriculture. FAC Publication: PB-P02

UNEP (2003). Action plan of the environment initiative of the New Partnership for Africa's Development (NEPAD), United Nations Environment Programme.

Vol. 13(23), pp. 1170-1176, 7 June, 2018
DOI: 10.5897/AJAR2018.13046
Article Number: 94FC5EF57310
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

The effect of velvet bean (*Mucuna cinerea)* extract on seedling growth of winter cereals

Cristiana Bernardi Rankrape[1], Ivan Carlos Zorzzi[2], Fabiana Rankrape[3], Jhessica Bortolotti[4], Pedro Valério Dutra Moraes[1], Dalva Paulus[1], Paulo Fernando Adami[1] and Patricia Rossi[5]

[1]Department of Agronomy, Federal Technologic University of Paraná, UTFPR, Dois Vizinhos, Paraná, Brazil.
[2]Gebana Brazil, Capanema, Paraná, Brazil.
[3]Department of Veterinary Medicine, Federal University of Fronteira Sul, UFFS, Realeza, Paraná, Brazil.
[4]Giro Produtos Agrícolas, Rio Verde, Goiás, Brazil.
[5]Department of Animal Science, Federal Technologic University of Paraná, UTFPR, Dois Vizinhos, Paraná, Brazil.

Received 7 February, 2018; Accepted 16 March, 2018

Some plants can have a beneficial or harmful effect on the germination and growth of other plants. This is known as the allelopathic effect. The objective of this study was to evaluate the effect of different doses of velvet bean (*Mucuna cineruim)* aqueous extract on germination and initial seedling growth of three winter cereals: white oat (*Avena sativa*), rye (*Secale cereale*) and wheat (*Triticum aestivum*). The experimental design was a completely randomized design, with four replications of five doses of aqueous extract (0, 5, 10, 15 and 20%). Of the three cereals, rye had the greatest allelopathic effect on the test variables in the different aqueous extract concentrations, while the white oat had the highest mean germination time. Negative effects of velvet bean on the growth of wheat were observed only in the applications of high doses. It can be concluded that velvet bean exhibits great allelopathic potential to control the germination and seedling growth of the cereals. This effect was primarily observed in the white oat and rye under the applications of higher extract doses.

Key words: Velvet bean, *Avena sativa*, *Secale cereale*, *Triticum aestivum*, germination, aqueous extract.

INTRODUCTION

The velvet bean (*Mucuna cinerea*) is a climbing legume that is used as a cover crop and is significant for its biomass production and adaptability to diverse soil conditions (Ribas et al., 2010). The velvet bean can also prevent the multiplication of plant-parasitic nematodes that cause great damage to crops (Sakai et al., 2007). They added that the velvet bean is one of the main crops used in the production of green manure in Brazil, due to its high productivity and the low cost of production.

In a crop rotation scheme, the velvet bean may be used prior to winter crops. Where, wheat (*Triticum aestivum*), white oat (*Avena sativa*) and rye (*Secale cereale*) are winter cereals belonging to the Poaceae family. These three cereals have great economic importance in Brazil and are used in crop rotation systems to produce grain. They are cultivated primarily in the southern region of Brazil where the climate is more conducive to growth.

Few studies had explored the allelopathic effect of

---

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

cover crops that precede winter crops in organic or conventional production systems. Therefore, studies are necessary to investigate the interaction of these crops with other plants in the production system, especially those that precede the crop.

In the environment, plants compete for light, water, space and nutrients. Thus, there is constant competition between species, which contributes to the survival of some species in an ecosystem and the development of defence mechanisms by other species based on the synthesis of secondary metabolites that are released into the environment and that interfere with some stage in the life cycle of another plant (Sampietro, 2002).

Other study, detected that the released secondary metabolites, which are released into the environment, may inhibit or stimulate the germination and/or growth of other plants that are relatively close, characterizing the allelopathic effect where one plant has an effect on another (Soares and Vieria, 2000). Resistance or tolerance to secondary metabolites is a species-specific characteristic, and more sensitive plants are considered as indicators of allelopathic activity (Alves et al., 2004).

While, the possibility of developing beneficial or unfavourable allelopathic effects between crops is of agronomic interest, especially in terms of crop rotation and intercropping (Silva et al., 2013). These findings may contribute to the development of adequate management and the determining of suitable species for crop rotation or for the use of cover crops (Bonfim et al., 2013).

On the other hand, there are numerous records of the allelopathic influence on crop rotation, as observed with wheat, black oat and rye. Although these crops did not reduce the germination of summer crops, they affected the growth of corn, soybean and bean plants (Ferreira and Aquila, 2000). In other study carried out with velvet bean showed an allelopathic effect on some species of weeds, such as black sting (Teixeira et al., 2004).

Therefore, the aim of the study was to evaluate the effect of applying velvet bean aqueous extract on the germination and seedling growth of three winter cereals: white oat, rye and wheat.

MATERIALS AND METHODS

The experiment was conducted in the Seed Analysis Laboratory of the Federal University of Technology of Paraná (UTFPR), Campus Dois Vizinhos, between April and June 2015.

The aqueous extract was prepared by collection of the aerial part of velvet beans during the grain-filling period. The plants were dried in a semi-enclosed greenhouse under ambient conditions of temperature and humidity until constant weight was obtained. Subsequently, the material was ground in a knife mill, packed in plastic bags and stored in a cold chamber until use.

The experimental design was a completely randomized design with four replications. The treatments consisted of five doses of velvet bean aqueous extract (0, 5, 10, 15 and 20%), and distilled water was used for the dilutions. The 0% concentration represented the control treatment that received only distilled water. Each replication included 100 seeds of oats, rye and wheat, which were used disinfected in 5% hypochlorite solution for 3 min. The seeds were then sown on two sheets of Germitest paper and another sheet was used to cover the seeds, which were then rolled and dampened with 60 mL of aqueous extract.

On the other hand, preparation of the highest concentration (20%) of aqueous extract (20 g of extract in 1 L of distilled water) was used. After dilution, the liquid was filtered and the remaining dilutions were carried out for the other concentrations. The treatments were conditioned in an incubator (BOD) at a constant temperature of 21±1°C, with no photoperiod in accordance with the recommendations of the Rules for Seed Analysis (RSA) (Brasil, 2009).

The germination percentage (G), germination speed index (GSI), mean germination time (MGT) and average speed of germination (ASG) were calculated daily. At the end of the test, the germination percentage, the length of the radicle (LR), aerial part length (APL), and radicle and shoot dry mass (DM) were determined. While, the G was calculated daily by counting the number of germinated seeds for seven days after germination began. The criterion applied to determine seed germination was morphological, that is the emergence of the radicle was considered as the defining factor (Ferreira and Aquila, 2000). The G was calculated using the formula G = (N/100) × 100, where N = Number of seeds germinated at the end of the test. Whereas the GSI was calculated according to the equation proposed by Maguire (1962): GSI = G1/N1+ G2/N2+...+ Gn/Nn, where G1, G2, ... Gn = number of normal seedlings from the first until the seventh day of counting, N1, N2, ..., Nn = number of days of sowing.

The radicle and shoot length were determined using a graduated ruler and all germinated seedlings were measured in each replication. Subsequently, the radicle and shoot samples were conditioned in a forced ventilation oven at 50°C until constant weight was obtained.

The MGT was calculated by formula *MGT = (Σniti)/ Σni*, where ni = number of seeds sprouted per day; ti = time; i = 3 to 9 days; and ASG was calculated using formula *ASG = 1/mean germination time in days.*

The percentages were transformed using sine-arc $\sqrt{x}/100$ for the normalization of its distribution. The results were submitted to analysis of variance (ANOVA) and the effect of the regression treatments was verified using ASSISTAT statistical software (Silva and Azevedo, 2009), at 5% probability of error.

RESULTS AND DISCUSSION

The velvet bean extract had a negative effect on the rye, white oat and wheat, and caused a low germination percentage (G) and low germination speed index (GSI). The mean germination time (MGT), average speed of germination (ASG), radicle length and dry mass of the radicle and shoot were also negatively influenced.

However, the increase in the extract dose resulted in the reduction of the germination percentage (G) in all winter cereals (Figure 1). Where, the rye had the lowest germination percentage at the highest dose, with only 3.25% in comparison with the control group that had a G of 88.5%, showing a decrease of 96.32%. While, the wheat had a G of 22.25% and the white oat showed 47% of germinated seeds at the highest dose. Similar findings were reported by Erasmo et al. (2004), who conducted a study in which a different species of velvet bean (Mucuna pruriens) was investigated, and a reduction in the number

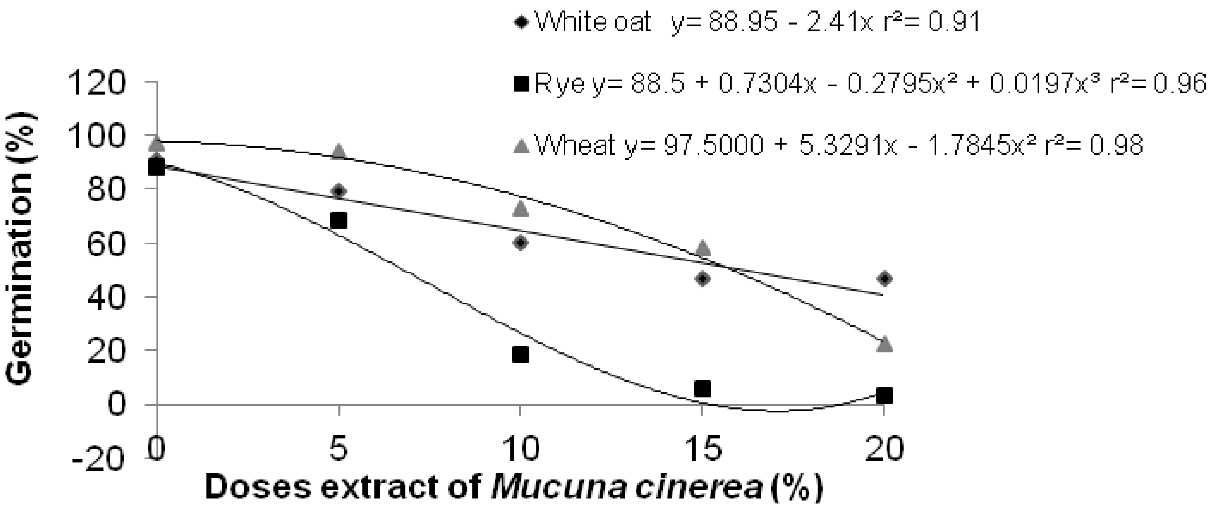


Figure 1. Germination percentage of winter cereals submitted to different doses of velvet bean aqueous extract.

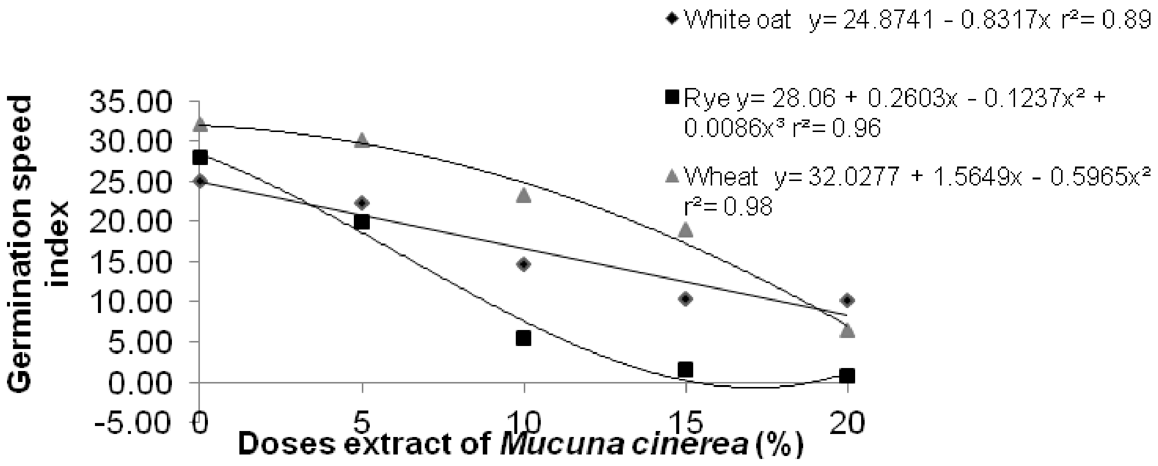


Figure 2. Germination speed index of winter cereals submitted to different doses of velvet bean aqueous extract.

of weeds confirmed the control potential of this species.

Currently, the germination speed index (GSI) also decreased for the three cereals (Figure 2) in relation to an increase in extract concentration. Similar to the G, rye was the crop that had the lowest GSI (0.83), followed by wheat (6.43) and oats (10.28). In comparison with the control group, the reductions were 96.97, 20.07 and 59.12%, respectively for each culture at the highest extract dose.

In the present study, the mean germination time (MGT), which represents the number of days required for seed germination, increased for all tested crops (Figure 3). Where, more days were required for the germination process to begin in the winter cereals. Therefore, the allelopathic qualities of the velvet bean delay the growth of these cereals. Oats were the most affected and, at an extract dose of 20%, germination started at 5.11 days^{-1}, while the time for the control group was 3.94 days^{-1}. While, the rye germination began at 4.30 days^{-1} for the highest extract dose. Little difference in MGT was observed in wheat for the different extract doses. This result may be related to an adaptive or physiological characteristic of the culture, as the species that establishes itself first in the environment has advantages in the competitive process. The competitive ability of a species is related to the efficient use of resources in the surrounding environment (Rizzardi et al., 2001). The delay or irregularity in germination is detrimental, as the seed is exposed in the field for long and is, thus, vulnerable to the attack of fungi, unfavourable climatic conditions such as drought, predation and interference in pre-germination phase, thereby having less capacity to

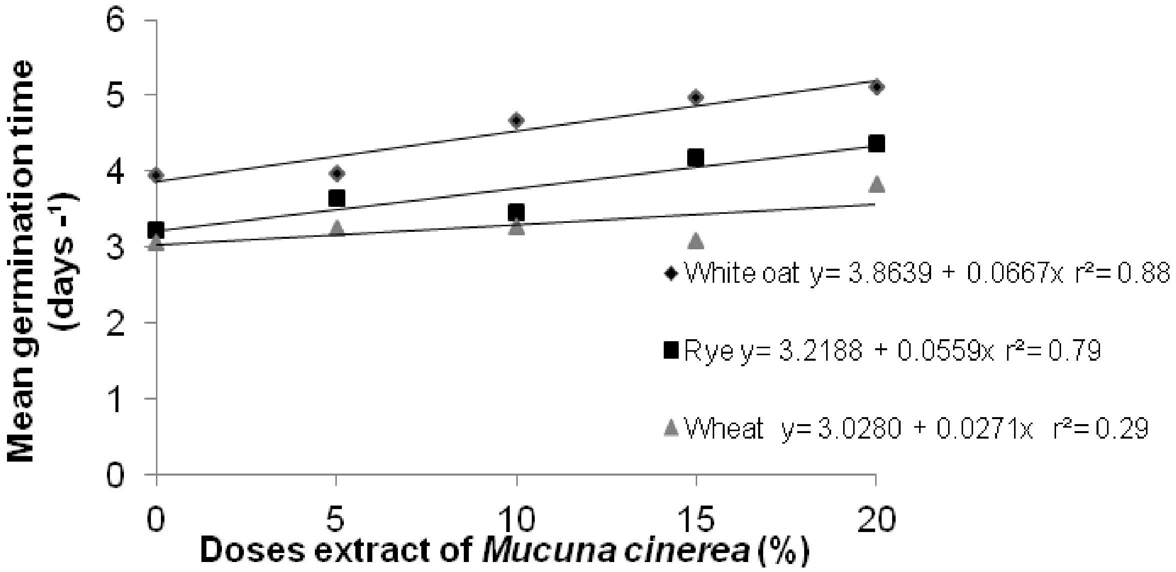


Figure 3. Mean germination time of winter cereals submitted to different doses of velvet bean aqueous extract.

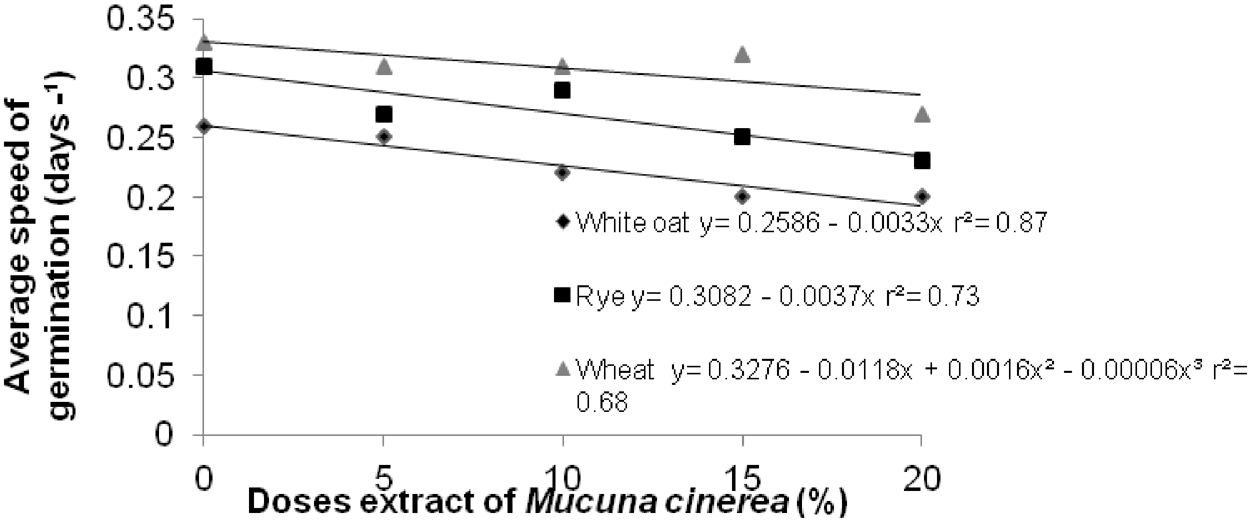


Figure 4. Average speed of germination of winter cereals submitted to different doses of velvet bean aqueous extract.

compete for environmental resources (Alencar et al., 2016).

In the present work, the average speed of germination (ASG) (Figure 4) is calculated from the MGT. Thus, as the mean germination time for the crops decreased with the application of the extract doses, the ASG also decreased. In the field, this may mean that the crops have a low competition power with weeds, thereby reducing the plant resistance and resulting in low grain production at the end of the crop cycle. According to Ferreira and Aquila (2000), the allelopathic effect is often not the final percentage of germination time, but of germination speed.

Regarding, the tested variables of seedling growth, the rye was the most affected by the velvet bean extract, and in the 20% dose there was no root growth (Figure 5), thereby demonstrating the strong allelopathic effect of the velvet bean on the crop. The reduction in root growth has a negative influence on crop growth, as it becomes more vulnerable to lodging and water stress, and thus lowers productivity.

The white oat also showed a reduction in radicle length (Figure 5), comparing the control treatment (7.27 cm) with the 20% dose (3.5 cm), showing a reduction of

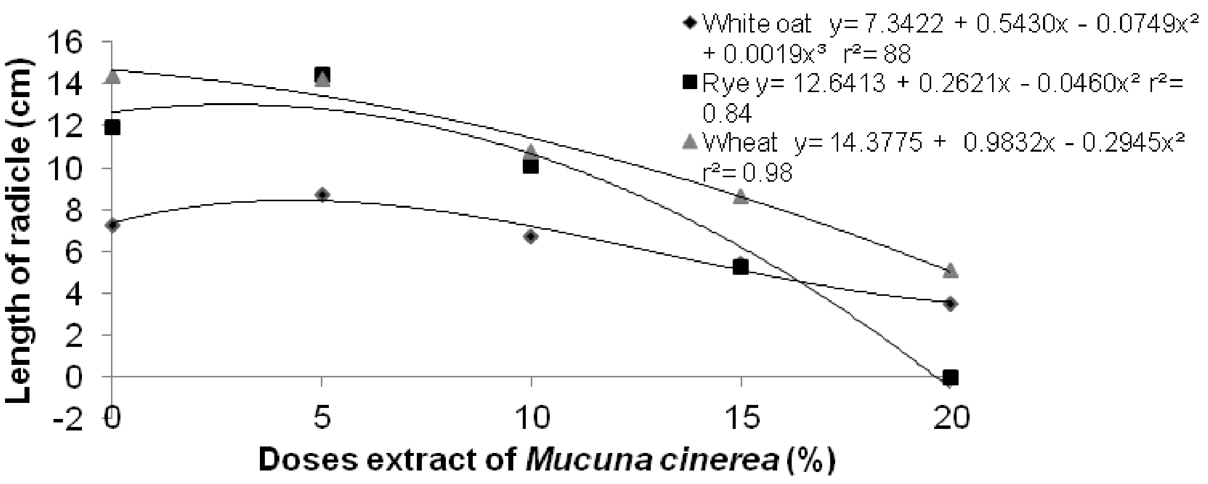


Figure 5. Length of radicle of winter cereals submitted to different doses of velvet bean aqueous extract.

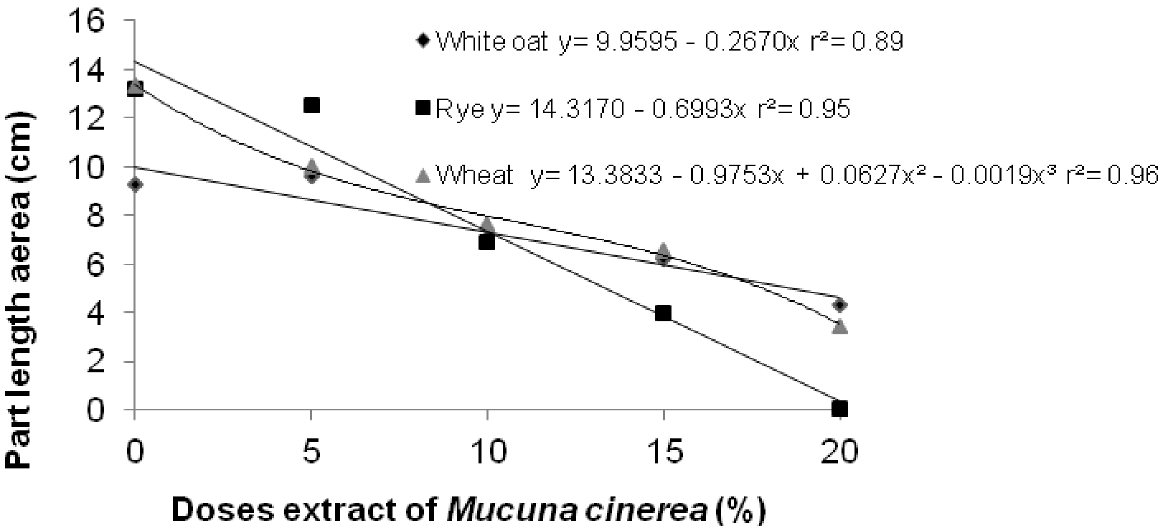


Figure 6. Aerial part length of winter cereals submitted to different doses of velvet bean aqueous extract.

51.85%. Wheat had a significantly reduced radicle length at the 10% (10.78 cm) dose, which may signify that in the field the development of the crop may be inhibited depending on the amount of dry matter mass present in the soil. The rapid root development of a crop after germination is a characteristic that can lead to a high establishment speed and, subsequently, the competitive advantage during the critical period of competition. According to Ferreira and Aquila (2000), germination is less sensitive to allelochemicals than seedling growth.

Results similar to what was observed concerning the radicle length were also recorded in the aerial part length of the cultures.

Also, rye had no aerial part development at the highest dose tested (20%) (Figure 6). The wheat gradually decreased its aerial part length area as the extract dose increased, where the control group was 13.32 cm and the 20% dose was only 3.46 cm. The oats also had their aerial development inhibited; however, when compared with the other cultures, the oats developed even in the highest applied dose and showed only a slight reduction. Based on the decrease of area growth the plant will have a smaller photosynthetically active leaf area, therefore the production of photo-assimilates will be lower, which will result in productivity losses.

The present findings on the shoot length and radicle reported that they were directly influenced by the dry mass of the crops, since both variables are correlated. No seedling growth occurred in the rye at the highest dose (20%); consequently, the dry mass values of the

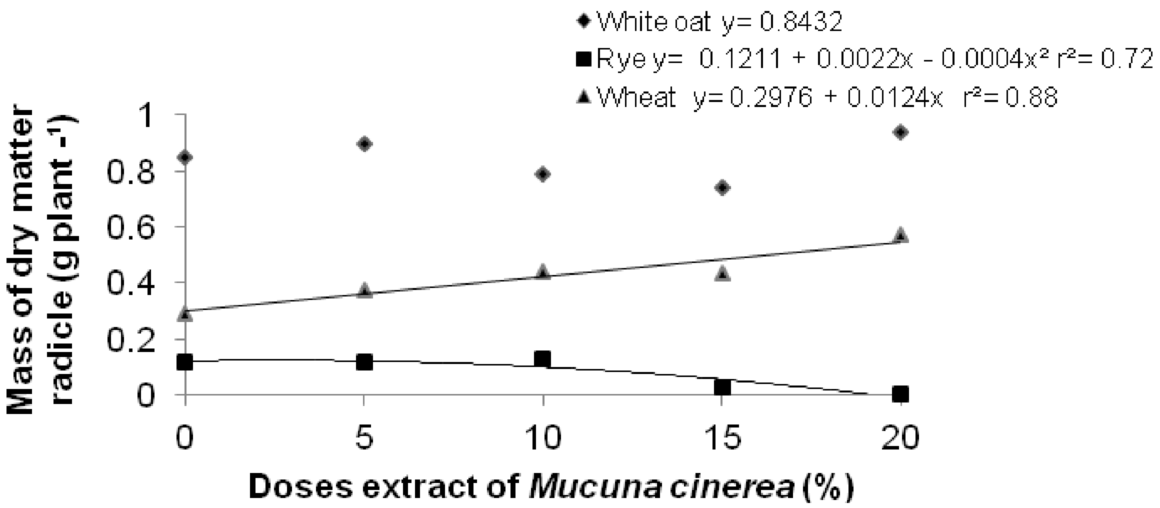


Figure 7. Mass of dry matter radicle of winter cereals submitted to different doses of velvet bean aqueous extract.

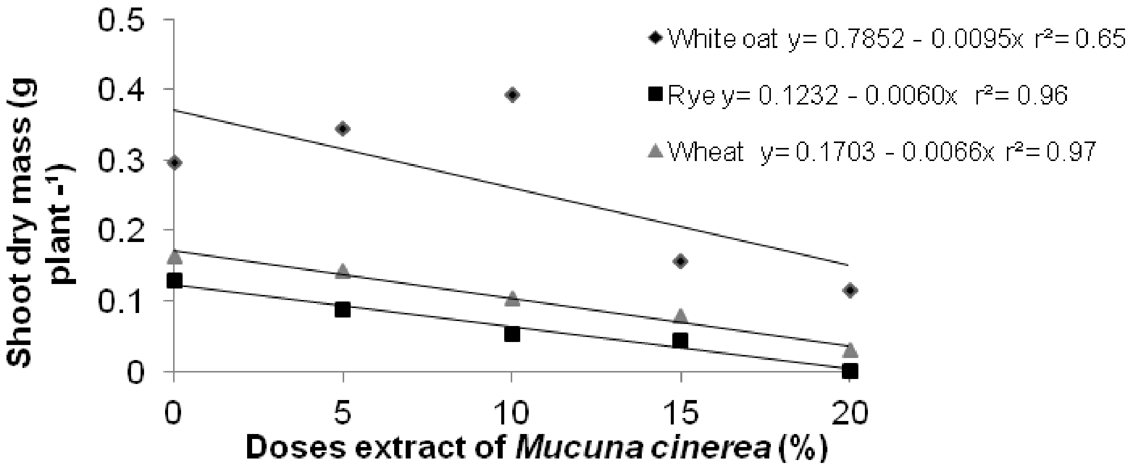


Figure 8. Shoot dry mass of winter cereals submitted to different doses of velvet bean aqueous extract.

radicle (Figure 7) and aerial part (Figure 8) were not obtained. In comparison to the control group, there was an increase in dry mass of the radicle in the wheat (Figure 7). This increase can be explained either by stimulation of the extract or by the presence of a greater amount of reserves in the endosperm, which decreased as the dose of the applied extract increased, having a reduction of 81.9% of the control group to the 20% dose. For the white oat, the results of the dry mass of the radicle did not exhibit a difference between the doses tested and in the aerial dry mass, reduction occurred mainly in the higher doses (15 and 20%). Therefore, for each culture and tested dose of velvet bean extract, a response occurred and the most significant reductions occurred when the highest doses were applied.

Conclusion

From the foregoing results it could be conclude that the velvet bean exhibited great allelopathic potential that affects all variables of germination and seedling growth of the three winter cereals.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Alencar SR, Silva MAP, Macêdo MS, Ribeiro DA, Santos MAF, Costa

NC (2016). Efeito fitotóxico de *Mangifera indica* L. (Anacardiaceae) em diferentes horários de coleta. Iheringia. Série Botânica, 71(2):175-183.

Alves MCS, Filho SM, Innecco R, Torres SB (2004). Alelopatia de extratos voláteis na germinação de sementes e no comprimento da raiz de alface. Pesquisa Agropecuária Brasileira, 39:1083-1086.

Bonfim FPG, Souza KF, Guimarães RGR, Dores MCM, Fonseca VWDC (2013). Efeito de extratos aquosos de funcho na germinação e vigor de sementes de alface e salsa. Revista Trópica: Ciências Agrárias e Biológicas, 7:218-228.

BRASIL (2009). Ministério da Agricultura, Pecuária e Abastecimento. Regras para análise de sementes. Brasília: Mapa/ACS P 399.

Erasmo EAL, Azevedo ER, Sarmento RA, Cunha AM, Garcia SLR (2004). Potencial de espécies utilizadas como adubo verde no manejo integrado de plantas daninhas. Planta Daninha 22:337-342.

Ferreira AG, Aquila, MEA (2000). Alelopatia: uma área emergente da ecofisiologia. Revista Brasileira de Fisiologia Vegetal 12:175-204.

Maguire JD (1962). Speeds of germination-aid selection and evaluation for seedling emergence and vigor. Crop Science, 2(2):176-177.

Ribas RGT, Santos RHS, Siqueira RG, Diniz ER, Peternelli LA, Freitas GB (2010). Decomposição, liberação e volatilização de nitrogênio em resíduos culturais de mucuna-cinza (*Mucuna cinerea*). Ciência e Agrotecnologia, 34:878-885.

Rizzardi MA, Fleck NG, Vidal RA, Merotto Jr, A, Agostinetto D (2001). Competição por recursos do solo entre ervas daninhas e culturas. Ciência Rural, 31(4):707-714.

Sampietro DA (2002). Alelopatía: concepto, características, metodología de estudio e importancia. Cátedra de Fitoquímica. Instituto de Estudios Vegetales “Dr. Antonio R. Sampietro” Facultad de Bioquímica, Química y Farmacia. Universidad Nacional de Tucumán Ayacucho 12.

Sakai RH, Silva PH, Ambrosano EJ, Mendes PCD, Rossi F, Guirado N, Ambrosano GMB, Arévalo RA, Canterella H, Rossetto R, Junior IA, Silva AMC, Mota B, Farias GB, Godoy APB, Menuzzo MM (2007). Avaliação agronômica de quatro espécies de mucuna utilizadas como adubos verdes em sistema agroecológico. Cadernos de Agroecologia 2:910-913.

Silva AA, Ferreira FA, Ferreira LR, Santos JB (2013). Biologia de Plantas Dainhas. In: SILVA AA.; SILVA JF. Tópicos em manejo de plantas daninhas. Viçosa, MG: Universidade Federal de Viçosa. Editora UFV 17-55.

Silva FAS, Azevedo CAV (2009). Principal Components Analysis in the Software Assistat-Statistical Attendance. In: World Congress On Computers In Agriculture, 7, Reno-NV-USA: American Society of Agricultural and Biological Engineers.

Soares GL, Vieira TR (2000). Inibição da germinação e do crescimento radicular de alface (cv. Grand Rapids) por extratos aquosos de cinco espécies de Gleicheniaceae. Floresta e Ambiente 7(1):180-197.

Teixeira CM, Araújo JBS, Carvalho GJ (2004). Potencial alelopático de plantas de cobertura no controle de picão-preto (*Bidens pilosa* L.). Ciência e Agrotecnologia, Lavras, 28:691-695.

Vol. 13(23), pp. 1177-1185, 7 June, 2018
DOI: 10.5897/AJAR2018.13177
Article Number: D269FBF57308
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

An on-farm comparison of the agronomics and economics of irrigated maize production systems in the Somali Deyr season

Ryan Gavin[1], Hussein Haji[2], Nicolas Jelinski[3] and Paul Porter[1*]

[1]Department of Agronomy and Plant Genetics, 411 Borlaug Hall, University of Minnesota, 1991 Upper Buford Circle, St. Paul, 55108, MN, USA.
[2]SATG, Somali Agriculture Technical Group, Safari Complex, Km5 Road, Hodan District, Mogadishu, Somalia.
[3]Department of Soil, Water and Climate, 439 Borlaug Hall, University of Minnesota, 1991 Upper Buford Circle, St. Paul, 55108, MN, USA.

Received 10 April, 2018; Accepted 26 April, 2018

Domestic production only supplies half of Somalia's cereal requirements and more than half of the country's population is considered food insecure. In this study, the Somali Agriculture Technical Group (SATG) used an on-farm participatory research approach to compare the economic viability and plant yield parameters of an improved maize production system (SATG system) with those of the traditional farming systems (traditional system) of the Lower Shebelle region of Somalia. The SATG system included urea, diammonium phosphate, insecticide application, and a greater than average planting population. This research was conducted on seventy-seven farms located near the villages of Afgoi and Awdhegle during the 2014/15 Deyr season and was compared with results from a similar 2014 Gu season trial. Significant plant yield and harvested plant population differences emerged for crop management system, location, and season. In the 2014/15 Deyr season, implementation of the SATG system yielded 124% more grain than the traditional system (SATG = 3,970 kg ha^{-1}) and had 28% more plants at harvest (SATG = 37,300 plants ha^{-1}). Analysis of 2014/15 Deyr season cost and revenue revealed that, while production costs associated with the SATG system were higher than those associated with the traditional system, greater net revenues and profit reliability were observed for the SATG system. When plant growth and yield parameters were compared across seasons, both the SATG and traditional systems exhibited greater yields and harvested plant populations in the 2014 Gu season. In both seasons, the greatest grain yields were observed on farms near Awdhegle. As soil fertility appears to be the primary maize yield constraint in the region, these locational differences may have may have resulted from underlying locational differences in soil electrical conductivity. Throughout the Lower Shebelle, however, implementation of the SATG system appears to increase maize yields and improve farm net income.

Key words: Deyr, fertility, maize, net income, on-farm, Somalia, participatory.

INTRODUCTION

For more than twenty-five years, Somalia has struggled to overcome the political instability, civil unrest, and infrastructure collapse that occurred when the Siad Barre government fell in 1991. Today, the country relies on an informal economic system (Little, 2008) and is heavily dependent on foreign aid and development assistance

(World Bank Group, 2018). With the majority of the Somali population being rural (World Bank Group, 2016), development schemes that focus on improving rural livelihoods will likely prove most effective. One powerful rural development tool is agricultural research (Thirtle et al., 2003).

Though agriculture is hugely important to its economy, the current agricultural situation in Somalia is dire. While crop production represents up to 20% of the country's GDP (Somali Development Bank, 2015) and agriculture employs 71% of the population (CIA, 2017), domestic cereal production only satisfies around half of the population's requirements (FAO, 2012), and food can account for 80% of household expenditures (FEWS, 2014). Recognizing this, the Somali Agriculture Technical Group (SATG, www.SATG.org) is working to advance Somali agriculture through targeted crop research in Somalia's Lower Shebelle region (Figure 1). In this study, SATG used a farmer participatory research approach to compare the agronomics and economics of a new irrigated maize cropping system with those of the region's traditional maize production system.

MATERIALS AND METHODS

Maize is the principal cereal crop in Somalia, and nearly all production takes place on the irrigated and rain-fed farmland along the Lower Shebelle river, where soils have been shaped by alluvial deposits over calcareous, unconsolidated and consolidated sedimentary formations (Jones et al., 2013; Gadain et al., 2016) and are dominated by Haplic Vertisols (70%), Fluvisols (11%), and Calcisols (2%) (Jones et al., 2013). Seasonality in the region is driven by rainfall, and maize production is restricted to two primary growing seasons: the Gu and the Deyr. The Gu season, which takes place between April and June and sees between 200 and 300 mm of rainfall (Muchiri, 2007), serves as the major growing season in the Lower Shebelle, while the Deyr season, which takes place between October and December and receives between 150 and 200 mm of rainfall (Muchiri, 2007), is the region's secondary growing season.

During the 2014/15 Deyr season, SATG utilized a multi-location randomized complete block (RCB) experimental design to compare the maize yield and growth parameters of two cropping systems: one that employed SATG best management practices (BMPs) and one that followed the traditional farming techniques practiced in the region. This research was performed on the farms of Lower Shebelle maize producers and under the supervision of SATG staff. In total, seventy-seven farmers participated in the 2014/15 Deyr season trial. Each of their farms was considered an experimental block, and each block was nested within a village (either Afgoi or Awdhegle). On each farm, one jibaal (625 m^2) of land was managed using the SATG system, while an adjacent jibaal was managed using each farmer's own traditional management practices.

The SATG system consisted of relatively simple BMPs: A desired SATG system plant population of 44,444 plants ha^{-1} was achieved with a plant spacing of 0.75 m between rows and 0.30 m within rows; a pre-plant broadcast application of diammonium phosphate (DAP) at a rate of 200 kg ha^{-1} (36 kg N ha^{-1}, 92 kg P_2O_5 ha^{-1}) and two 75 kg ha^{-1} (34.5 kg N ha^{-1}) applications of urea were used to supplement soil fertility (one banded application at planting and one at the V4 growth stage); control of spotted stem borer (*Chilo partellus*) (Overholt, 2008) was achieved by applying the insecticide Bulldock® (Beta-Cyfluthrin) at a rate of 5 kg ha^{-1}; and timely weeding and irrigation events were performed. These BMPs were selected because they significantly increased maize yields in the 2014 Gu season, and have been repeatedly recognized as important crop production factors in other geographies (Mwangi, 1996; Asim et al., 2013). The open-pollinated maize variety "Somtux" was used in both the SATG and traditional systems, and with the exception of land preparation, which is commonly performed with a tractor in the Lower Shebelle, all aspects of field management and harvest for both systems were performed by hand.

Data were collected on each farm by taking the average of two representative 3 m^2 subsamples from both the SATG and traditional system plots. The main parameters of interest for this trial included the grain yield, stover yield, and plant population at harvest. Grain yield measurements were obtained after the grain had been removed from the cob and sun-dried. After drying, grain moisture measurements were taken with a handheld moisture meter, and grain weights were standardized to 15.5% moisture content. The stover was also sun-dried before weighing, but because stover moisture content was not assessed, these weights could not be standardized to specific moisture content and stover yield data must be viewed with skepticism. Further, technological availability limited the measurement precision of weights to 0.05 kg, which likely contributed to the high standard deviations observed in this trial. Plant population at harvest was assessed by hand counting.

Because the methods employed in this study were similar to those employed in the 2014 Gu season (Gavin et al., 2018), the agronomics of these crop management systems were also compared across seasons. Though similar, some methodological differences did exist between the 2014 Gu and 2014/15 Deyr seasons. In the 2014 Gu season, the SATG system had a greater desired plant population (53,300 plants ha^{-1}), which was achieved with a denser plant spacing of 0.75 m between rows and 0.25 m within rows, and received 50 kg ha^{-1} (23 kg N ha^{-1}) more urea. Eighty-one farmers participated in the 2014 Gu season trial (Gavin et al., 2018).

After randomly removing the data of several farmers, a final balanced dataset consisting of seventy-four farms in each season and thirty-seven farms at each location was obtained for statistical analysis. An analysis of variance (ANOVA) was performed using the package PROC ANOVA in the statistical software SAS™ at a significance level of $\alpha = 0.05$ ($p \leq 0.05$). Mean separation was conducted using the Tukey's Honest Significant Difference (Tukey's HSD) post-hoc test (SAS, 2016).

The size of the 2014/15 Deyr season dataset also afforded the opportunity to explore potential relationships that might exist between grain yield, planting date, and plant population at harvest (for an examination of these relationships in the 2014 Gu season, see Gavin et al., 2018). Data from all seventy-seven farmers who participated in the 2014/15 Deyr season trial were used to examine the relationship between maize yield and harvested plant population, while planting date data were only available from the thirty-seven farms near Awdhegle. These relationships were evaluated via simple linear regression in R (R Core Team, 2016).

---

*Corresponding author. E-mail: pporter@umn.edu.

Figure 1. A satellite image illustrating the location of the Afgoi and Awdhegle villages in the Lower Shebelle agricultural region of Somalia.

A farm-level economic analysis of 2014/15 Deyr season maize production in the Lower Shebelle was also performed. Utilizing data from thirty-one farmers located near Awdhegle, an ANOVA was conducted to better understand how the SATG and traditional management systems differed in terms of input costs, gross revenue, and net revenue. This analysis was completed using the PROC ANOVA package in SAS^{TM}, with statistical significance assessed at an α level of 0.05 and using Tukey's HSD for post-hoc mean separation (SAS, 2016). For the analysis, input costs were aggregated into six broad cost categories: land preparation costs, planting costs, growing costs, harvesting costs, labor costs, and capital costs. Gross revenues were determined by associating each farmer's maize yield with the average price of maize in the region, 10,000 Somali Shillings kg^{-1}. This figure was reported by SATG staff and falls in line with the 2015 average retail maize price, as compiled by the Famine Early Warning System (FEWS, 2015). Currency conversion into USD was conducted using the 2015 U.N operational exchange rate of 1 USD to 24,300 SOS (United Nations, 2017), making the average price of maize $0.41 USD kg^{-1}.

RESULTS AND DISCUSSION

Grain yield

In the 2014/15 Deyr season, the grain yield of the SATG system (3,970 kg ha^{-1}) was 124% greater than that of the traditional system, and this pattern persisted when each location was examined independently (Table 1). The grain yield of the SATG system was 127% greater than the traditional system on farms near Afgoi (3,570 kg ha^{-1}) and 121% greater on farms near Awdhegle (4,370 kg ha^{-1}). It was also observed that farms near Awdhegle had higher grain yields than farms near Afgoi, regardless of which management system was employed. Farms near Awdhegle saw a 22% greater grain yield for the SATG system (4,370 kg ha^{-1}) and a 26% greater grain yield for the traditional system (1,970 kg ha^{-1}) than farms near Afgoi.

These locational grain yield disparities can likely be attributed to locational differences in either farm management or soil chrematistics. For the SATG system, where adequate fertilizer was supplied, these yield differences were most likely caused by locational differences in plant population. A regression analysis on the relationship between plant population at harvest and grain yield demonstrated that when adequate fertilizer was supplied, as was the case for the SATG system, greater plant populations at harvest resulted in higher yields. This relationship was not observed when soil fertility was lacking, as was the case for the traditional system (Figure 2). Similarly, planting date may influence grain yield when other constraints are satisfied but is not a yield driver in traditional, fertility limited systems (Figure 3). These results indicate that increasing plant population or planting early alone will not result in higher grain yields if fertility is lacking, and that fertility is likely the greatest yield constraint in the irrigated maize production systems of the Lower Shebelle. It also suggests that the low plant populations and elastic planting dates employed by Somali farmers in their traditional production system are appropriate given their soil fertility limitations. It should be noted, however, that these trials were not designed to explicitly study plant population or planting date effects on yield and further research is merited.

The locational differences observed for the traditional system, therefore, were likely driven by differences in soil

Table 1. Crop management system, location and season differences for maize grain and stover yield and plant population at harvest in the Lower Shebelle region of Somalia.

System	Location	Season	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest plant population (plants ha^{-1})
SATG	Afgoi	Gu	3460	12150	45600
Traditional	Afgoi	Gu	2180	8960	38300
SATG	Awdhegle	Gu	5130	12860	51300
Traditional	Awdhegle	Gu	3040	7930	32600
SATG	Afgoi	Deyr	3570	14580	35600
Traditional	Afgoi	Deyr	1570	7620	30700
SATG	Awdhegle	Deyr	4370	12320	39000
Traditional	Awdhegle	Deyr	1970	6380	27600
Management system averaged across season					
SATG	Afgoi	—	3510	13370	40600
Traditional	Afgoi	—	1870	8290	34500
SATG	Awdhegle	—	4750	12590	45100
Traditional	Awdhegle	—	2510	7160	30093
Management system averaged across location					
SATG	—	Gu	4290	12500	48400
Traditional	—	Gu	2610	8440	35400
SATG	—	Deyr	3970	13450	37300
Traditional	—	Deyr	1770	7000	29200
Location and season averaged across management system					
—	Afgoi	Gu	2820	10550	41900
—	Awdhegle	Gu	4080	10390	41900
—	Afgoi	Deyr	2570	11100	33200
—	Awdhegle	Deyr	9350	93500	33300
Management system averaged across location and season					
SATG	—	—	4130^{a}	12980^{a}	42800^{a}
Traditional	—	—	2190^{b}	7720^{b}	32300^{b}
Location averaged across management system and season					
—	Afgoi	—	2690^{B}	10830^{A}	37500
—	Awdhegle	—	3630^{A}	9870^{B}	37600
Season averaged across management system and location					
—	—	Gu	3450^{aa}	10470	41900^{aa}
—	—	Deyr	2870^{bb}	10230	33200^{bb}
			Summary statistics		
Tukey's HSD (System)			213	856	1217
Tukey's HSD (Location)			213	856	NS
Tukey's HSD (Season)			213	NS	1217
R^2			0.71	0.54	0.75
CV (%)			29	36	14
System (P>f)			<.0001	<.0001	<.0001
Location (P>f)			<.0001	0.0294	0.9344
Season (P>f)			<.0001	0.5700	<.0001
Season × Location (P>f)			0.0023	0.0692	0.9055
Location × System (P>f)			0.0058	0.6803	<.0001
Season × System (P>f)			0.0184	0.0065	<.0001
Season × Location × System (P>f)			0.3397	0.1130	0.0506

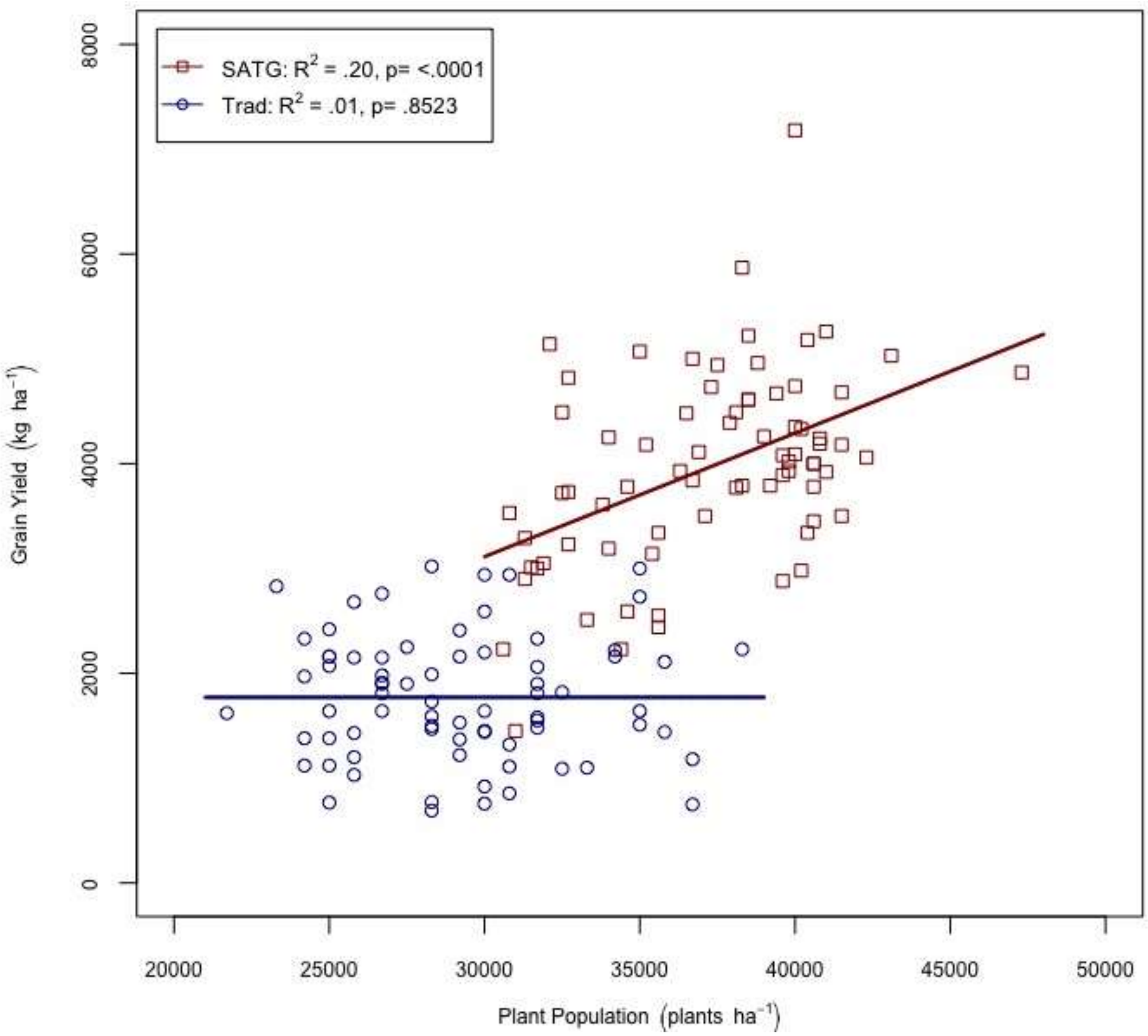


Figure 2. Relationship between maize plant population at harvest and grain yield on seventy-seven farms in the Lower Shebelle region of Somalia during the 2014/15 Deyr season.

fertility inherent in each location. Previous research into the soil properties of the Lower Shebelle saw significant locational differences in soil sand proportion and electrical conductivity (EC) values. Soils near Afgoi had nearly twice as much sand and a ten-fold higher EC than those near Awdhegle (Gavin et al., 2018). While the locational differences in sand proportion are unlikely to have majorly influenced plant growth in the heavily clay soils of the Lower Shebelle, the high EC values observed near Afgoi could have adversely affected crop yields by inhibiting plant development (Maas et al., 1983; Farooq et al., 2015).

Locational differences in irrigation ability could have also contributed to the locational differences in grain yield observed in this trial; farms near Awdhegle typically use gravity to move their irrigation water, whereas farms near Afgoi must often rely on diesel pumps to move water (Haji, 2017). As a result, irrigation can be costlier for farms near Afgoi, and farmers near Awdhegle may have been able to irrigate more frequently in this trial. These locational differences in irrigation practice could also be a driver of locational differences in soil EC (Jianjun et al., 2016).

When grain yield data were compared across seasons, significant interactions were observed (Table 1). The 2014 Gu season saw higher grain yields than the 2014/15 Deyr season. This was true for both management systems, but this difference was much greater for the traditional system. While the grain yield of SATG system was 8% higher in the 2014 Gu season (4,290 kg ha^{-1})

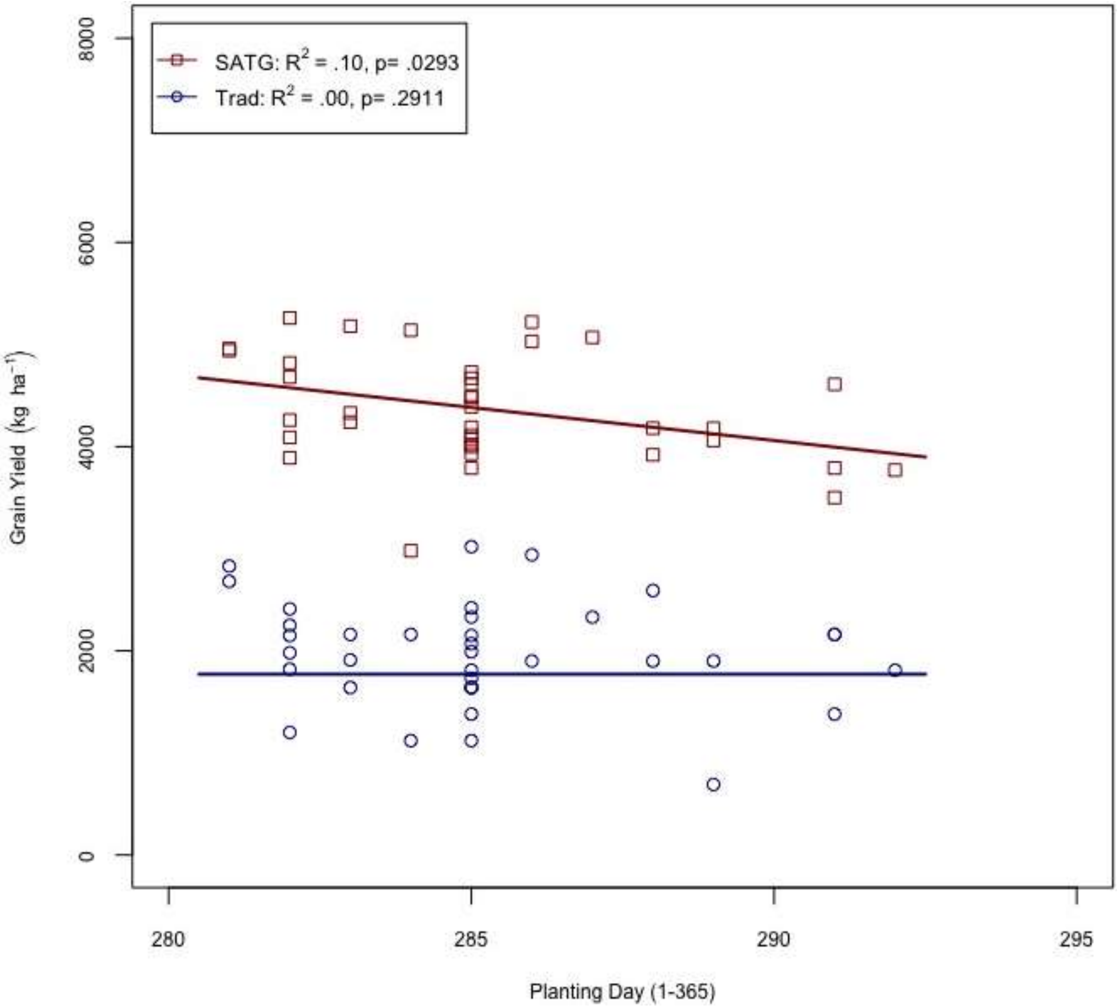


Figure 3. Relationship between maize planting date (January 1st = 1) and grain yield on thirty-four farms near Awdhegle in the Lower Shebelle of Somalia during the 2014/15 Deyr season.

than in the 2014/15 Deyr season, this difference was 47% for the traditional system (2,610 kg ha^{-1}). These differences can probably be best explained by seasonal differences in plant population for the SATG system and harsher growing conditions for the traditional system. This is because, while increasing the plant population appears to increase yields when soil fertility is adequate, that does not appear to be the case under native soil fertility constraints (Figure 2), and with the Deyr being a much drier growing season, the increased soil fertility of the SATG system may have helped to alleviate drought stress through increased root growth (Hu and Schmidhalter, 2005).

A significant season by location interaction also manifested for grain yield (Table 1). In both seasons, grain yields were higher on farms near Awdhegle than on farms near Afgoi, but this difference was much greater in the 2014 Gu season than in the 2014/15 Deyr season. Across both management systems, farms near Awdhegle saw 45% higher grain yields (4,080 kg ha^{-1}) than farms near Afgoi in the 2014 Gu season and just 23% higher grain yields in the 2014/15 Deyr season (3,170 kg ha^{-1}). The 2014 Gu season may have seen a greater magnitude difference between locational grain yields, because the locational differences in harvested plant population were much greater in that season.

When the seasonal datasets were combined, a significant interaction between season and management system was observed, but this interaction was due to differing magnitudes of system effect in each season and not inconsistencies in system effects across seasons. Across both seasons, the grain yield of the SATG system (4,130 kg ha^{-1}) was 89% greater than that of the traditional system, with this difference being 65% in the 2014 Gu season (4,290 kg ha^{-1}) and 124% in the 2014/15 Deyr season (3,970 kg ha^{-1}). These seasonal differences can likely be attributed to the abovementioned seasonal differences in climate, recommended plant population, and perhaps soil fertility amendments.

Stover yield

While stover yields are here reported, these numbers should be viewed as suspect because of the abovementioned difficulties standardizing stover moisture contents. With this in mind, the stover yield trends observed in these trials still provide meaningful information about maize production in the Lower Shebelle. In the 2014/2015 Deyr season, the stover yield of the SATG system (13,500 kg ha^{-1}) was 92% greater than that of the traditional system, with farms located near Afgoi producing more stover than those near Awdhegle. Much of this increase in stover production can be attributed to the significantly higher plant populations recommended by the SATG system. Across seasons and management systems, the 2014 Gu season saw greater stover yields than the 2014/15 Deyr season, with seasonal differences likely resulting from plant population at harvest and moisture content differences at the time of weighing. Across both seasons, both locations, and both systems, the harvest index (HI), a measure of crop efficiency (Hay, 1995), ranged from 17% for the traditional system on farms near Afgoi during the 2014/15 Deyr season to 29% for the SATG system on farms near Awdhegle during the 2014 Gu season. In part, these low HIs can be attributed to the unimproved, open-pollinated variety of maize being grown in the region.

Plant population at harvest

In the 2014/15 Deyr season, the SATG system had a 28% greater plant population at harvest (37,300 plants ha^{-1}) than the traditional system (Table 1). The magnitude of this difference, however, varied significantly between locations. On farms located near Afgoi, the plant population at harvest of the SATG system (35,600 plants ha^{-1}) was 16% greater than the traditional system. On farms near Awdhegle, this difference was 41% (SATG = 39,000 plants ha^{-1}). Both lower than expected SATG system plant populations at harvest and greater traditional system plant populations at harvest on farms near Afgoi contributed to this locational interaction. The plant population at harvest of the SATG system was 9% lower in Afgoi than in Awdhegle, while the traditional system plant population at harvest was 11% higher.

For both the SATG and traditional management systems, higher plant populations at harvest were observed in the 2014 Gu season than in the 2014/15 Deyr season. The plant population at harvest for the SATG system was 48,400 plants ha^{-1} in the 2014 Gu season, 30% higher than in the 2014/15 Deyr season. This difference was 21% for the traditional system, with the traditional system having 35,400 plants ha^{-1} at harvest in the 2014 Gu season. Though the plant populations at harvest of the SATG system were greater than those of the traditional system in both seasons, these differences were narrower in the 2014/15 Deyr season, which resulted in a significant season by management system interaction. Seasonal differences in plant population at harvest for the SATG system can be explained by SATG's decision to increase their within-row plant spacing recommendation from 0.25 m in the 2014 Gu season to 0.30 m in the 2014/2015 Deyr season. For the traditional system, seasonal differences in plant population at harvest are more difficult to explain. It is possible that, as the Deyr season is the shorter secondary growing season with less precipitation and warmer temperatures, farmers have learned to reduce their planting populations in order to ensure maximum time and resource efficiency.

Locational differences in plant population were more consistent across seasons, and no significant interaction was observed. In both seasons, the plant populations of the SATG system and those of the traditional system were much more closely aligned on farms near Afgoi than on farms near Awdhegle. Traditionally, farmers near Afgoi appear to plant more maize per hectare than those near Awdhegle.

Economic analysis

The abovementioned data demonstrate that the SATG system increased maize yields in the Lower Shebelle region during both the 2014 Gu and 2014/15 Deyr seasons, but because the costs associated with new agricultural technologies often hamper their adoption (Muzari et al., 2012), it is also important to examine the economic viability of the SATG system. When production cost and revenue data were examined in the 2014/15 Deyr season, statistically significant differences were observed between the total revenues, net revenues, capital costs, labor costs, and growing costs of the SATG and traditional management systems (Table 2). In each case, the SATG system was costlier and elicited greater economic returns than the traditional system. The land preparation, planting, and harvest costs were not found to be significantly different between the two management systems. This is likely because maize farmers in the Lower Shebelle rented tractor equipment at a daily rate and relied heavily on family labor at planting and harvest time, regardless of whether the SATG or traditional system was employed.

The differences observed between the net revenue and cost of the two management systems are of particular importance to farmers. In the 2014/15 Deyr season, the growing costs of the SATG system ($540 ha^{-1}) were 671% greater than the traditional system (Table 2). This cost, however, was more than compensated for by a 143% increase in net revenue over the traditional system

Table 2. Cost and revenue differences in USD between two maize crop management systems in the Somali 2014-15 Deyr season.

System	Total revenue	Net revenue	Capital cost	Labor cost	Preparation cost	Planting cost	Growing cost	Harvest cost
	($ ha^{-1})							
SATG	1277^{A}	362^{A}	390^{A}	525^{A}	178^{NS}	85^{NS}	540^{A}	112^{NS}
Traditional	592^{B}	149^{B}	186^{B}	256^{B}	178^{NS}	82^{NS}	70^{B}	112^{NS}
HSD	77	82	4	16	NS	NS	17	NS
R^2	0.84	0.31	0.99	0.95	—	—	0.98	—
CV%	16	63	3	8	—	—	11	—
System (P>f)	<0.0001	<0.0001	<0.0001	<0.0001	NS	NS	<0.0001	NS

($149 ha^{-1}). Perhaps of more importance is that the SATG system was highly reliable. In the 2014/2015 Deyr season, the SATG system did not result in negative net revenues on any of the thirty-one farms examined, whereas the traditional system resulted in economic losses for 23% of the participating farmers. The range of net revenues for the SATG system was also 8% narrower than that of the traditional system. With less variability in expected income, farmers can better plan for the future and improve long-term livelihood outcomes via investments in social capital. These economic data further bolster the argument for wide-scale implementation of the SATG system in the Lower Shebelle region.

Conclusion

Somalia was thrust into a state of political instability and conflict when the Siad Barre government collapsed in 1991. This maize cropping system investigation represented a unique attempt to both perform applied scientific research and build domestic research capacity. Led by SATG in the 2014/15 Deyr season, this on-farm research demonstrated that Somali maize farmers can increase yields (124%) and profits (143%) by implementing the best management practices being recommended by SATG.

These conclusions echo those of maize research performed by SATG in the 2014 Gu season (Gavin et al., 2018), but that season was found to have higher grain and stover yields. While far from an exhaustive examination of Somali maize production, this research represents one of the first efforts to perform cropping system and farm-level economic research in Somalia in more than a quarter century. Future efforts should focus on determining optimal irrigation techniques, planting densities, and soil fertility requirements, as well as examining different maize germplasm.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

ACKNOWLEDGEMENTS

This work would not have been possible without the dedicated Somali farmers who participated in this trial or the commitment of the Somali Agriculture Technical Group's staff, especially Mohammed Abdulkadir Abikar. This research was financially supported in part by the United States Agency for International Development (USAID) under the Partnership for Economic Growth (PEG) initiative.

REFERENCES

Asim M, Akmal M, Khattak RA (2013). Maize response to yield and yield traits with different nitrogen and density under climate variability. Journal of Plant Nutrition, 36(2):179-191.

Central Intelligence Agency (CIA) (2017). Somalia. The World Fact Book. Retrieved August 15, 2017. https://www.cia.gov/library/publications/the-world-factbook/

Farooq M, Hussain M, Wakeel A, Siddique KHM (2015). Salt stress in maize: Effects, resistance mechanisms, and management. A review. Agronomy for Sustainable Development, 35(2):461-481.

Famine Early Warning System (FEWS) (2014). Somalia- Food Security Outlook. Retrieved August 16, 2016. http://wwwfews.net/east-africa/somalia/food-security-outlook/august-2014.

Famine Early Warning System (FEWS) (2015). Somali Price Bulletin - January 2015. Retrieved August 18, 2017. http://www.fews.net/sites/default/files/documents/reports/Somalia_2015_01_PB.pdf

Food and Agriculture Organization of the United Nations (FAO). (2012). Somali Agriculture Building Drought Resilience. Somalia Agriculture Issue N°001.
http://www.fao.org/3/a-as782e.pdf

Gadain H, Stevanovic Z, Upton KÓ, Dochartaigh BÉ (2016). Africa Groundwater Atlas: Hydrogeology of Somalia. British Geological Survey. Accessed October 20, 2017. http://earthwise.bgs.ac.ukindex.php/Hydrogeology_of_Somalia

Gavin R, Hussein H, Jelinski N, Porter P (2018). On-farm Irrigated Maize Production in the Somali Gu Season. African Journal of Agricultural Research, 13(19):969-977.

Hay RKM (1995). Harvest index: a review of its use in plant breeding and crop physiology. Annals of Applied Biology 126(1):197-216.

Hu Y, Schmidhalter U (2005). Drought and salinity: a comparison of their effects on mineral nutrition of plants. Journal of Plant Nutrition and Soil Science, 168(4):541-549.

Jianjun J, Ran S, Liu T (2016). Impact of irrigation methods on soil salt content and their differences in whole cotton growing season in arid area of northwest china. Journal of Resources and Ecology, 7(6):453-463.

Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S, Jones R, Kilasara M, Le Roux P, Micheli E, Montanarella L, Spaaragaren O, Thiombiano L, Van Ranst E, Yemefack M, Zougmoré R, (eds.), (2013). Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg, 176 p.

Little PD (2008). Crisis and food security profile: Somalia. Beyond relief: food security in protracted crises. 97-106. ISBN: 978 9 25105 589 2 https://www.researchgate.net/profile/Luca_Russo3/publication/257870568_Beyond_the_blueprint_Implications_for_food_security_analysis_and_policy_responses/links/00b7d525fe017b5a71000000.pdf#page=116

Maas EV, Hoffman GJ, Chaba GD, Poss JA, Shannon MC (1983). Salt sensitivity of corn at various growth stages. Irrigation Science, 4(1):45-57.

Muzari W, Gatsi W, Muvhunzi S (2012). The impacts of technology adoption on smallholder agricultural productivity in sub-Saharan Africa: a review. Journal of Sustainable Development, 5(8):69. ISSN: 1913-9063

Muchiri PW (2007). Climate of Somalia. Technical Report No W-01, FAO-SWALIM, Nairobi, Kenya. http://www.faoswalim.org/resources/site_files/W-01%20Climate%20of%20Somalia_0.pdf

Mwangi WM (1996). Low use of fertilizers and low productivity in sub-Saharan Africa. Nutrient Cycling in Agroecosystems 47(2):135-147.

Overholt WA (2008). Distribution of Major Stem Borers of Maize, Sorghum, Rice and Pearl Millet. In Encyclopedia of Entomology. pp. 1637-1637. Springer Netherlands. https://doi.org/10.1007/978-1-4020-6359-6

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

SAS (2016). Some of the data analysis for this paper was generated using SAS software. Copyright © 2016 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA. https://www.sas.com/

Somali Development Bank (2015). Livestock and Agriculture. Retrieved August 17, 2017. http://www.sodevbank.so/livestock-and-agriculture/

Thirtle C, Lin L, Piesse J (2003). The impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. World Development, 31(12):1959-1975. doi: 10.1016/j.worlddev.2003.07.001

United Nations (2017). UN Operational Rates of Exchange. Retrieved August 15, 2017. https://treasury.un.org/operationalrates/OperationalRates.php

World Bank Group (WBG) (2016). Rural Population (% of Total Population) Somalia. World Bank Open Data. Washington D.C., USA. Retrieved August 18, 2017. https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=SO

World Bank Group (WBG) (2018). Net ODA Received (% of GNI) Somalia. World Bank Open Data. Washington D.C., USA. Retrieved April 9, 2018. https://data.worldbank.org/indicator/DT.ODA.ODAT.GN.ZS?locations=SO

Vol. 13(23), pp. 1186-1197, 7 June, 2018
DOI: 10.5897/AJAR2018.13141
Article Number: 649AB4757312
ISSN: 1991-637X
Copyright ©2018
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Response of taro (*Colocasia esculenyta* (L.)) to variation in planting density and planting dates on growth, radiation interception, corm and cormels yield in Southern Ethiopia

Alemu Dessa[1*], Bizuayehu Tessfaye[2], Walelign Worku[2], Amsalu Gobena[2] and Anne Kathrine Hvoslef-Eide[3]

[1]College of Agriculture and Natural Resource, Dilla University P. O. Box 419, Dilla, Ethiopia.
[2]College of Agriculture, Hawassa Universities, P. O. Box 05, Hawassa, Ethiopia.
[3]Department of Plant Science, Faculty of Biosciences, Norwegian University of Life Sciences (NMBU), P. O. Box 5003, 1432 As, Norway.

Received 23 March, 2018; Accepted 7 May, 2018

Taro production is mainly affected by agroecology, planting time and planting density. To this effect, a field study was conducted to determine influences of planting density and planting dates on growth, radiation interception and yields of taro (*Colocasia esculenyta* (L.)). The experiment was conducted using four levels of planting density (15037, 19607, 26666 and 38461 plants ha^{-1}) and four planting dates from mid-February to mid-April at 21 days interval at Areka and Hawassa locations. SAS statistical software package was used for the analysis of the data derived from the experiment. From the analysis, interaction of location by planting dates significantly ($p<0.01$) influenced date of emergence, stand count and plant height. While, leaf area, leaf area index (LAI) and plant height, were significantly influenced due to location by planting density interactions. However, dry matter production (DMP) was influenced by planting density only. Cumulative interception photosynthetically active radiation (CIPAR), corm weight, cormels number, marketable yield and total yield per plant were significantly ($p\leq0.05$) influenced both by plant density and planting dates. Maximum total and marketable yield were obtained from 15037 plant ha^{-1} at late and early March planting dates. Plant density and planting dates are therefore important agronomic management practices to improve the productivity of taro through enhancing the capacity of plant for light interception, growth and dry matter production.

Key words: Corm, cormels, dry matter, radiation interception, leaf area index (LAI).

INTRODUCTION

In Ethiopia taro (*Colocasia esculenta* (L)) is among the list of major root and tuber food crops that are consumed across the country. The crop is produced on about 52,201 ha of land with 40,600 ton per annum production (CSA, 2011). Since many tropical areas often experience unfavorable environmental conditions, the crop is

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

particularly important for food security to fill seasonal food gaps when other crops are not in the field (Beyene, 2013). In Ethiopia, Taro has extensively been cultivated in dense populated and high rainfall areas of South, Southwest and Western parts of the country (Dagne et al., 2014). Currently, taro production areas are increasing in Ethiopia due to the fact that the level of dependence on sweet potato and enset crop is shifting to maize and taro (Dagne et al., 2014; Tsedalu et al., 2014). Taro crop have multi-fold nutritional advantages; its corms are high in carbohydrate in the form of starch and low in fat and protein (John, 2007). It contains about 7% protein on a dry weight basis. This is more than yam, cassava or sweet potato (FAO, 1999). Its leaf also rich in protein, containing about 23% proteins on a dry weight basis. It is also a rich source of calcium, phosphorus, iron, Vitamin C, thiamine, riboflavin and niacin, which are important constituents of human diet (FAO, 1999; Onwueme, 1999; Ndon et al., 2003). Despite all this nutritional advantages, the current taro production in Ethiopia is very low (7.6 t/ha), compared to other countries like Egypt (31.1 t/ha), Mauritius (11.6 t/ha) (Manner and Taylor, 2011) and Malesia (50 t/ha in low land and 25 t/ha in dry land) (De la Pena and Plucknett, 1972). This indicates the need of further work to improve the situation.

In Ethiopia, farmers undertake taro planting at different times. Some farmers undertake planting at onset of rain (late March to early April); some plant during off season using residual moisture (November to December); some plant in dry season (January to February). But, planting is not common during main rainy season (May to September) (Personal communication with taro Breeder at Areka Agricultural Research Center). In general, there is no scientific recommendation of taro planting time in Ethiopia. On the other hand, the current climate change is another scenario that makes the rainy season unpredictable and shifting of seasons from year to year due to the latitudinal position of the country (Paul and Balaji, 2007).

The impact of climate change does not end in seasonal shifting but also affect both the macro and micro climatic environments. Thus, synchronization of planting dates with current situation may be a vital approach to cope up with the challenge. Concurrently, reports by Mare (2009) revealed that delayed planting negatively affected cormels number per plant and fresh cormels mass. In addition, Mare and Modi (2012) reported that delay in planting significantly decreased starch content on certain cultivars of taro.

On the other hand, radiation is one of the important basic meteorological parameters for crop production. Under favorable conditions, radiation plays a decisive role in vegetative growth and development. Excessive or insufficient exposure of taro crop to radiation was reported to reduce taro productivity (Bernardes et al., 2011). Interception of radiations on leaf surface cannot be controlled but can be manipulated for their maximum use by crop management means. Crop growth can be analyzed in terms of its efficiency to use intercepted radiations and the method has been used in various field crops (Hussain et al., 1998, 1999, 2002; Bernardes et al., 2011).

The fraction of radiation intercepted by crops increases hyperbolically with LAI; in many crops 80-85% of the incident radiation is intercepted when LAI is between 3.0 and 4.0, and 95% when LAI reaches 5.0 (Scott and Jaggard, 1978; Hussain et al., 2002). This shows that establishment of adequate plant canopy has important role on radiation interception and crop biomass production. Thus, the chosen crop spacing is based on the hypothesis that there is optimal plant population density that allows interception of ≥95% of the available photosynthetically active radiation (PAR) to give highest possible yield at specific growth period (Hussain et al., 2002). Purcell et al. (2002) reported that no additional yield advancement with further increase of plant population density can occur because of decrease in radiation use efficiency at higher plant population density. In addition, Maddonni et al. (2001) observed that light interception varied in different row distance and that changes leaf area index. Similarly, planting date has also relation with light interception. Uzun (1996) reported that when planting is commenced earlier than the actual time, plants are exposed to light radiation with a certain leaf area before adverse climate conditions. This is important particularly with respect to light and daily temperature unit accumulated during the growth period. There is also a case in which plant density depends on planting dates. According to Gendua et al. (2001), farmers may consider planting with a wider spacing during cooler months and with a narrower spacing during hotter months to optimize corm size and production. Similarly, reports by Abd-Ellatif et al. (2010) indicated that planting date and intra-row spacing interaction has a significant effect on vegetative growth parameters and total yield in which, early planting dates with closer distances between plants give the highest values for these characters.

In Ethiopia, so far, research on taro is mainly focused on breeding aspects such as germplasm collection, characterization, and selection activities while information on agronomic management such as plant density and planting date is very limited. Thus, information derived from this study expected to supports farmers' decision on planting date and planting density and gives researchers preliminary information for further taro plant eco-physiology studies in tropical environment. Therefore, the current study was initiated with the following objectives:

1. To evaluate the effect of planting density and planting dates on taro growth and canopy light interception
2. To investigate the effect of planting density and planting dates on taro corm and cormels yield and yield

Table 1. Soil physicochemical characteristics of the experimental site.

Location	Physicochemical characteristics							
	pH	Sand (%)	Silt (%)	Clay (%)	Texture	OC (%)	P (ppm)	TN (%)
Areka	5.3	16.9	33	50	Clay	2.3	6.6	0.15
Hawassa	7.6	40.9	29	30	Clay loam	2.8	17.7	0.08

OC: Organic matter content; P: Phosphourus; TN: Total nitrogen.

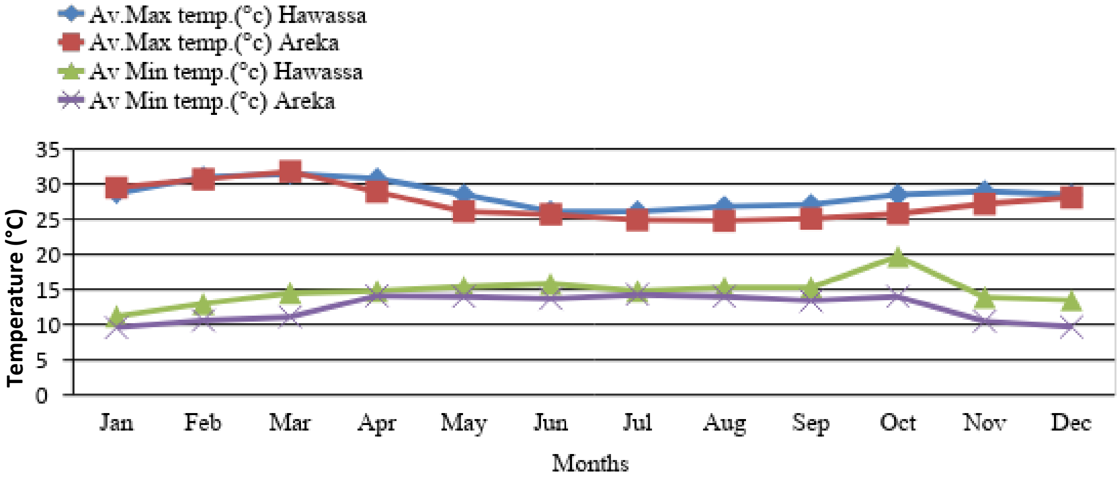


Figure 1A. Mean maximum and minimum temperature of the experimental site during the experimental period.

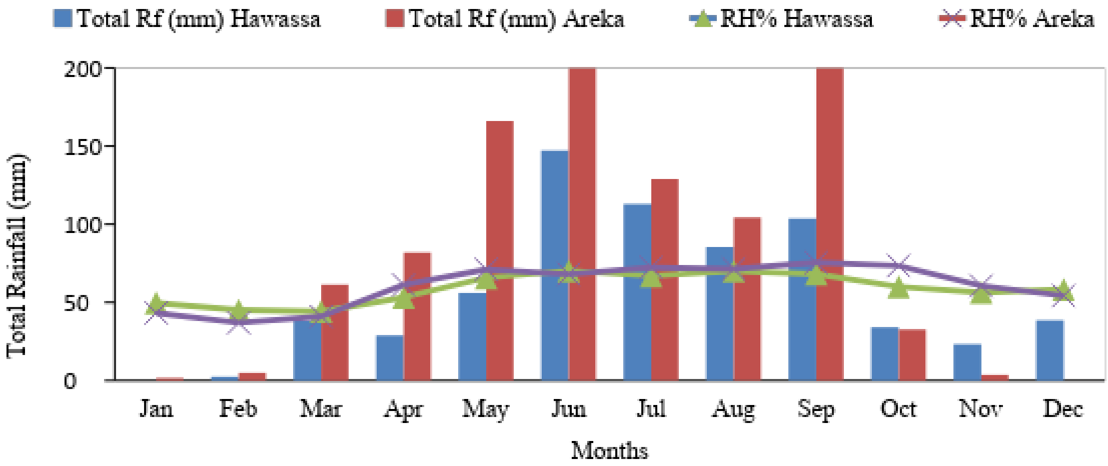


Figure 1B. Total rainfall and RH of the study area during the experimental year.

components

MATERIALS AND METHODS

Experimental sites

The experiment was conducted at Hawassa University (7°03' N latitude and 38°30'E longitude) and Areka Agricultural Research Center (7°06' N latitude and 38°37' E longitude), Southern Ethiopia, from February to December, 2015. Hawassa is located at 1700 m while Areka is located at 1800 m above sea level.

The physicochemical characteristics of the soil of the experimental sits presented in Table 1 are almost similar with the type of soil that suit taro production (Manner and Taylor, 2011).

The average maximum and minimum temperatures during the experimental period were 28.6 and 14.8°C at Hawassa and 26 and 15°C at Areka, respectively (Figure 1A). The total rainfall and relative humidity during the experimental period was also presented in Figure 1B.

Table 2. ANOVA table for date of emergency, stand count, plant height, shoot number, leaf number leaf area, LAI and CIPAR as affected by location, planting density and planting dates.

Sores of variation	Mean sum of square							
	Date of emergency	Stand count (%)	Plant height (cm)	Shoot number	Leaf number	Leaf area	LAI	CIPAR
Location (L)	368.2**	13608.84***	6581.11***	91.83***	3513.11**	4.47*	16.61^{ns}	-
Replication (Rep)	32.4^{ns}	1008.75**	1156.800***	8.43^{ns}	156.58^{ns}	5.02**	24.45*	489301***
Planting density (PP)	34.7^{ns}	47.59^{ns}	762.92***	21.17**	516.99**	5.68**	59.69***	125216**
Planting date (PD)	4282.1***	1907.70***	1039.37***	7.78**	120.99^{ns}	3.46*	15.31^{ns}	79040*
L*PP	65.1^{ns}	137.82^{ns}	454.52**	2.00^{ns}	62.76*	1.68^{ns}	35.68***	-
L*PD	316.5**	1097.34*	569.05***	0.57^{ns}	31.48^{ns}	0.66^{ns}	4.18^{ns}	-
PP*PD	66.6^{ns}	183.43^{ns}	129.69^{ns}	2.45^{ns}	45.32^{ns}	1.08^{ns}	7.72^{ns}	29356
L*PP*PD	69.2^{ns}	212.17^{ns}	105.94^{ns}	2.04^{ns}	45.38^{ns}	0.88^{ns}	7.28^{ns}	-

*, **and *** where significant at $P<0.05$, $P<0.01$ and $P<0.001$, respectively.

Treatments and experimental design

Four levels of planting density (15037, 19607, 26666 and 38461 plant ha^{-1}) and planting dates consisting February 14 (Mid-February), March 5 (Early March), March 26 (Late March), and April 16 (Mid-April) at 21 days interval were used as treatments at two locations (Areka and Hawassa). The experiment was conducted in RCBD factorial arrangement using three replications. Uniform corm size (250-300 g) of improved taro cultivar (Boloso-1) was used as a planting material.

Agronomic practices

The lands for the experiment were prepared in January and the first planting was made on 13th and 16th February 2015 at Areka and Hawassa respectively and the other three successive plantings were done at 21 days interval at each location. Equal does of P and N at 200 kg ha^{-1} were applied in the form of Triple Super Phosphate (TSP) and urea (CH_4N_2O). The nitrogen fertilizer was applied in spilt application at planting and 50 days after planting (Tadesse and Tesfaye, 2010). All agronomic managements were made manually as required during the growing period.

Data collection

Random sample of five plants from the three inner rows of each experimental plot were considered to determine plant height, shoot number per plant, number of leaf per plant, leaf area and leaf area index. To determine corm/cormels yield and other yield parameters, only three central rows were harvested and yield parameters such as number, length, diameter and weight of corm and cormels, marketable and total yield were recorded. Marketable yield was determined based on size and physical quality (Marketable = corm/cormels free from mechanical and pest injury, undeformed shape and acceptable size (>100 g)). All the vegetative growth data were collected during maximum physiological growth stage from 145 to 150 days after planting while the yield data were collected after all the vegetative growth are completed and the above ground biomass withered.

The radiation interception was evaluated for Hawassa site only. The data for cumulative Intercepted Photosynthetic Active Radiation (CIPAR) was determined from the incoming global radiation and ground cover data collected at ten days interval throughout growing period. Accordingly, the fraction of incoming Photosynthetic Active Radiation (PAR) intercepted by the canopy was recorded by measuring the ground cover at ten days interval using grids of 40×65, 50×75, 60×85 and 70×95 cm divided into 100 equal rectangles for planting densities of 38461, 26667, 19607 and 15037 plants per hectare, respectively. At every ten days, the grids were put between rows and three measurements were taken at each plot by counting the number of rectangles more than half filled with green leaf and the fraction of intercepted PAR (f) by the canopy was determined assuming 1:1 relationship between percentage of ground cover and percentage of intercepted radiation (Tsegaye and Struik, 2003; Worku and Demissie, 2012):

$$(IPARi)=(PARi\times GCi)$$

Where: IPARi = amount of incoming PAR intercepted at ith sampling date; PARi = recorded PAR above the canopy at ith sampling date, and GC_i=ground cover of the crop at ith sampling date

The CIPAR during the growth period was determined by summing up fortnightly intercepted radiation as follows:

$$(CIPAR)=n[(IPARn.i+IPARn)/2](tn-tn.i)$$

Where, $IPAR_{n.i}$ is IPAR at sampling time $t_{n.i}$ and $IPAR_n$ is IPAR at sampling time $t_{n.}$

Statistical analyses

Data were analyzed using the general linear model procedure of SAS statistical software. Means were separated using Fisher's Least Significant Difference (LSD) test at 5% significance level.

RESULTS AND DISCUSSION

The analysis of variance and statistical significance levels of different growth parameters and CIPAR is summarized in Table 2. The result indicates that most of the growth parameters such as plant height, shoot number, leaf number, leaf area and leaf area index are significantly affected by main effects and interaction effects such as

Table 3. Summary of ANOVA table for corm number, cormels number, corm weight, cormels weight, corm length, corm diameter, marketable yield, and total yield of taro as affected by location, planting density and planting dates.

Sores of variation	Mean sum of square								
	Dry matter (kg plant^{-1})	Corm number plant^{-1}	Cormels number plant^{-1}	Corm weight (kg plant^{-1})	Cormels weight (kg plant$^{-1)}$	Corm length	Corm diameter	Marketable yield (kg plant^{-1})	Total yield (kg plant^{-1})
Location	-	4.03**	17.91*	2.49**	1.86***	1224.87***	13.11**	8.65***	7.46***
Replication	0.16**	0.12^{ns}	1.57^{ns}	0.29**	0.42**	6.12^{ns}	1.47*	1.42***	1.41*
Planting density (PP)	0.11**	0.48^{ns}	8.02*	0.19**	0.36**	8.59*	0.18^{ns}	1.07**	2.30**
Planting date (PD)	0.03^{ns}	1.27*	5.51^{ns}	0.25***	0.19^{ns}	11.24*	1.29^{ns}	0.51*	0.71^{ns}
L*PP	-	0.73^{ns}	1.90^{ns}	0.03^{ns}	0.02^{ns}	0.65^{ns}	0.61^{ns}	0.02^{ns}	0.28^{ns}
L*PD	-	0.53^{ns}	3.09^{ns}	0.03^{ns}	0.05^{ns}	1.80^{ns}	0.54^{ns}	0.014^{ns}	0.03^{ns}
PP*PD	0.03^{ns}	0.49^{ns}	2.25^{ns}	0.07^{ns}	0.05^{ns}	1.51^{ns}	0.23^{ns}	0.20^{ns}	0.26^{ns}
L*PP*PD	-	0.22^{ns}	3.21^{ns}	0.03^{ns}	0.06^{ns}	3.60^{ns}	0.34^{ns}	0.12^{ns}	0.31^{ns}

*, **and *** where significant at P<0.05, P<0.01 and P<0.001, respectively.

location, planting density, planting dates, location by planting density and location by planting dates (Table 2). Similarly, in Table 3 the ANOVA results and significance level of main and interaction effects of treatments on taro corm and cormels yield and yield components are summarized (Table 3). The results of the interaction effects of all the growth and yield parameters considered in the study are discussed under their respective sub head in this section of the paper.

Date of emergence and stand count (%)

Date of emergence and stand count percentage were affected significantly (p<0.01) by interaction of location by planting dates. Early emergences (33.0 days after planting) and higher stand counts (91.7%) were recorded from late March planting at Areka (Table 4). In contrast, late emergence (65.3 days) and minimum stand count (47.6%) were recorded from mid-February at Areka and mid-April at Hawassa, respectively. The main reason for such variation in emergence date and stand count were due to the variability in soil texture that could affect the soil moisture holding capacity as the soil texture of the locations were 50% clay at Areka and 30% clay at Hawassa (Table 1). Similarly, the variation of rainfall between the two locations take the share for the result as the total Rainfall at Areka is exceeding that of Hawasssa (Figure 1B).

Generally, early planting in mid-February delayed the emergence of taro for more than 60 days at both locations (Table 4) whereas, late planting in late March and mid-April during onset of rainy season accelerated date of emergency both at Areka and Hawassa almost by 50 to 48% and 34 to 45%, respectively. The result assures the importance of available moisture for emergence and successive plant stand in the field as the rain was very low during February, and March at both locations (Figure 1B). The corm dormancy may also be another expected reason for such delays of the emergency as corms can remain underground and survive during unfavorable environmental conditions (Onwueme, 1999; Safo-Kantaka, 2004). On the other hand, early emergency and relatively effective plant stand coincide at Areka in late march planting. That was mainly due to availability of moisture. Though, the onset of rainfall in both site was parallel, Areka site received relatively more amount of rainfall compared to Hawassa. In addition, Areka soil texture supported to conserve moisture for emergency and successive plant stands.

Plant height

Plant height was influenced by both planting density and planting dates at the two locations. In which plant height increased as planting density increasing at both locations (Table 5) and maximum plant heights (103.71 and 82.71 cm)

Table 4. Interaction effect of location by planting dates on date of emergence and stand count.

Location	Planting date	Date of emergence	Stand count (%)
Areka	Mid-February	65.3^{a}	74.9^{b}
	Early March	42.5^{c}	87.3^{a}
	Late March	33.0^{d}	91.7^{a}
	Mid-April	34.2^{d}	59.2^{cd}
Hawassa	Mid-February	61.5^{a}	62.3^{c}
	Early March	54.5^{b}	52.4^{cd}
	Late March	40.8^{c}	55.6^{cd}
	Mid-April	33.8^{d}	47.6^{d}
Mean		45.7	66.4
LSD5%		5.95	12.3
CV		16.0	22.7

Table 5. Interaction effect of location by planting density on plant height.

Location	Planting density (plant/ha)	Plant height (cm)
Areka	15037	82.56^{c}
	19607	93.311^{b}
	26667	102.02^{ab}
	38461	103.71^{a}
Hawassa	15037	78.33 ^{c}
	19607	76.30^{c}
	26667	78.03^{c}
	38461	82.71^{c}
Mean		87.12
LSD5%		9.96
CV		14.1

were recorded from maximum plant density (38461plants ha^{-1}) at both Areka and Hawassa, respectively. Form the interaction of location by planting dates maximum plant height (106.4 m) was recorded at Areka from late March planting (Table 6).

Similar result was reported by Abd-Ellatif et al. (2010) on taro, Sener et al. (2004) on maize (*Zea mays*) and in pea (*Pisun sativum*) by Saiful et al. (2002) in which plant height was increased with planting density. The result may be attributed to increased competitions for sun light radiation in higher planting density as well as an adaptation mechanism to increased level of mutual shade. However, an opposite result was also reported in pigeon pea (*Cajanus cajan*)) by Worku and Demissie (2012), in which plant height has decreased with increasing planting density. Early studies on potato crop by Allen and Wurr (1973) also revealed that planting density significantly increased the height of main stem, in which they had justified further competition for more light interception.

Shoot and leaf number per plant

Number of shoot per plant was influenced by planting density and location, but not by planting dates. Number of shoot declined as planting density increased and maximum number of shoot per plant (8.4) was recorded from the minimum planting density (15037 plant ha^{-1}), whereas minimum number of shoot per plant (6.2) was obtained from the maximum planting density (38461 plant ha^{-1}) (Table 7). Likewise, Gendua et al. (2000) and Tsedalu et al. (2014) reported the same result on taro and Masariramb et al. (2012) on potato. This could be due to competition for light radiation and limited soil nutrient in higher planting density per unit area.

Like that of shoo number, leaf number per plant was significantly ($p<0.01$) affected by planting density and location but not by planting dates. Leaf number per plant declined against increasing planting density (Table 7). The maximum leaf number per plant (34.6) was recorded from the minimum planting density (15,037 plants ha^{-1})

Table 6. Interaction effect of location by planting dates on plant height.

Location	Planting date	Plant height (cm)
Areka	Mid-February	88.5^{b}
	Early March	102.0^{a}
	Late March	106.4^{a}
	Mid-April	84.7^{bc}
Hawassa	Mid-February	78.8^{cd}
	Early March	73.7^{d}
	Late March	85.7^{bc}
	Mid-April	77.2^{cd}
Mean		87.12
LSD5%		9.5
CV		13.4

Table 7. Effect of location and planting density on shoot number, total leaf number, leaf area and leaf area index per plant.

Location	SHN	LN	LA	LAI
Areka	6.4^{b}	23.2^{b}	2.8^{b}	7.6^{a}
Hawassa	8.3^{a}	35.2^{a}	3.2^{a}	6.7^{a}
LSD5%	0.7	3	0.4	NS
Planting density				
15037	8.4^{a}	34.6^{a}	3.49^{a}	5.3^{c}
19607	7.8^{ab}	30.9^{ab}	3.2^{a}	6.8^{b}
26667	6.9^{bc}	27.3^{bc}	3.0^{ab}	7.5^{b}
38461	6.2^{c}	23.9^{c}	2.4^{b}	9.1^{a}
Mean	7.3	29.2	3.0	7.17
LSD5%	1.04	4.2	0.61	1.5
CV	24.6	25.2	35.1	36.4

SHN = Shoot number; LN=Leaf Number; LA=Total leaf area per plant; LAI = Total leaf area index, per plants.

(Table 7). Like that of shoot number, leaf number per plant declined against planting density. However, Tsedalu et al. (2014) reported that, plant density has no significant effect on leaf number per plant, but, similar with the current result, Abd-Ellatif et al. (2010) reported most of the vegetative growth including leaf number per plant influenced by planting density. Though, unlike the current result they reported that most of vegetative growth parameters including leaf number per plant increased with increasing plant density.

Leaf area and leaf area index

Leaf area per plant was affected by location, planting density and planting dates. Maximum leaf area (3.2 m^{2}) was recorded at Hawassa. Leaf area per plant declined with increasing planting density with maximum leaf area per plant (3.49 m^{2}) being recorded from the minimum density (15037 ha^{-1}) (Table 7). The reason behind this result is the limited resource availability for each plant as plant density increased limiting the amount of assimilates available for leaf development. Similar result is also reported on pigeon pea by Worku and Demissie (2012). From planting dates, Late March planting significantly influenced the leaf area compared to other planting dates. Similarly, Mare (2009) also reported that leaf area per plant was affected by planting dates. Early investigation by Nanda et al. (1995) also indicated that early planting of brassica species significantly increased leaf number per plant than the same species planted late. In this study, late March planting seems appropriate time as early emergency and maximum plant stand were recorded particularly at Areka location. That may aid for maximum interception of light and subsequent vegetative growth. Comparable report by Wajid et al. (2004) also

Table 8. Effect of planting dates on leaf area per plant.

Planting date	LA (m^2)
Mid-February	2.9^b
Early March	2.7^b
Late March	3.6^a
Mid-April	2.9^b
Mean	3.00
LSD	0.61
CV%	35.08

Means within a column followed by the same letter (s) are not significantly different

Table 9. Interaction effect of location and planting dates on leaf area index of taro.

Location	Planting density (plant/ha)	LAI
Areka	15037	4.4^c
	19607	5.7^{bc}
	26667	7.9^{ab}
	38461	9.0^a
Hawassa	15037	6.1^{bc}
	19607	9.4^a
	26667	5.8^{bc}
	38461	9.1^a
Mean		7.2
LSD5%		2.2
CV		37.0

Table 10. Effect of planting density on dry matter production and cumulative intercepted photosynthetic radiation (CIPAR MJ m^{-2}).

Planting density (plant/ha)	DMpg/plant	CIPAR MJ m^{-2}
15037	0.58^a	344.00^c
19607	0.48^{ab}	358.19^{bc}
26667	0.44^b	393.05^{ab}
38461	0.37^{bc}	414.83^a

indicate that early sowing intercepted more PAR than the late sowing probably due to longer duration in wheat under semi-arid conditions.

LAI was influenced by interaction effects of planting density and location (Table 2), but not by location and planting dates independently (Table 8). Unlike LA, LAI increased with increasing density (Table 7). From interaction of location by planting density the highest LAI (9.0 and 9.1) was recorded from the maximum planting density (38461 ha^{-1}) at both Hawassa and Areka respectively (Table 9) that was because of bulky leaf number contribution from large number of plants per unit area. Similarly, Tsedalu et al. (2014) reported maximum LAI per plant from maximum plant density in taro planting material type and population density study; Zhou et al. (2011) also found out maximum LAI in narrow plant spacing of soybean crop spacing investigation. Correspondingly, in wetland-grown taro plant populations and seedbed type studies LAI was increased with increasing density (Tumuhimbise et al., 2009).

Light interception and dry matter production

CIPAR and dry matter production (DMP) were influenced by planting density (Tables 2 and 3). CIPAR increased with increasing planting density but, dry matter production per plant decreased as planting density increased (Table 10).

Table 11. Effect of planting dates on cumulative interception photosynthetically active radiation (CIPAR MJ m^{-2}).

Planting date	CIPAR MJ m^{-2}
Mid-February	382.63^{ab}
Early March	363.33^{b}
Llate March	411.27^{a}
Mid-April	352.84^{b}
Mean	377.518
LSD	4250
Cv%	13.5

Table 12. Effect of planting dates on number of corm per plant, weight of corm, number of cormel, weight of cormel, Corm and cormel length (cm) and diameter (cm), marketable yield and total yield.

Location	Corm number	Corm weight (kg/plant)	Cormels number	Cormels weight (kg/plant)	Corm length (cm)	Corm diameter (cm)	Marketable (kg/plant)	Total yield (kg/plant)
Areka	2.24^{a}	0.96^{a}	6.4^{a}	0.9^{a}	18.7^{a}	7.56^{b}	1.9^{a}	2.1^{a}
Hawassa	1.83^{b}	0.64^{b}	5.5^{b}	0.7^{b}	11.5^{b}	8.3^{a}	1.3^{b}	1.5^{b}
LSD5%	0.22	0.08	0.7	0.11	0.74	0.27	0.17	0.22
Planting dates								
Mid-February	1.9^{bc}	0.8^{b}	6.5	0.9	14.8^{b}	7.76^{b}	1.65^{a}	1.9^{ab}
Early March	2.3^{a}	0.9^{a}	6.1	0.8	14.9^{b}	7.95^{ab}	1.66^{a}	1.9^{a}
Late March	2.1^{ab}	0.9^{a}	5.7	0.7	16.1^{a}	8.25^{a}	1.67^{a}	1.9^{a}
Mid-April	1.8^{c}	0.7^{b}	5.3	0.7	14.6^{b}	7.76^{b}	1.37^{b}	1.6^{b}
LSD	0.31	0.12	NS	NS	1.04	0.38	0.24	0.31
Cv%	26.3	24.4	29.2	34.9	12.0	8.2	25.9	29.9

On the other hand, DMP were not influenced by planting dates except the CIPAR (Table 11) where maximum CIPAR was recorded from late March planting but, significant variation was not observed among the other planting dates (Mid- February, Early march and Mid-April).

CIPAR increased with increasing planting density whereas, dry matter production decreased against planting density. However, Oluwasemire and Odugbenro (2014) in soya bean reported that higher solar radiation intercepted increased radiation use efficiency (RUE), and dry matter production under uniform planting density. That could be due to the high competition and shading effect in high planting density. Similar result was also reported by Macanawai et al.(2012) indicating that the shading effect from crops and other weeds would reduce light intensity within the crop and the reduction in biomass production.

Corm and cormels number per plant

Corm number per plant was influenced by location and planting dates (Table 3). Maximum corm numbers per plant (2.24 and 2.3) was recorded from Areka location and Early March planting respectively (Table 12). On the other hand, cormels number per plant was affected by location and planting density.

Maximum cormels number per plant (6.2 and 6.4) recorded from 26667 and 15037 plant ha^{-1} respectively. The lowest number of cormels per plant (5.1) was recorded from the maximum planting density (38461 plant ha^{-1}) (Table 13). Masariramb et al. (2012) reported that in potato crop tuber numbers were significantly affected by plant population density, in which lower number of tubers per plant was recorded from the highest density.

Though, in the current study cormels number was not influenced by planting dates, Mare (2009) reported that the number of cormels per plant significantly decreased when planting date was delayed. In the same way, Abd-Ellatif et al. (2010) also reported that early planting dates gave the highest values of weight of corm and cormels per plant under irrigation condition.

Table 13. Effect of planting density on corm number and weight per plant, and cormels, number and weight per plant , corm and cormels length and diameter, marketable yield and total yield per plant.

Planting density	Corm number	Corm weight (kg/plant)	Cormels number	Cormels weight (kg/plant)	Corm length (cm)	Corm diameter (cm)	Marketable yield (kg/plant)	Total yield (kg/plant)
15037	2.0	0.9^{a}	6.2^{a}	0.9^{a}	15.8	7.94	1.8^{a}	2.2^{a}
19607	2.2	0.8^{a}	6.0^{ab}	0.8^{a}	15.1	7.88	1.6^{ab}	1.8^{b}
26667	2.0	0.8^{ab}	6.4^{a}	0.8^{ab}	15.1	7.86	1.6^{b}	1.7^{bc}
38461	1.9	0.7^{b}	5.1^{b}	0.6^{b}	14.3	8.05	1.3^{c}	1.5^{c}
Mean	2.0	0.80	5.9	0.8	15.1	7.93	1.59	1.81
LSD	NS	0.1	1.2	0.2	NS	NS	0.24	0.31
Cv%	26.3	24.4	29.2	34.9	12.0	8.2	25.9	29.9

Corm and cormels weight per plant

Corm weight per plant was significantly influenced by location, planting density and planting dates (Tables 12 and 13). Maximum corm weight (0.96, 0.90 and 0.89 kg plant^{-1}) was recorded from Areka, 15037 plant ha^{-1} and early and late March planting, respectively. Corm weight per plant decreased as planting density increased; the minimum corm weight per plant, 0.69 kg plant^{-1}, was recorded from 384616 plants ha^{-1} (Table 13).

On the other hand, cormels weight per plant was affected by planting density and location but not by planting date (Tables 12 and 13). The highest weight of cormels per plant was recorded from the minimum planting density (15037 plant ha^{-1}) (Table 13).

Similar finding was also reported by Tsedalu et al. (2014) in which large corm weight per plant is recorded from the lowest planting density. Similarly, Abd-Ellatif et al. (2010) found out that increasing the spacing between plants from 20 to 50 cm significantly increased the weight of corm and cormels per plant. This could be due to the fact that an optimum planting density allows efficient utilization of soil nutrient and maximum light interception for more photosynthesis and dry matter accumulation in their storage organs.

Corm length and diameter

Corm length and diameter per plants were not influenced by planting density but by planting dates and location (Tables 12 and 13). Maximum corm length (18.66 cm) and diameter (8.3 cm) were obtained from Areka and Hawassa respectively. The result was similar with the result of Tumuhimbise et al. (2009) in which they found both corm parameters were not significantly influenced by planting density. However, Tsedalu et al. (2014) reported differences in mean corm length per plant due to plant density in which they found the highest mean corm length from the lowest plant density. In potato tuber, similar result was also reported by various authors in which average tuber size has been shown to decrease nonlinearly in response to increasing crop density (Knowles and Knowles, 2006; Zebarth et al., 2006). Abd-Ellatif et al. (2010) also reported the effect of planting date, intra-row spacing and their interactions on corm diameter, corm length and their ratio.

Marketable and total yield per plant

Average marketable yield per plant was significantly affected by location, planting density and planting dates (Tables 12 and 13). However, all planting dates are at par except for Mid-April. Total yield was also influenced by planting density but not by planting dates. Both marketable yield and total yield per plant decreased as planting density increased. Maximum marketable yield and total yield per plant were recorded from the minimum planting density (15037plant ha^{-1}) (Table 13). Similar finding was also reported by Mangani et al. (2015) in which marketable yield significantly increased in wider spacing.

Conclusion

The current study revealed that plant density is an important agronomic management practice to improve the productivity of root crops through enhancing the capacity of plant for light interception, and thereby dry matter production. The minimum planting density (15037 plant ha^{-1}) outscored in vegetative growth, DMP, marketable and total yield per plant. Planting date is also an important management practice; Late March planting was identified best in vegetative growth, CIPAR, DMP, marketable yield and total yield of taro. However, during the field experiment, the onset of rain was late from the usual at both locations; as a result the first planting date at mid-February took about 63.4 days in average before emergence due to extended dry season. The results of the current experiment confirm that the availability of soil moisture was more important than the time of planting.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

Hawassa University College of Agriculture and Norwegian Agency for Development Cooperation (NORHED) thankfully acknowledged for financial support. Areka Agricultural Research Center (AARC) is also acknowledged for providing planting materials and facilitating field experiment at Areka.

REFERENCES

Abd-Ellatif AA, Shehata AE, Youssef SM (2010). Effect of Planting Date and Intra-row Spacing on Growth, Yield and Quality of Taro. Research Journal of Agriculture and Biological Sciences, 6(6):806-814.

Allen EJ, Wurr DCE (1973). A comparison of two methods of recording stems densities in the potato crop. Potato Research, 16:10-20.

Bernardes CO, Martins CA da S, Santos F, da Rocha MJR, Xavier TMT (2011). Leaf Area, Leaf Area Index and Light Extinction Coefficient for Taro Culture. ENCICLOPÉDIA BIOSFERA, Centro Científico Conhecer –Goiânia, 7(12).

Beyene TM (2013). Morpho- Agronomical Characterization of Taro (*Colocasia esculenta* L.) Accessions in Ethiopia, Plant, 1(1):1-9. doi: 10.11648/j.plant.20130101.11

Central Statistical Agency (CSA) (2011). Federal democratic republic of Ethiopia Central Statistical Agency Crop production forecast sample survey, 2010/11 (2003 e.c.) (Conducted from September 12 to October 25, 2010)

Dagne Y, Mulualem T, Kifle A (2014). Development of high yielding Taro (*Colococia esculenta* L.) Variety for mid altitude growing areas of Southern Ethiopia. Journal of Plant Sciences, 2(1):50-54.

De la Pena RS, Plucknett DL (1972). Effects of nitrogen fertilization on the growth, Composition and yield of upland and lowland taro (*Colocasia esculenta* L.). Experimental Agriculture, 8:187-194.

Food and Agriculture Organization (FAO) (1999). Taro cultivation in Asia and the Pacific, Food and Agriculture Organization of the United Nations, (FAO), Rome, Italy.

Gendua PA, Risimeri JB, Maima JB (2001). The effect of planting density on the marketable corm yield of taro (*Colocasia esculenta* (L.) Schott). In: Bourke, R.M., Allen, M.G. and Salisbury, J.G. (eds) Food Security in Papua New Guinea. ACIAR Proceedings, No. 99, Canberra pp. 764-774.

Gendua PA, Risimeri JB, Maima JB (2000). The effect of planting density on the marketable corm yield of taro (*Colocasia esculenta* (L.)Schott). Bubia Resarch station, National Agricultural Research Institute (NARI) Morobe PNG. Printed in: NARI. pp. 764-767.

Hussain A, Azam M, SA, Waji D, Musaddique M (1999). Growth, yield and water use of lentils (*Lens culinaris*). Proc. Nat. Workshop on Water Resources: Achievements and Issues in 20th Century and Challenges for the next millennium, June 28–30, Islamabad, Pakistan pp. 207-11.

Hussain A, Nawaz M, Chaudhry FM(1998). Radiation interception and utilization by chickpea (*Cicer arietinum* L.) at different sowing dates and plant population. Agricultural Sciences, 3:21-25.

Hussain A, Wajid A, Maqsood M, Ahmad A, Rafiq M (2002). Effect of drought on wheat yield and radiation use efficiency. Proc. Nat. Symp. On Drought and Water Resources in Pakistan, March 18, 2002, Lahore Pakistan. pp. 75-80.

John J, Roy C, Yamakawa A, James H (2007). Hawaiian, Kalo, Past and future, Corporative Extension service, college of Tropical Agriculture and HumanNutrition, University of Hawaii at Manoa.

Knowles NR, Knowles LO (2006). Manipulating stem number, tuber set, and yield relationships for northern and southern-grown potato seed lots. Crop Sciences, 46:284-296.

Macanawai AR, Day MD, Tumaneng-Diete T, Adkins SW (20012).Vegetative Growth and Development of Mikania Micrantha In Taro and Cassava Production In Viti Levu, Fiji. Pak. Journal Weed Science Research, 18:377-384.

Maddonni GA, Otegui ME, Cirilo AG (2001). Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. Field Crop Research, 71:183-193

Mangani R, Mazarura U, Matiata TA, Shayanowako A (2015). Growth yield and Quality Responces to Plant Spacing in Irish potatoes: A Review. African Journal of Agricultural Research, 10(7):727-730.

Manner HI, Taylor M (2011). Farm and Forestry Production and Marketing Profile for Taro (*Colocasia esculenta* L.). In: Elevitch, C.R. (ed.). Specialty Crops for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawaiʻi. http://agroforestry.net/scps (Accessed on March/11/2016)

Mare R (2009). Taro (*Colocasia esculenta* L. Schott) Yield and Quality Response to Planting Date and Organic Fertilization. A PhD Dissertation Submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (Crop Science) in the School of Agricultural Sciences and Agribusiness University of KwaZulu-Natal Pietermaritzburg, South Africa.

Mare RM, Modi AT (2012). Taro corm quality in response to planting date and post-harvest storage: I. Starch content and reducing sugars. African Journal of Agricultural Research, 7(19):3014-3021.

Masariramb MT, Mandisodza FC, Mashingaidze AB, Bhebhe E(2012). Influence of plant population and seed tuber size on growth and yield components of potato (*Solanum tuberosum* L.). International Journal Agricultural Biology, 14:545-549.

Nanda R, Bhargava SC, Rawson HM (1995). Effect of sowing date on rates of leaf appearance,final leaf numbers and areas in*Brassica campestris, B. juncea, B. napus* and *B. carinata,* Field Crops Research, 42:125-134.

Ndon BA, Ndulaka NH, Ndaeyo NU (2003). Stabilisation of yield parameters and some nutrient components in cocoyam cultivars with time in Uyo, southern Nigeria. Global Journal of Agricultural Sciences, 2:74-78.

Oluwasemire KO, Odugbenro GO (2014). Solar Radiation Interception, Dry Matter Production and Yield among Different Plant Densities of Arachis spp. in Ibadan, Nigeria. Agricultural Sciences, 5:864-874.

Onwueme IC (1999). Taro cultivation in Asia and the Pacific. RAP Publication: 1999/16. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific. Bangkok, Thailand

Paul B, Balaji R (2007). Interannual Variability and Ensembles Forecast of Upper Blue Nile Basin Kiremt Season Precipitation. Journal Hydrometeor, 8:327-343

Purcell LC, Ball RA, Reaper JD, Vories ED (2002). Radiation use Efficiency and biomass production in soya bean at different plant population densities. Crop Science, 42:172-177

Saiful IM, Rahman MA, Salam MA, Masum AS, Rahman MH (2002). Growth and vegetable pod yield of edible podded pea as influenced by sowing time and plant density. Journal Biological Science, 2:706-709.

Safo-Kantaka O (2004). *Colocasia esculenta* (L.) Schott. Record from Protabase. PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale) [ed. by Grubben, G. J. H. \Denton, O. A.]. Wageningen, Netherlands: PROTA. http://database.prota.org/search.htm

Scott RK, Jaggard KW (1978). Theoretical criteria for maximum yield. Proc. 41 Winter Cong. Int. Inst. Sugar Beet Res. Brussel, pp. 179-98

Sener O, Gozubenli H Konuskan O, Kilinc M (2004). The effect of intera-row spacing on the grain yield and some agronomic characteristics of maize (*Zea mays* L.) hybrids Asian Journal Plant Science, 3:429-432

Tadesse Y, Tesfaye B (2010). Response of Taro to Applied Nitrogen and Potassium fertilizer Levels: Nitrogen, Potassium, Growth and Yield. VDM Verlag Dr. Muller, Germany, ISBN-13: 978-3639274288, P 104.

Tsedalu M, Tesfaye B, Goa Y (2014). Effect of Type of Planting Material and Population Density on Corm Yield and Yield Components of Taro (*Colocasia Esculenta* L.). Journal of Biology Agriculture and Healthcare, 4(17):2224-3208

Tsegaye A, Struik PC (2003). Growth, Radiation Use Efficiency and yield potential of Enset (*Enset ventricosum*) at different site in Southern Ethiopia. Annual Applied Biology, 142:71-81

Tumuhimbise R, Talwana HL, Osiru DSO, Serem1 AK, Ndabikunze BK, Nandi JOM, Palapala V (2009). Growth and Development of Wetland-Grown Taro under Different Plant Populations and Seedbed Types in Uganda. African Crop Science Journal, 17(1):49-60

Uzun S (1996). The quantitative effects of temperature and light environment on the growth, development and yield of tomato and aubergine. Ph.D. Thesis, The University of Reading, England.

Wajid A, Hussain A, Ahmad A, Rafiq M, Goheer AR, Ibrahim M (2004) Effect of Sowing Date and Plant Density on Growth, Light Interception and Yield of Wheat under Semi-Arid Conditions. International Journal of Agricultural Biology, 6(6):1560-8530. http://www.ijab.org

Worku W, Demisie W (2012). Growth, light Interception and Radiation use efficiency response of pigeon pea (*Cajanus cajan*). Journal of Agronomy, 11(4):85-93.

Zebarth BJ, Arsenault WJ, Sanderson JB (2006). Effect of seed piece spacing and nitrogen fertilization on tuber yield, yield components, and nitrogen use efficiency parameters of two potato cultivars. American Journal Potato Research, 83:289-296.

Zhou XB, Chen YH, Ouyang Z (2011). Row spacing effect on leaf area development, light interception, crop growth and grain yield of summer soybean crops in Northern China. African Journal of Agricultural Research, 6(6):1430-1437.

Vol. 13(23), pp. 1198-1212, 7 June, 2018
DOI: 10.5897/AJAR2018.13064
Article Number: 089B8CC57314
ISSN: 1991-637X
Copyright ©2018
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Climate analysis for agricultural improvement of the Economic Community of West African States according to Köppen and Thornthwaite

MÜLLER, Marcela dos Santos[1], DOURADO-NETO, Durval[1], TIMM, Luís Carlos[3], REICHARDT, Klaus[2], SARTORI, Felipe Fadel[1*] and FELISBERTO, Guilherme[1]

[1]Crop Science Department, Esalq, University of São Paulo (USP), Piracicaba, SP, C.P. 9. 13.418-900, Brazil.
[2]Soil Physics Laboratory, Cena, University of São Paulo (USP), Piracicaba, SP, C.P. 96. 13.416-903, Brazil.
[3]Rural Engineering Department, Faem, Universidade Federal de Pelotas (UFPEL), Pelotas, RS, C.P. 354, 96.001-970, Brazil.

Received 19 February, 2018; Accepted 10 April, 2018

The Economic Community of West African States (also known as ECOWAS from its name in French: *Union Économique et Monétaire Ouest-Africaine*) is composed of eight countries: Benin, Burkina Faso, Ivory Coast, Guinea-Bissau, Mali, Niger, Senegal and Togo. This study is restricted to ECOWAS because it stems from a survey mission headed by the second author and aims to characterize the climate of the territory as a basis for better land use by improving agricultural activities. The climate classification systems proposed by Köppen (1900) and Thornthwaite (1948) were used to carry out the study. As expected, most of the territory belonging to ECOWAS was classified as arid. With respect to the improvement of agricultural management, the climate classes found for the territory give a gross idea of the potential of each country for agricultural exploitation. The climate diversity over relatively short distances obligates detailed studies on land adaptability for growing food crops, which is in practice not made based on scientific criteria. This study shows that there is still room for an expansion of the area for agricultural purposes, and in this way, increasing food production.

Key words: Africa, Economic Community of West African States (ECOWAS), agriculture, crops.

INTRODUCTION

The Economic Community of West African States (ECOWAS), in French: *Union Économique et Monétaire Ouest-Africaine,* is an organization that was established to promote the economic integration among eight countries of West Africa (Benin, Burkina Faso, Ivory Coast, Guinea Bissau, Mali, Niger, Senegal and Togo) that share the use of the same language and currency, the CFA Franc. These countries appear in the lower

---

[*] Corresponding author. E-mail: felipefsartori@gmail.com

Figure 1. Map of Africa and the ECOWAS territory. (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

quarter of the HDI (Human Development Index), indicating a large room for improvement, mainly in agricultural management aiming for higher food production.

Also, the West African countries have been experiencing huge climate variability in the last decades with direct impact in the groundwater (Tirogo et al., 2016), although it has been shown a resilience for short-term inter-annual variation (Lapworth et al., 2013). Climate variability has also been verified by differences on tree-rings along countries such as Ivory Coast (de Ridder et al., 2013). The ECOWAS was created on January 10, 1994, in Dakar, Senegal, through an agreement signed by Government Chief Members of Benin, Burkina Faso, Ivory Coast, Mali, Niger, Senegal and Togo. On May 2, 1997, Guinea Bissau became the eighth member of ECOWAS (Figure 1) (Wikipedia, 2014).

Many studies in the last decades were carried out in order to analyze the economic and social development challenges of ECOWAS, where food production may possess a major role influencing on Gross Domestic Product (GDP), population health and wealth, and public security (Koffi-Tessio, 1998; Decaluwé et al., 2001; Dissou, 2002; Decaluwé et al., 2004; Bakhoum, 2005; Nubukpo, 2007a, b; Ouattara, 2007; Tanimoune et al., 2008; Esso, 2009; Kablan, 2009; Keho, 2010; Bakhoum, 2011; Heubes et al., 2012; Lansana, 2012a, b; Sablah et al., 2012; Carrère, 2013; Oguntunde et al., 2017). To develop information that can improve food production in these countries that depend on imports of basic food for their subsistence and to generate energy, we assume that climate is one of the main constrains in their agriculture. We use climatic data to apply Köppen´s and Thornthwaite´s methods. Köppen developed the first quantitative climate classification in 1900 and among the numerous methods available (Kottek et al., 2006; Belda et al., 2014), this is the mostly used one. As an example, Sparovek et al. (2007) also used Köppen’s classification to map Brazilian climates. Although this type of analysis has been performed before for the West Africa countries, it is known that anthropogenic actions may have severe consequences on the climate characterization in this region, with a likely impact on plant diversity (Sylla et al., 2016a, b; Heubes et al., 2013).

Therefore, this study has as objective the application of the climatic classification systems of Köppen (1900) and Thornthwaite (1948), using rainfall and air temperature data (Figure 2), to supply information for the establishment of an agricultural zoning for food crops, such as corn and soybean or sugarcane for energy, based on real and potential productivities (Tables 1 and 2).

MATERIALS AND METHODS

The methodology of this study is based on concepts already known and published (Belda et al., 2014), however, carried out with geoprocessing tools, computational programming and spatial modeling. Meteorological data were compiled from public data bases found in Hijmans et al. (2005), covering the period 1950 to 2000, with the criterion of covering the full area of the ECOWAS. A strategic methodology was adopted to equalize the availability of georeferenced information to the continental scale of operation of the model and to the need of generating information sufficiently precise for the proposed characterization. After being compiled and structured in a common format, the bases of original data were integrated and processed by computational routines to generate derived variables to feed the following stages of the model.

Air temperature data were organized in average monthly minimum temperature (T_n); average monthly maximum temperature (T_x); average monthly temperature (T_d) in a way to allow the construction of maps and cyclic water balances (CWB), and rainfall data were also organized in an adequate way to generate rainfall maps and CWBs.

Potential evapotranspiration (ET_0, mm month^{-1}) is a meteorological variable that corresponds to the evaporation and transpiration of plant water under a non-limiting soil water condition,

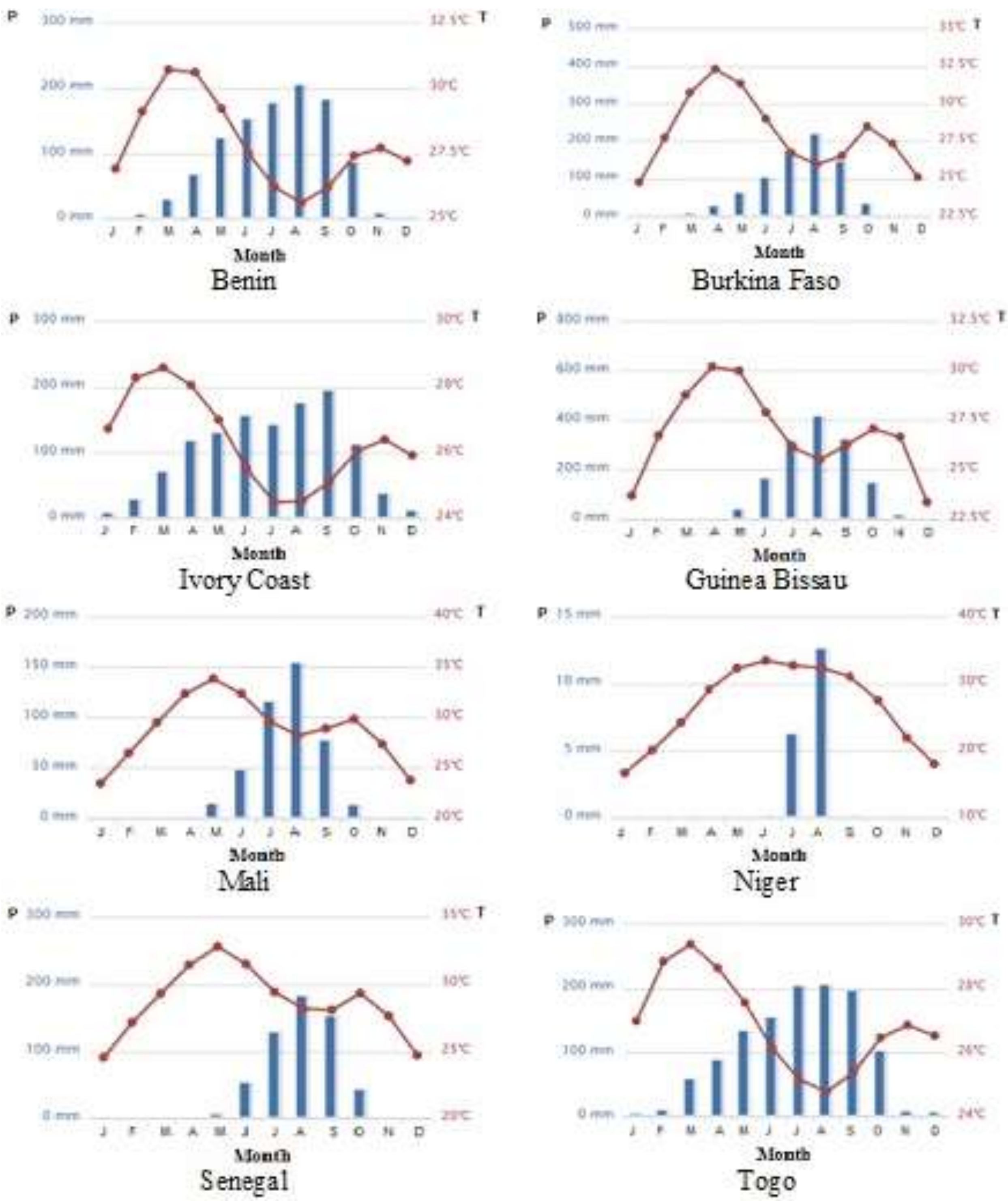


Figure 2. Country average values for rainfall (P, mm) and air temperature (T, °C) in ECOWAS countries for the period 1990 to 2009.
Source: World Bank (2014).

therefore corresponding uniquely to a response of a crop to atmospheric conditions. Several climatic variables contribute to ET_0, mainly solar radiation, air temperature, humidity and wind, but due to the lack of such records in many regions of the world, Thornthwaite (1948) developed an equation to estimate monthly ET_0 based only on air temperature data, which will be used in this

Table 1. General information for ECOWAS countries.

Country	Benin	Burkina Faso	Ivory Coast	Guinea Bissau	Mali	Niger	Senegal	Togo
Latitude	6º10' to 12°25'N	9° to 15° N	4° to 6°N	11° to 13°N	10º to 25°N	11º to 24ºN	12º e 17ºN	6º to 11ºN
Longitude	0°45' to 3°55'E	6°W to 3°E	2° to 9°W	13° to 17°W	13ºW to 5°E	0° to 16ºE	11º e 18ºW	0^{o} to 2ºE
Area (10^3 km^2)	113	274	322	36	1,240	1,267	197	57
HDI (2013) (rank)	0.476 (165th)	0.388 (181st)	0.452 (171st)	0.396 (177th)	0.407 (176th)	0.337 (187th)	0.485 (163rd)	0.473 (166th)
Population (hab)	$10.1\ 10^6$	$16.5\ 10^6$	$16.9\ 10^6$	$1.5\ 10^6$	$15 \cdot 10^6$	$17.2 \cdot 10^6$	$13.7 \cdot 10^6$	$6.6 \cdot 10^6$
Density (hab km^{-2})	89.7	60	52	42	12	13	69	115
GIP (US$)	15 bi	22 bi	n.a.	n.a.	17 bi	n.a.	n.a.	n.a.
GIP (US$ *per capita)*	1,619	1,302	n.a.	n.a.	1,091	n.a.	n.a.	n.a.
Growth (% y^{-1})	4.4	6.5	2.3	n.a.	5.8	n.a.	2.6	2.1
Arable area (ha)	$7 \cdot 10^6$	$9 \cdot 10^6$	$21 \cdot 10^6$	n.a.	n.a.	n.a.	n.a.	n.a.

Source: World Bank (2013); FAO (2015); Wikipedia (2014); United Nations Development Programme (2015); BTI (2014a, b, c, d).

study:

$$\mathrm{ETo}_{\mathrm{i}} = 1.6\left(\frac{\sum_{i=1}^{12} 10.T_i}{I}\right)^{\sum_{j=0}^{3} a_j I^j} \tag{1}$$

$$\mathrm{I} = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.514} \tag{2}$$

in which i is the month sequential number, I the thermal index calculated from the average monthly air temperature (T_i, ºC), and a_i are empiric coefficients determined through a regression analysis using average monthly values of temperature. In our case, j defines a_0 = 0.49239, a_1 = 0.01792, a_2 = -0.0000771 and a_3 = 0.000000675 (Thornthwaite, 1948).

With rainfall and ET_0 data, the components of a cyclic water balance (CWB) can be calculated. Such a water balance allows determining periods of water deficit or excess.

The pedological database was obtained from FAO (2012). Standardization of attributes, nomenclatures and other soil data for the whole study region was based on the World Reference Base for Soil Resources (WRB) according to FAO (2006), which included the need to correlate information with the Brazilian Soil Classification System (SiBCS) based on the Brazilian Agricultural Research Corporation, EMBRAPA (2006). Soil altitude and slope data were obtained from the Shuttle Radar Topography Mission (2010).

Thornthwaite and Mather (1955, 1957) presented a basic equation for soil water depletion as a function of soil water storage (A, mm):

$$\mathrm{A} = \mathrm{A_c} \mathrm{e}^{-\frac{\mathrm{L}}{\mathrm{A_c}}} \tag{3}$$

in which A_c (mm) is the soil water holding capacity defined as the difference between volumetric water content at field capacity (FC) and at the permanent wilting point (PWP) times 1000 mm (considering a 1 m deep soil), and L is a water balance component related to the cumulated water deficit as defined in Thornthwaite and Mather (1955, 1957), Mendonça (1958) and Dourado Neto et al. (2010).

The climate classification systems proposed by Köppen (1900) and by Thornthwaite (1948) are frequently used in the world (Kottek et al., 2006; Belda et al., 2014). The Köppen classification employs climatic values for summer and winter. Summer was considered to comprise the months of May, June and July, and the winter the months of November, December and January.

RESULTS AND DISCUSSION

Edaphic characterization

Soil water holding capacity

The soil water holding capacity (A_c, mm) of the soils of the ECOWAS countries (FAO, 2012) is illustrated in Figure 3. Such data in a country-scale manner constitute a novelty for the area. In general, fertile soils present high values of A_c, of the order of 300 mm for a 1 m deep profile. Medium values of A_c are of the order of 200 mm,

Table 2. Climatic description of the ECOWAS countries.

Country	Description	Crop	Production – t.ha^{-1} (2016)
Benin	Characterized by two well defined climatic zones separated by a transition zone. South: two rainy seasons per year (March to July, September to November), humid and warm; a long dry season (December to March) with the warm and dry wind "harmattan"; Center: Transition climate with spatial and temporal fluctuations that make dryland agriculture risky; North: characterized by a single rainy season.	Maize	1,376,683
		Oil Palm Fruit	654,542
		Rice	281,428
		Seed cotton	346,935
		Sorghum	129,665
Burkina Faso	Presents an interchange of dry and wet season; wet season longer in the south; dry season determined by the "harmattan" wind; country divided in three climatic zones:. (i) South Sudan, highest rainfall amount; (ii) North Sudan, medium rainfall amount during 4 to 5 months, with presence of forest vegetation under human pressure; and (iii) Sahel, very low rainfall during 3 months, shrub vegetation.	Cotton	900,448
		Maize	1,583,421
		Sorghum	1,742,116
		Millet	1,056,931
Ivory Coast	Very warm and humid the whole year, with two distinct seasons: dry winter and wet summer. Three agroecologic zones: (i) south (50% of the area), with most of the rain and including almost all forest, four climatic seasons, dry from December to March, rainy from March to June, short dry spell from July to August, and a short rainy season from September to November; planted to coffee, cacao, palm oil, rubber and coconut; (ii) Sudan Guineans' zone (19% of the area), transition between forest region and the north, with four seasons: long dry spell from November to February, long rainy season from March to June, short dry spell from July to August, and a short rainy season from September to October; irregular rainfall that harms agricultural practices; and (iii) Sudanese zone (31% of the country): northern region with a single rainy season that enables dry land agriculture.	Rice	1,768,121
		Maize	881,733
		Millet	54,499
		Coffee (green)	102,960
		Cocoa beans	1,472,313
		Seed cotton	378,303
		Banana	330,946
		Cassava	321,614
		Coconut	142,439
		Oil Palm Fruit	1,696,078
		Cashew	607,300
		Pineapple	46,258
		Rubber tree	310,655
Guinea Bissau	Between Equator and Tropic of Cancer, warm and humid with two distinct seasons: dry (December to April) and wet (May to November); comprises an insular territory of more than 80 islands; presents three agro ecologic zones: north, with one dry season (November to March) and one wet season (July to October); southeast with a tropical humid climate, with great agricultural potential; northwest with a moderate rainy and hot climate, also presents a good agricultural potential.	Cashew nuts	153,888
		Rice	186,000
		Sorghum	17,000
		Millet	14,000
		Roots ans tubers	89,086
		Oil Palm Fruit	81,259
Mali	High average temperatures and an interchange of a wet season (June to September) with a dry season (October-November to May-June. Four climatic subtypes are found: (i) Sudan-Guinea: southern part (6%) of the territory, with forests; (ii) Sudan area (17%) with a more or less dense vegetation; (iii) Sahel (26%), northern area with very low rainfall, occupying most of the Niger delta; and (iv) sub-Saharan zone (51%) with minimum rainfall.	Rice	2,780,905
		Maize	2,811,385
		Millet	1,806,559
		Sorghum	1,393,826
		Seed cotton	597,237
		Sugarcane	365,119

Table 2. Contd.

Niger	With 2/3 of its territory occupied by the Sahara desert, Niger has an extremely dry climate. Territory with desert lowland and dunes. Presents four climatic zones: (i) sub-Saharan zone (65% of the territory) with desert climate; (ii) Sahel-Sahara (12.2%), semi-desert climate with a long dry season (October to May) followed by a low rainfall season (June to September); (iii) Sudan-Sahel (12.9%) with somewhat better precipitation and (iv) Sudanese zone (0.9%) with better rainfall.	Maize	38,022
		Sorghum	1,808,263
		Millet	3,886,079
		Rice	30,167
		Cassava	146,563
		Cow pea	1,987,100
		Groundnut	453,577
		Seed cotton	10,622
Senegal	Two well defined dry and wet seasons. Rainfall in the south is about 5 times higher than in the north. Climate is directly influenced by the sea and the harmattan winds during the dry season.	Groundnut	719,000
		Sugarcane	696,992
		Millet	612,563
		Rice	885,284
		Maize	314,703
Togo	Very well distributed rainfall during the whole year, July, August and September being the most humid. More concentrated rainfall in the north.	Cassava	1,027,476
		Yam	813,985
		Maize	826,896
		Sorghum	272,776
		Rice	137,106
		Seed cotton	69,215
		Coffee (green)	10,985
		Cocoa beans	51,627

Sources: FAO (2015); World Bank (2015) and FAOSTAT (2018).

and low values 100 mm. Even being a desert area, the north of Mali presents relatively high values of A_c, reaching 125 mm due to marine formations, calcareous soils, soils with calcium sulphate, as well as saline soils, and organosoils. Neosols from the desert area of Mali and Niger present A_c values of the magnitude order of 100 mm, which could be explained by the conjugated presence of Vertisols and Gleisoils along the Niger river crossing Niger and Mali, as well as in the Chad Lake region, extreme southeast of Niger at the border of Chad, Cameroon and Nigeria.

The highest A_c values south of parallel 15º N, however in a mosaic composition, varied from 50 mm to more than 125 mm. Guinea Bissau and Senegal present most part of their territories covered by soils of A_c greater than 100 mm.

Temperature

Figure 4 presents the average monthly temperatures for the ECOWAS territory. Since this region is located between the Equator and the

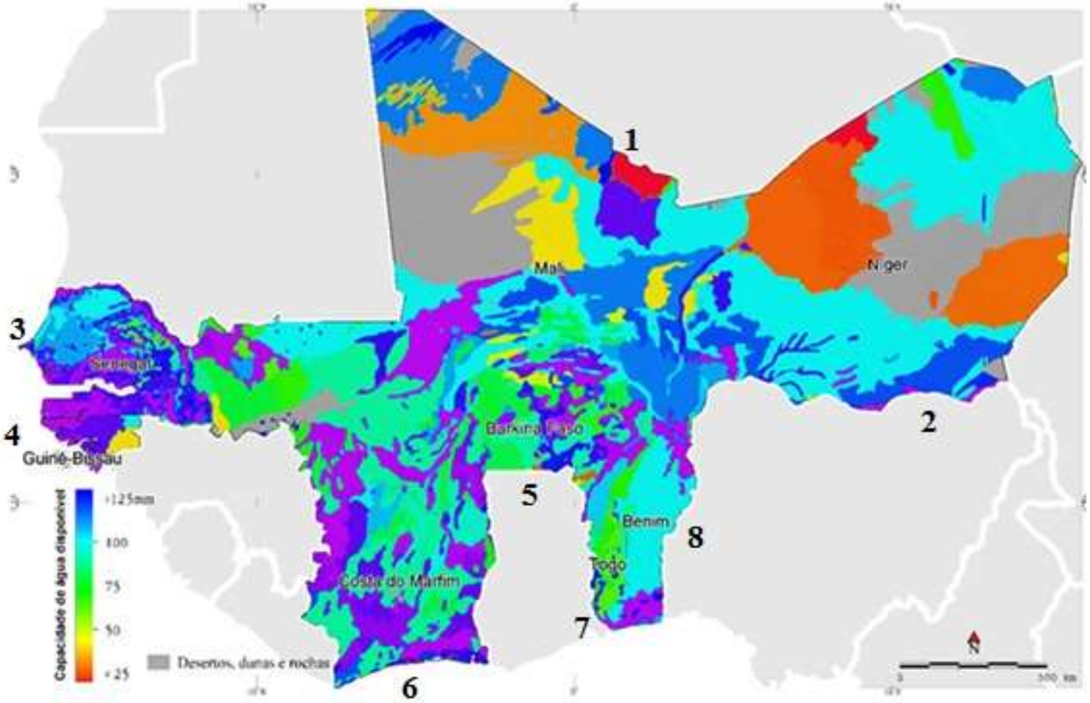


Figure 3. Soil water holding capacity (A_c, mm) of the ECOWAS territory: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

tropic of Cancer, Figure 4 shows that ECOWAS can roughly be divided into three temperature zones according to latitude: (i) from the Equator to parallel 10º N (Ivory Coast, Togo and Mali); (ii) between parallels 10º N and 15º N (Guinea Bissau, Senegal, south Mali, Burkina Faso and south Niger); and (iii) north of parallel 15º N (north central Mali and Niger). The northern part (above 15º N) including Mali and Niger, belongs to the Sahara desert including hilly regions, and presents the lowest average temperatures, reaching about 17°C in January. During May and June the temperature reaches 35ºC, while in the Northern regions of low altitude in in Mali, Niger and Burkina Faso the average winter temperature varies from 20 to 27ºC and remains in this range with the arrival of the summer. Figure 4 also shows that the coastal countries Togo, Benin, Ivory Coast, Guinea Bissau and Senegal (with exception of the northern part) present the smallest thermal amplitudes during the year, between 20 and 30ºC, as well as the highest rainfall.

Figure 5 shows that the minimum air temperatures of ECOWAS oscillate between15 and 20ºC, with the lowest values found in the more arid regions, between Sahel and the Sahara desert. The extreme north of Niger and Mali presents minimum temperatures below 17ºC, which leads to thermal amplitudes greater than 30ºC.

Figure 5 also shows that maximum air temperatures of ECOWAS are in the range 28 to 48ºC. The lowest are in the Southern part of the territory, between 28 and 33ºC; in the center, in the Sahel, temperatures are of the order of 35 to 40ºC, and north, in the desert, temperatures can reach values above 45ºC; a few points of exception with low maximum temperatures are found in the hilly regions.

With the Equator line projecting well in its center, Africa is the continent with the largest tropical area of the world. In the few mountain peaks, lower temperatures can be found even in the equatorial band. Large temperature ranges depend on the seasons and the solar radiation, which depends on latitude, altitude and proximity to the ocean.

The climate parameters that result from the thermal conditions should suffer along the seashores, the cooling provided by the sea breeze, which is actually lower in the interior, however, the influence of the sea is probably less effective over the excessively humid seashores due the similarity of the thermal parameters between ocean and coastal zone (Carter, 1948).

Rainfall

One of the main characteristics of rainfall described by several authors are the great differences among the rain volumes found in the different parts of the African continent (Carter, 1948), and the same is true for the

January February

March April

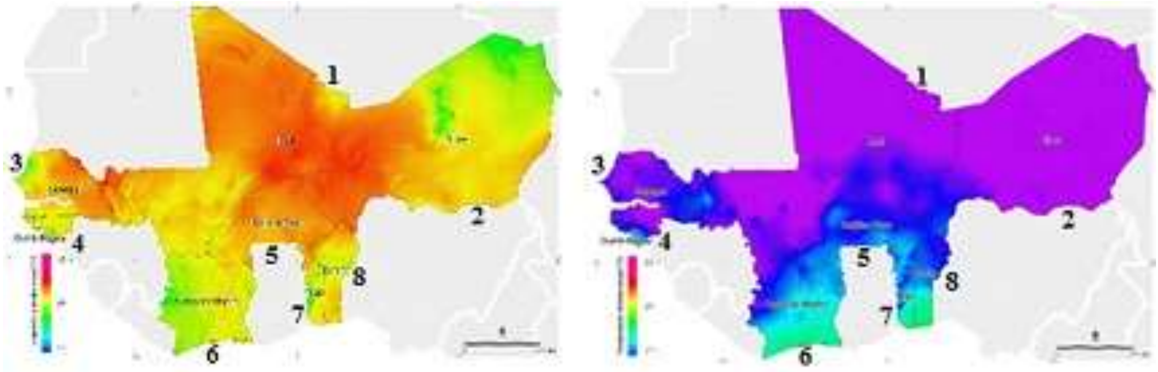
May June

July August

July August

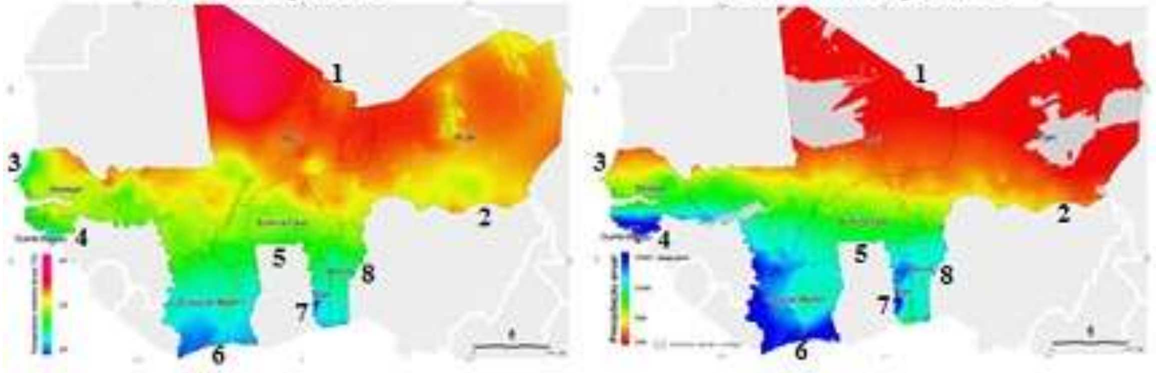
November December

Figure 4. Mean monthly air temperature (°C) of the ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).



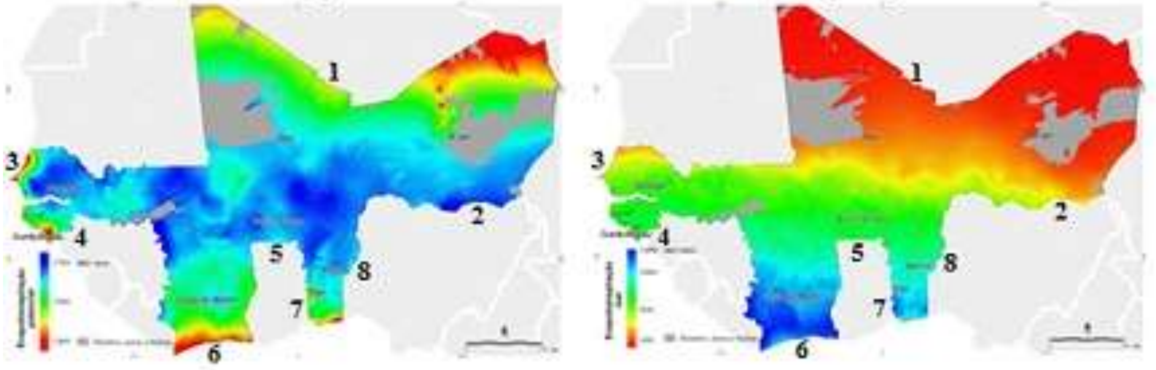
Mean temperature

Minimum temperature



Maximum temperature

Pluvial precipitation



Reference potential evapotranspiration

Actual evapotranspiration

Figure 5. Mean, minimum and maximum annual air temperature (°C), mean annual pluvial precipitation (mm year^{-1}), mean annual reference potential evapotranspiration (ETo, mm year^{-1}), and mean annual actual evapotranspiration (ETa, mm year^{-1}) of the ECOWAS territory: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

countries belonging to ECOWAS. Mean annual averages of rainfall are found in Figure 5 for these countries. In the desert region of Sahara, average rainfall is below 100 mm year^{-1}, while at the coastal strip (south of the parallel 12º 30'N) of Guinea Bissau, Ivory Coast, central Togo and southeast Benin, they are above 1,500 mm year^{-1}. However, independently of the historical rainfall volumes, the majority of these countries present a rainy season limited to a few months per year. The greatest rainfall values of continental Togo are due to the presence of a mountain chain. In contrast, the region above parallel 15º N, in the Sahara desert, presents an extreme aridity with values below 100 mm $year^{-1}$; the Sahel strip somewhat below, presents averages from 400 to 500 mm $year^{-1}$.

In a general way, ECOWAS countries are faced to two well defined seasons: one rainy and the other dry. The rainy seasons coincide with the summer, but the distribution along the months is different for each country. In Ivory Coast and in Togo (Figure 5) the rainy seasons are more intense than in in the other countries, once their distributions are better spread through the year, starting from April and extending to October.

Due to rainfall, the high air temperatures of the ECOWAS countries are reduced by about 8ºC. Niger and Mali are the ECOWAS countries with lowest rainfall incidence, with very low historic average values. An exception has to be made to the extreme South of these territories that present values above 500 mm $year^{-1}$.

In Köppen´s (1900) climatic classification method, rainfall is one of the most important criterion; however, in Thornthwaite´s (1948) classification this variable is not used directly, it is compared to ET_0 and A_c during the calculation of water deficits or excesses.

Potential evapotranspiration

ET_0 calculated from Equation 1, which is based on average T measurements, is somewhat a reflection of the T distributions discussed above. It is also important to remind that the ET_0 is a climatological variable. Figure 5 illustrates the average annual potential evapotranspiration of the ECOWAS countries. The areas with lowest ET_0 levels, around 1,300 mm $year^{-1}$, coincide with the coastal areas of Senegal, Guinea Bissau, Ivory Coast, Togo and Benin, as well as the extreme north of Niger and Mali. The lower values at the coastal areas are due to the milder temperatures of this region, and in the extreme north they are influenced by the relief.

Our results are in agreement with Virmani et al. (1980), who observed that ET_0 in West Africa is inversely proportional to the rainfall distribution, with lowest values at the coastal areas and increasing in the direction of the Sahel.

The region represented by blue colors (Figure 5), ranging from parallel 10º N to 20º N, presents the highest values of ET_0, reaching volumes of 1,700 mm $year^{-1}$. This region presents the highest summer air temperatures (Figure 5), comprising the whole semi-desert and desert belt, in which ET_0 calculated by Thornthwaite (1948) surpasses by far the rainfall volumes, clearly demonstrated in Figure 5. Walker (1962) calculated ET_0 values for the Sahara desert of the order of 2,000 mm $year^{-1}$.

Actual evapotranspiration

ET_a is a measure of the evapotranspiration that occurs in real terms. It is equal or less than ET_0, that is, the maximum possible value under defined conditions and is a result of the water balance (WB) calculation, here made by Thornthwaite and Matter (1955) methodology. Figure 5 also presents average values of ET_a for the ECOWAS countries, where it is possible to see that for regions north of parallel 15º N, the values are less than 100 mm $year^{-1}$, a region where ET_0 values are above 1,500 mm $year^{-1}$, due to the condition of extreme hydric limitation. However, in the coastal belts of Ivory Coast, Togo and Benin, ET_a becomes close or equal to ET_0 of 1,300 mm $year^{-1}$, demonstrating that in a general way there is no hydric restriction. The transition between the South regions and those North of parallel 15º N, illustrated in yellow (Figure 5), is the Sahel strip, in which ET_a is between 300 and 500 mm $year^{-1}$, demonstrating clearly the reduction in water availability when we depart from the Equator in direction to parallel 20° N.

Cyclic water balance

Water deficit

In Figure 6, we see that water deficit prevails in more or less degree in the whole territory of ECOWAS, comprising also the coastal region of Ivory Coast, Togo and Benin, a region where rainfall reaches values greater than 1,500 mm $year^{-1}$. The region north of parallel 15ºN presents hydric deficiency greater than 1,000 mm $year^{-1}$. The coastal zones of Ivory Coast, Togo and Benin present a much less intense hydric deficiency, of the order of 100 mm $year^{-1}$, at least in one period of the year; in the coastal zone of Senegal and Guinea Bissau, the deficiency is greater, reaching 1,000 mm $year^{-1}$, which demonstrates that their climatic condition imposes harder climatic characteristics in relation to those areas situated close to the sea.

Water deficit is the difference between potential (ET_0) and actual (ET_a) evapotranspiration, which was not supplied by rainfall. Figure 6 demonstrates that more than half of the ECOWAS territory presents a hydric deficiency of at least 400 mm $year^{-1}$, similar to the rest of the African continent (CARTER, 1948).

As expected, the greatest hydric deficit levels occur in the Sahara desert, where more than 1,400 mm $year^{-1}$ would be necessary to correct this dry condition. This region presents an average water deficit very close to our calculated ET_0 values (1,600 to 1,700 mm $year^{-1}$).

Water excess

When a soil reaches A_c, the additional rain water is called water excess, which is lost by runoff or by deep drainage. Figure 7 shows that for the ECOWAS countries, water excess is present in greater or minor degree only in

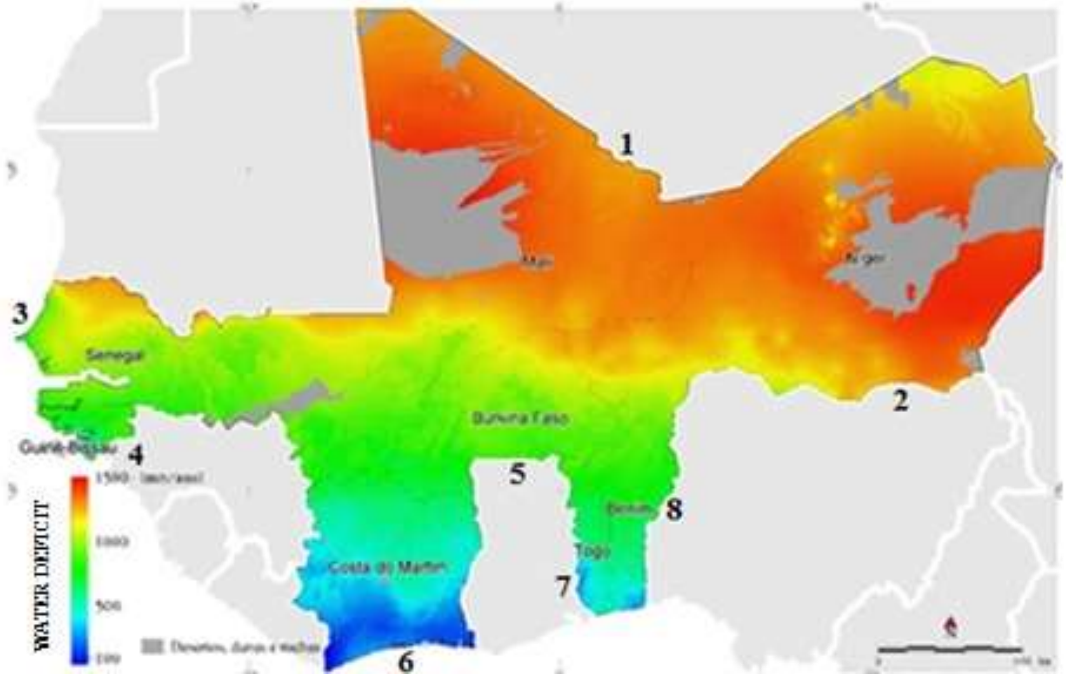


Figure 6. Average water deficit (WD, mm year^{-1}) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

latitudes below 15º N, i. e. south Senegal, Guinea Bissau, the extreme Southwest of Mali, central and south Burkina Faso, Ivory Coast, Benin and Togo. North to this area there is no excess water because rainfall values are below 100 mm year^{-1}.

In the part of the territory where no water excess occurs, extreme levels of water deficiency occur, of the order of 1,500 mm y^{-1}, a condition that prevails in north Senegal, north Burkina Faso, and practically the whole area of Mali and Niger.

Areas with water excess higher than 500 mm y^{-1} are those of South Senegal, Guinea Bissau, the extreme south of Mali, the western and coastal part of Ivory Coast and central Togo.

The east frontier of Ivory Coast with Liberia and Guinea is covered by natural reserves, within a chain of mountains, including Mount Nimba, presenting therefore the greatest water excess. Based on these facts, water excess of more than 500 mm y^{-1}, as for Guinea Bissau, certainly present a serious local problem due to the high rainfall concentration in one single season, in this case the summer, from June to August.

Climatic classification by Köppen (1900)

Figure 8 illustrates the climatic classes as proposed by Köppen (1900) for the ECOWAS countries, represented by climate classes A (tropical) and B (arid), subdivided in six climatic types.

Classifying climates for entire Africa, Peel et al. (2007) identified three classes (A, B and C), being B (arid) the predominant one representing 52.7% of the territory, followed by A (31.0%) and the temperate C (11.8%).

For ECOWAS, the Af climate was identified only for a small region at the extreme southwest coast of the Ivory Coast; whereas Am covers a large land portion south of parallel 12º 30’ N, south Senegal and Mali, Guinea Bissau, Ivory Coast, south Burkina Faso, Togo and Benin.

From the above exposition, it can be observed that the ECOWAS region is divided in almost parallel climatic strips in relation to the Equator. Above latitude 12º 30’ N, the ECOWAS territory is classified as arid (B). The strip between parallels 12º 30’N and 15º N is represented by the arid or semiarid steppe climates (BSw), extending from the West coast of Senegal, crossing the territory of Mali, north Burkina Faso to South of Niger. This climate is characterized by being more humid than the arid climate of the desert; more north of this strip we find the climate of largest projection within ECOWAS and the complete African continent, as cited by several authors, which is the arid desert climate *(BWw),* that prevails from north of Senegal, crossing a great portion of Mali and dominating almost all territory of Niger.

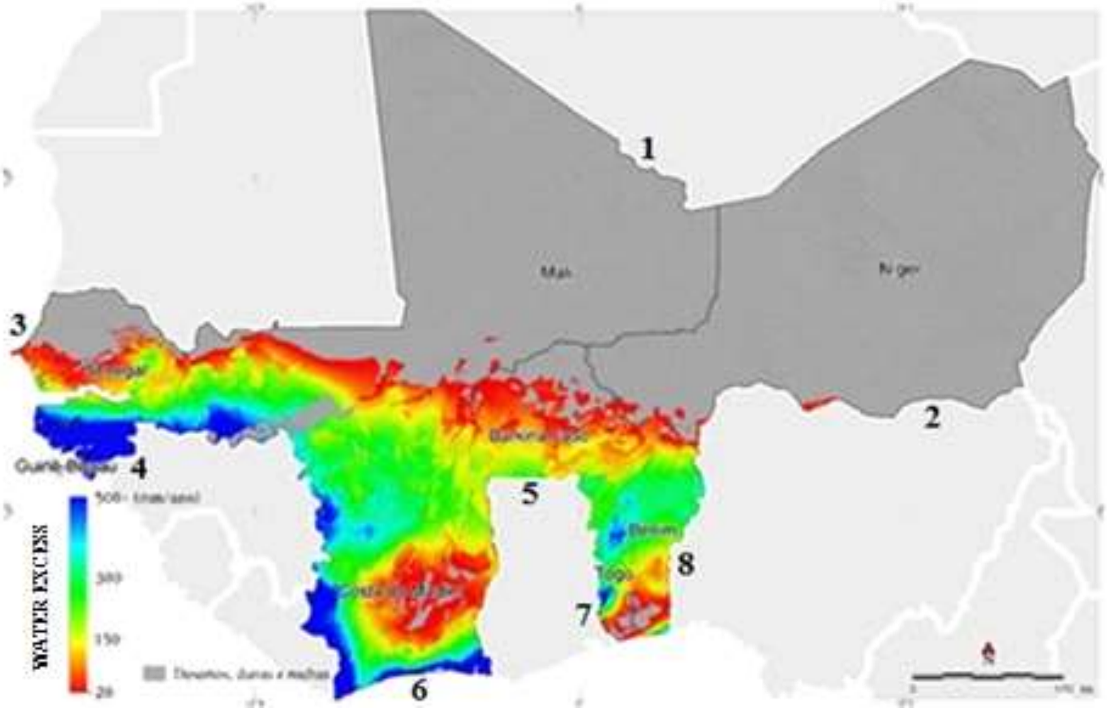


Figure 7. Average water excess (WE, mm year-1) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

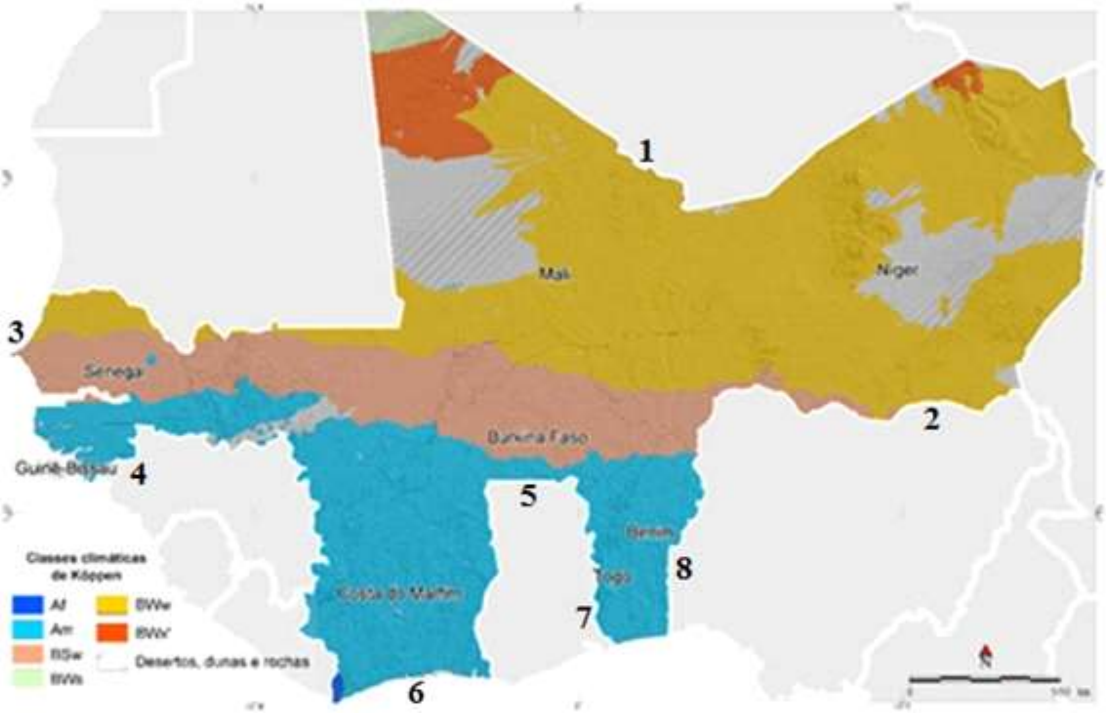


Figure 8. Climatic classes proposed by Köppen (1900) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

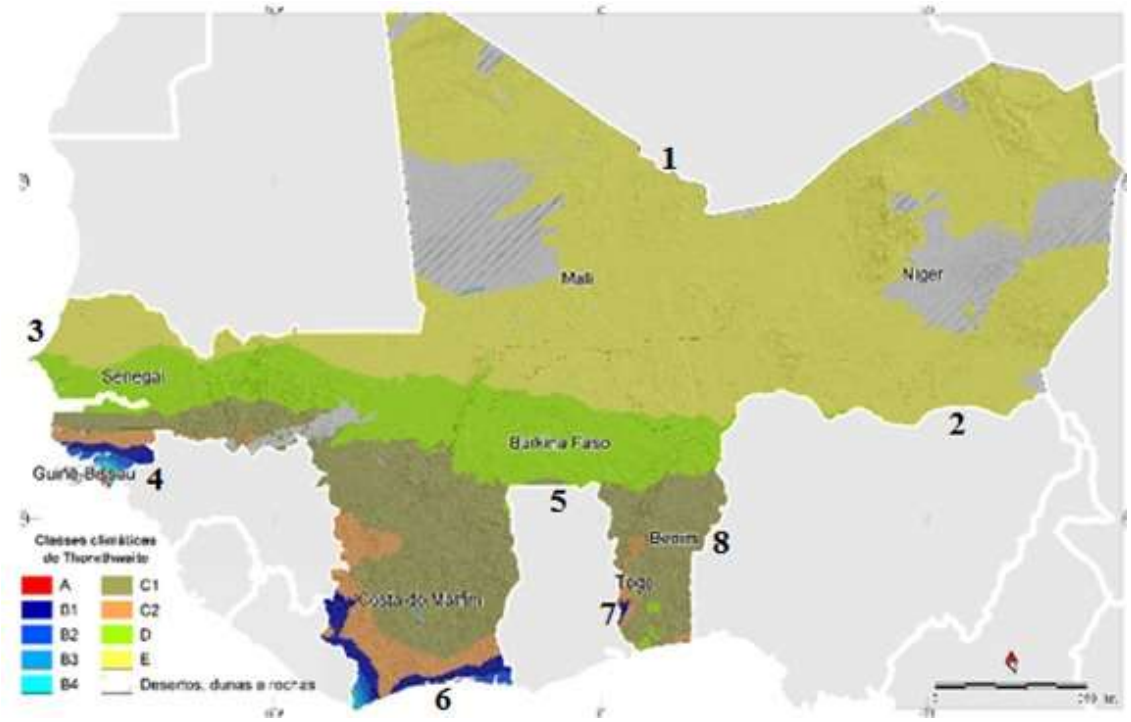


Figure 9. Climatic classes proposed by Thornthwaite (1948) for ECOWAS countries: (1) Mali, (2) Niger, (3) Senegal, (4) Guinea Bissau, (5) Burkina Faso, (6) Ivory Coast, (7) Togo and (8) Benin.
Source: Müller (2015).

North of parallel 20º N, two other arid climate types are found, BWx' occupying the north of Mali and a small portion of Niger, and BWs, in the extreme north of Mali.

According to the classification of Jones et al. (2013), the African continent is divided in bands parallel to the Equator, which cross the whole continent from the Atlantic Ocean to the Red Sea and more South to the Indic Ocean. In the Sahara desert, in Mali and Niger, there is a wide branch classified as hot arid, followed towards South by the semiarid climate, equatorial savanna with a dry winter, and the equatorial monsoon.

Climatic classification by Thornthwaite (1948)

Figure 9 illustrates the climatic classes according to Thornthwaite (1948) for the ECOWAS countries, where five great climatic groups are subdivided into nine types of climate. According to Rohli and Vega (2012), these climatic groups are: very humid (A), humid (B), sub humid (C), semiarid (D) and arid (E).

Climate A was detected only in a small portion of the southeast extreme of Ivory Coast, at the frontier with Liberia, surrounded by climate B areas, which characterize the neighboring areas between Ivory Coast and Liberia, the coastal region of Ivory Coast and all territory of Guinea Bissau. Other larger blocks belong to climate C, within Ivory Coast, Togo, Benin and the South of Senegal, south of parallel 12º 30' N.

Between parallels 12º 30'N and 15º N is the Sahel band with climate D, which goes from the Atlantic coast of Senegal, including the capital Dakar, to the extreme east of Burkina Faso; this is the transition zone between climates C and E, the last one covering the desert of Sahara, dominating the territories of Mali and Niger. Climates D and E form a block and occupy more than 50% of the ECOWAS countries, without climatic differentiation between low land and mountains. According to Carter (1948), the regime E also dominates the other areas of the African territory.

From the evaluation of the ECOWAS territory, it can be concluded that in relation to the climatic classification of Köppen (1900): (i) north of parallel 15°N in the north/south direction the classes: BWs, BWx´ e BWw (predominant class – arid climate), and (ii) south of parallel 15° N in the direction north/south, the following climatologic classes are found: BSw (semiarid), Am (predominant class – tropical climate of monsoons) and Af (climate of the tropical forest – small area); and (B) in relation to the climatic classification of Thornthwaite (1948): (i) north of parallel 15°N, we find in the direction north/South the following classes: E (predominant class - arid climate), and (ii) south of parallel 15° N, also from north to south, the following classes: D (semiarid climate), C (sub humid climate), B (humid climate) and A (very humid climate – small area).

Conclusions

With respect to agricultural management improvement, the climate classes found for the ECOWAS territory give a gross idea of the potential of each country for agricultural exploitation. The climate diversity over relatively short distances obligates detailed studies on land adaptability for growing food crops, which is actually not done based on scientific criteria. This study shows that there is still room for an increase in agricultural area, and in this way, an increasing food production.

The following integrated agrarian policies can be useful for extending agricultural area: (i) technological advancements in agro-genetics and machinery, (ii) strengthening the secondary and vocational agricultural education, (iii) crops' intensification and yields' maximization, and (iv) governmental subsidies and policy initiatives taken towards a stable and viable agricultural production within the countries examined.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Bakhoum M (2005). Competition law allocation of competencies between the west african economic and monetary union and its members [Répartition et exercice des compétences entre l'union et les états membres en droit de la concurrence dans l'union économique et monétaire ouest-africaine (UEMOA)]. Revue Internationale de Droit Economique, 19(3):319-354.

Bakhoum M (2011). Institutional coherence and effectivity of a regional competition policy: The case study of the west African economic and monetary union (WAEMU) [Cohérence institutionnelle et effectivité d'une politique régionale de la concurrence: le cas de l'union économique et monétaire ouest-africaine (UEMOA)]. Revue Internationale de Droit Economique, 25(3):305-332.

Belda M, Holtanová E, Halenka T, Kalvová J (2014). Climate classification revisited: from Koeppen to Trewartha. Climate Research, 59:1-13.

Bertelsmann Transformation Index (BTI) (2014a). Bertelsmann Stiftung's Transformation Index, Benin Country Report. Gutersloh. Available at: <http://www.bti-project.de/uploads/tx_itao_download/BTI_2014_Benin.pdf>. Access in: 21 Jan. 2015.

Bertelsmann Transformation Index (BTI) (2014b). Bertelsmann Stiftung's Transformation Index, Burkina Faso Country Report. Gutersloh. Available at: <http://www.bti-project.de/uploads/tx_itao_download/BTI_2014_Burkina_Faso.pdf>. Access in: 21 Jan. 2015.

Bertelsmann Transformation Index (BTI) (2014c). Bertelsmann Stiftung's Transformation Index, Cote d'Ivoire Country Report. Gutersloh. Available at: <http://www.bti-project.de/uploads/tx_itao_download/BTI_2014_Cote_d_Ivoire.pdf>. Access in: 21 Jan. 2015.

Bertelsmann Transformation Index (BTI) (2014d). Bertelsmann Stiftung's Transformation Index, Mali Country Report. Gutersloh. Available at: <http://www.bti-project.de/uploads/tx_itao_download/BTI_2014_Mali.pdf>. Access in: 23 Jan. 2015.

Carter DB (1948). Climates of Africa and India according to Thornthwaite's classification. Publ. Climatol. 11(4):35.

Carrère C (2013). UEMOA, CEMAC: What performance regarding trade? [UEMOA, CEMAC: Quelle performance en matière de commerce?]. Agriculture and Economic Development, 27(1):33-60.

De Ridder M, Trouet V, Van den Bulcke J, Hubau W, Van Acker J, Beeckman H (2013). A tree-ring based comparison of *Terminalia superba* climate-growth relationships in West and Central Africa. Trees - Structure Function, 27(5):1225-1238.

Dissou Y (2002). Dynamic effects in Senegal of the regional trade agreement among UEMOA countries. Rev. Int. Econ. 10(1):177-199.

Decaluwé B, Dissou Y, Robichaud V (2004). Regionalism and labour market structure: A CGE analysis of UEMOA customs union. Journal of African Economies, 13(2):302-332.

Decaluwé B, Dissou Y, Patry A (2001). Customs union among uemoa countries: a quantitative assessment [Union douanière au sein de l'uemoa une analyse quantitative]. Review of Economics, 52(4):811-830.

Dourado Neto D, Jong van Lier Q, Metselaar K, Reichardt K, Nielsen DR (2010). General procedure to initialize the cyclic soil water balance by the Thornthwaite and Mather method. Scientia Agricola, 67:87-95.

Embrapa (2006). Empresa Brasileira de Pesquisa Agropecuária. Centro Nacional de Pesquisa em Solos. Sistema brasileiro de classificação de solo. Rio de Janeiro, 306 p.

Esso LJ (2009). Divergence of UEMOA countries: Does financial development matter? International Research Journal of Finance and Economics, 33:77-86.

Food and Agriculture Organization (FAO) (2006). World reference base for soil resources: a framework for international classification, correlation and communication. Rome, 145 p. (World Soil Resources Reports, 103).

Food and Agriculture Organization (FAO) (2012). Harmonized world soil database: version 1.2. Vienna: International Institute for Applied Systems Analysis; ISRIC-World Soil Information; Institute of Soil Science; Chinese Academy of Sciences; Joint Research Centre of the European Commission 50 p.

Food and Agriculture Organization (FAO) (Statistics division) (2015). Production – Crops. Statistics division. Available at: <http://faostat3.fao.org/download/Q/QC/E>. Access in: 17 Mar. 2015. Kindly provide work title

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005). Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol. 25:1965-1978.

Heubes J, Schmidt M, Stuch B, García Márquez JR, Wittig R, Zizka G, Thiombiano A, Sinsin B, Schaldach R, Hahn K (2013) The projected impact of climate and land use change on plant diversity: An example from West Africa. Journal of Arid Environments, 96:48-54.

Heubes J, Heubach K, Schmidt M, Wittig R, Zizka G, Nuppenau EA, Hahn K (2012). Impact of Future Climate and Land Use Change on Non-timber Forest Product Provision in Benin, West Africa: Linking Niche-based Modeling with Ecosystem Service Values [L'impact du changement climatique et l'aménagement du territoire sur les produits forestiers non ligneux en Benin, Afrique de l'Ouest: Combiner niche-based modeling aux valeurs des services écosystémiques]. Economic Botany, 66 (4):383-397.

Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S, Jones R, Kilasara M, Le Roux P, Micheli E, Montanarella L, Spaargaren O, Thiombiano L, van Ranst E, Yemefack M, Zougmore R (2013). Soil atlas of Africa. Luxembourg: European Commission, Publications Office of the European Union 176 p.

Keho Y (2010). Effect of financial development on economic growth: Does inflation matter? Time series evidence from the UEMOA countries. International Economic Journal, 24(3):343-355.

Kablan S (2009). Measuring the effectiveness of banks in developing countries: The case of the West African Monetary and Economic Union (UEMOA) [Mesure de l'Efficacitédes Banques dans les Pays en Voie de Développement: Le Cas de l'Union Economique et Monetaire Ouest Africaine (UEMOA)]. African Development Review, 21(2):367-399.

Köppen W (1900). Versuch einer klassifikation der klimate, vorzugsweise nach ihren Beziehungen zur Pflanzenwelt. Geographic Zeitschrift 6:657-679.

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006). World map of the Koeppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15:259-263.

Koffi-Tessio EM (1998). Food security in sub-saharan Africa: Evidence from the union economique et monétaire ouest-africaine (UEMOA). Agrekon, 37(3):296-312.

Lansana B (2012a). Application models ARCH / GARCH on volatility inflation and economic growth: UEMOA countries [Application des modèles ARCH / GARCH sur la volatilité de l'inflation et de la croissance économique: Pays de l'UEMOA]. International Research Journal of Finance and Economics, 95:24-47.

Lansana B (2012b). Cointegration and causality between financial development and economic growth: Country of ECOWAS and UEMOA [Cointégration et causalité entre croissance économique et développement financier: Pays de la cedeao et de l'UEMOA]. International Research Journal of Finance and Economics, 91:78-97.

Lapworth DJ, MacDonald AM, Tijani MN, Darling WG, Gooddy DC, Bonsor HC, Araguás-Araguás LJ (2013). Residence times of shallow groundwater in West Africa: Implications for hydrogeology and resilience to future changes in climate [Temps de séjour de ll'eau superficielle en Afrique de l'Ouest: Implications hydrogéologiques et résilience aux futurs changements climatiques]. Hydrogeology Journal, 21(3):673-686.

Mendonça PV (1958). Sobre o novo método de balanço hidrológico do solo de Thornthwaite-Mather. In: Congresso Luso-Espanhol Para O Progresso Das Ciências, 24., Madrid. Anais... Madri, pp. 271-282.

Müller MS (2015). Climate classification by Köppen and Thornthwaite and agricultural zoning for maize and soybean in the Economic Community of West African States. Dissertation (Doctorate). “Luiz de Queiroz” College of Agriculture. University of São Paulo. 150 p.

Nubukpo K (2007a). Dépenses publiques et croissance des pays de l'Union économique et monétaire ouest-africaine (UEMOA). Contemporary Africa, 222(2):223-250.

Nubukpo K (2007b). Effectiveness of monetary policy under conditions of uncertainty and extraversion: The case of the West African Economic and Monetary Union (UEMOA) [L'efficacité de la politique monétaire en situation d'incertitude et d'extraversion: Le cas de l'Union Economique et Monétaire Ouest Africaine (UEMOA)]. European Journal of Development Research, 19(3):480-495.

Oguntunde PG, Abiodun BJ, Lischeid G (2017). Impacts of climate change on hydro-meteorological drought over the Volta Basin. West Africa Global and Planetary Change, 155:121-132.

Ouattara W (2007). Productivity and externalities of public expenditure in the UEMOA zone [Productivités et externalités des dépenses publiques en zone UEMOA]. African Development Review, 19(3):481-500.

Peel MC, Finlayson BL, McMahon TA (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences Discussions 4:439-473. Available at: <http://www.hydrol-earth-syst-sci-discuss.net/4/439/2007/hessd-4-439-2007.pdf>. Access in: 18 Feb. 2015.

Rohli RV, Vega AJ (2012). Climatology. Baton Rouge: Louisiana State University 432 p.

Sablah M, Klopp J, Steinberg D, Touaoro Z, Laillou A, Baker S (2012). Thriving public-private partnership to fortify cooking oil in the West African Economic and Monetary Union (UEMOA) to control vitamin A deficiency: Faire Tache d'Huile en Afrique de l'Ouest. Food and Nutrition Bulletin, 33(4):S310-320.

Sylla MB, Elguindi N, Giorgi F, Wisser D (2016a). Projected robust shift of climate zones over West Africa in response to anthropogenic climate change for the late 21st century. Climatic Change, 134(1-2):241-253.

Sylla MB, Nikiema PM, Gibba P, Kebe I, Klutse NAB (2016b). Climate change over West Africa: Recent trends and future projections. Adaptation to Climate Change and Variability in Rural West Africa, pp. 25-40.

Shuttle Radar Topography Mission (2010). U.S. Department of the Interior | U.S. Geological Survey. Available at: <http://srtm.usgs.gov/>. Access in: 20 Jan. 2015.

Sparoveck G, Van Lier QDJ, Dourado Neto D (2007). Computer assisted Koeppen climate classification: a case study for Brazil. International Journal of Climatology, 27:257-266.

Thornthwaite CW (1948). An approach towards a rational classification of climate. Geographical Review 38:55-94.

Thornthwaite CW, Mather JR (1955). Water balance publication in climatology. Drexel Institute of Technology, 8:1-104.

Thornthwaite CW, Mather JR (1957). Instructions and tables for computing potential evapotranspiration and the water balance. Publication Climatology, 10(3):185-311.

Tanimoune NA, Combes JL, Plane P (2008). Threshold effects of fiscal policies on economic activity in WAEMU states [La politique budgetaire et ses effets de seuil sur l'activite en union economique et monetaire ouest africaine (UEMOA)]. Economics Preview, 186(5):145-162.

Tirogo J, Jost A, Biaou A, Valdes-Lao D, Koussoubé Y, Ribstein P (2016) Climate variability and groundwater response: A case study in Burkina Faso (West Africa). Water, 8(5):171.

United Nations Development Program (2015). Human development reports. Available at: <http://hdr.undp.org/es/reports>. Access in: 20 Jan. 2015.

Virmani SM, Reddy SJ, Bose MNS (1980). A handbook on the rainfall climatology of West Africa: data for selected locations. Andhira Pradesch: International Crops Research Institute for the Semi-Arid Tropics. Information Bulletin, 7. Available at: <http://oar.icrisat.org/763/1/RA_00041.pdf>. Access in: 17 Feb. 2015.

Walker HO (1962). Weather and climate. In: Wills JB (ed.) Agriculture and land use in Ghana. London: Oxford University Press, pp. 7-59.

Wikipedia (2014). Economic Community of West African States. Available at: <http://en.wikipedia.org/wiki/West_African_Economic_and_Monetary_Union>. Access in: 12 May 2014.

World Bank (2014). Climate change knowledge portal for development practitioners and policy makers. Available at: <http://sdwebx.worldbank.org/climateportal/>. Access in: 20 Jan. 2015.

World Bank (2013). International bank for reconstruction and development: world development indicators. Washington. Available at: <http://databank.worldbank.org/data/ download/WDI-2013-ebook.pdf>. Access in: 23 Jan. 2015.

World Bank (2015). Historical climate. Available at: <http://sdwebx.worldbank.org/ climateportal/index.cfm?page=country_historical_climate&ThisRegion=Africa&ThisCCode=CIV#>. Access in: 16 Feb. 2015.

Vol. 13(23), pp. 1213-1219, 7 June, 2018
DOI: 10.5897/AJAR2018.13085
Article Number: DC477C757318
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Estimation of amylose, protein and moisture content stability of rice in multi locations

Misbah Riaz*, Muhammad Akhter, Muhammad Iqbal, Sultan Ali, Rana Ahsan Raza Khan, Mohsin Raza, Farrah Shamim and Neelum Shahzadi

Rice Research Institute, Kala Shah Kaku, Lahore, Pakistan.

Received 27 February, 2018; Accepted 4 April, 2018

Rice quality is measured of the rice grown on different five locations by an auto grain analyzer. Auto Grain analyzer works on the Near-Infrared transmittance (720 - 1100 nm). Protein, amylose and moisture contents of the rice samples of 9 fine lines were tested. Different environment tested entries were evaluated and found that all the values have highly significant effect of environment and genotypes. The environment and genotype ranking in the Additive Main effect and Multiplicative Interaction (AMMI) model were studied and PK8680-13-3-1 and check variety Basmati 515 were found most stable lines in most micro environment with respect to amylose contents and moisture contents. Protein contents were studies in PK8892-4-2-1-1 and PK3810-30-1 are best suited in the all environments. The results indicated that grain analyzer may be used for Amylose and Protein contents and effect of different locations on these traits in early breeding generations for quality control in the food industry.

Key words: Rice, environment, amylose, protein, auto grain analyzer.

INTRODUCTION

For over half of the world's population, rice is the main food. Quality of the grain is of much important with respect to the rice scientists, producers and as well as consumers. In bid to spread the rice genetic base, due to which there is possibility to breed for the purpose of improved crop yield, crosses have been made between distant parents (e.g. *Indica* × *Japonica* crosses) (Wu et al., 1996; Zhuang et al., 1997). Additionally, in spite of the total poorer agronomic phenotypes detected in wild species, they have been a valued basis of favorable genes from the start of modern breeding. Among the diverse modules factors of agronomy packages for rice cultivation, transplanting is one of the significant features of rice quality impacts (Mahajan et al., 2015). The introgression of wild rice alleles has been effectively used as an actual method in cultivated rice breeding plans for additional development of agronomic traits like quality (Thomson et al., 2003; Aluko et al., 2004; Fasahat et al., 2012; Xiao et al., 1998; Septiningsih et al., 2003). The cooking excellence of rice is significantly affected by the two attributes amylose contents and protein contents in the rice (Champagne et al., 1998). The amylose content (AC) is strictly associated by the sensual possessions of the freshly cooked rice (Champagne et al., 2004),

---

*Corresponding author. E-mail: misha_riaz99@hotmail.com, misbahriaz23@gmail.com.

although the protein content (PC) dictates to the consistency (texture) of the cooked rice by hindering absorption of the water and starch puffiness during the cooking (Xie et al*.,* 2008).

Rice is consumed primarily as a full grain and the texture of the whole grain is a matter of prime significance. Cultivars of waxy and non-waxy rice are generally categorized conferring to their amylose content, grain sizes, amylograph reliability, gelatinization possessions of the take out starches and of the texture (hardness and sensory dimensions) of the cooked rice (Juliano, 1985). Texture is a significant characteristic of food acceptance by the consumers and also a dire step in the assessment of quality of rice. Texture is proposed as it is the sensory appearance of the food arrangement and the style in which that arrangement responds to the applied force, so amylose content had rice variety affects the rice texture (Szczesniak, 1968).

The greatest essential aspect inducing the cooking and processing appearances of rice is amylose content which is considered to be one of them. It is normally used as an objective index for the texture of cooked rice (Webb, 1991). Low amylose contents are linked with cohesive, tender, and glossy rice on the cooking. On the contrary, high levels of amylose content cause rice to absorb extra water and accordingly expand more throughout the cooking, and the cooked grains tend to dry, fluffy and detached (Juliano, 1971). Rice breeders consistently are anxious regarding having new rice lines with suitable amylose content and protein contents. Rice is a vital source of protein, delivering additional 50% of the entire protein consumed in the more or less countries. Even a modest rise in protein contents levels in rice would provide an important nutritional enhancement to the hundreds of millions of people who rely on it. In the selection of each variety and market value, determination of rice quality is very much important in many countries (Fitzgerald et al*.,* 2008; Champagne et al*.,* 1999).

G × E interaction is common when genotypes (G) are verified crosswise on different environments (E). Based on the range of the interface, classification of genotypes can differ through the environments. Several approaches have been projected to analyses the genotype-by-environment relations, illustrations being the combined analysis of variance (ANOVA). The combined ANOVA can check the significance of interactions and main effects; then again it does not aid clarification of the arrays of the G × E interaction. To this purpose, AMMI is the classical model of first choice when main effects and the interactions are together essential (Zobel et al*.,* 1988). Dissimilarities in nutrient readiness and soil moisture, ambient temperature and atmospheric composition also affected starch functionality which ultimately impacts on amylose contents (Beckles and Thitisaksakul, 2014). This technique assimilates ANOVA and principal component analysis (PCA) into a combined method.

Table 1. List of evaluated genotypes under study.

S/N	Designation	Variant code
1	PK8892-4-2-1-1	FV1
2	PK8647-11-1-1	FV2
3	PK8431-1-2-1-2-4	FV3
4	PK8430-1-2-1-3	FV4
5	PK8431-6-1-1-1	FV5
6	PK8667-8-5-1	FV6
7	PK8680-13-3-1	FV7
8	Basmati 515 (Check)	FV8
9	PK3810-30-1	FV9

METHODOLOGY

Nine basmati lines of rice PK8892-4-2-1-1, PK8647-11-1-1, PK8431-1-2-1-2-4, PK8430-1-2-1-3, PK8431-6-1-1-1, PK8667-8-5-1, PK8680-13-3-1, Basmati 515, PK3810-30-1 were categorized as fine variants FV1, FV2, FV3, FV4, FV5, FV6, FV7, FV8, FV9, respectively (Table 1) grown in 5 major rice producing areas (Farooqabad, Gujranwla, Faisalabad, Shorkot and Kala Shah Kaku) of Punjab, Pakistan during the year 2014 in Regional Adaptability Yield Trial (RAYT-14). The sample population was collected for the amylose, protein and moisture content in the form of milled rice. Auto Grain Analyzer is used for measurement of the characters evaluated. The measurement system is Near-Infrared Transmittance (720-1100 nm) and was used to define the amylose content, proteins contents and moisture contents in the rice.

The AN-900 Near infrared microscopy is accomplished for calculating moisture content, protein and amylose contents in the short, long brown rice as well as milled rice. Elements were calculated based on the transmittance of the light. Measurements are happening by simply loading a sample into the sample case. This method permitted rapid, simple and non-destructive constituent examination of the traits. Paralleled to the infrared reflectivity measurement method, the Near-Infrared Transmittance method engaged by the AN-900 is quite affected by the shape or color of the sample and therefore excellent measurement characteristics. To access a sample, 60 ml of the rice sample (milled) was simply filled in sample case and the rice sample case was inserted into the slot on top of the AN-900. In less than 30 s, all of the measurement components were displayed on the large digital screen and output is taken on computer or optional printer.

Statistical analysis

For the statistical analysis of data, attained software Statistx 8.1 and GENSTAT 12.1 were used. Additive Main effect and Multiplicative Interaction (AMMI) model of stability was applied to study the genotype and environment interactions.

RESULTS AND DISCUSSION

The mean values of nine genotypes grown in five different environments were calculated. Apart from the environments, the genotypes and all others traits were found to be highly significant. Different locations were studied for the quality traits of rice with different environmental temperature, rainfall pattern and soil. In

Faisalabad, PK8892-4-2-1-1 have higher amylose contents (25.3%) compared to other locations and also was higher from the check Basmati 515 approved cultivated variety. While in Farooqabad, the Basmati 515 performed at higher level of amylose contents with the value of 25.6% and the fine variant PK3810-30-1 also produces the amylose contents 25.3%. In Gujranwala, the 25.5% amylose contents were produced in another fine variant named PK8680-13-3-1, whereas in Kala Shah Kaku, 26% highest value was obtained for the amylose contents by the same variant who performed in the Faisalabad PK8892-4-2-1. In Shorkot variant, line PK8680-13-3-1 again performed at highest level for amylose contents with the mean value of 25.05%. So it is assumed that despite the different environmental effects, 3 lines along with checks produced highest level of amylose contents in different environments. However, in case of other fine variants there is similar expression. The lowest amylose contents 21.9% were produced in the PK8647-11-1-1 in Farooqabad location and the same line produced the same pattern of amylose contents production in different environments.

Like amylose, protein content was affected by the environmental parameter when it was checked in different locations. At two locations, viz; Faisalabad and Farooqabad, the maximum value of protein content was 8.3% produced by the variants PK8430-1-2-1-3 and PK8892-4-2-1-1. Fine variant PK3810-30-1 with 8.4%, PK8647-11-1-1 with 8.35%, PK8892-4-2-1-1 with 8.2% produced maximum protein content in the locations Kala Shah Kaka, Gujranwala and Shorkot, respectively. The minimum value for protein content (7.5%) was observed in the PK8667-8-5-1 in Farooqabad and Shorkot. In case of protein contents, it was studied that the PK8892-4-2-1 is the most stable line in different environments.

In both Farooqabad and Gujranwala locations, the moisture content was maximum (14.5%) in PK8667-8-5-1; however, in other locations: Faisalabad, Kala Shah Kaku and Shorkot, the moisture content was stable and less than 13% which are more desirable. The ANOVA revealed highly significant G × E interactions as well as significant differences among genotypes and among environments for all traits. For the significance of analysis of variance the data was normalized to apply AMMI analysis and the variability among genotypes for different environments was checked in initial data analysis.

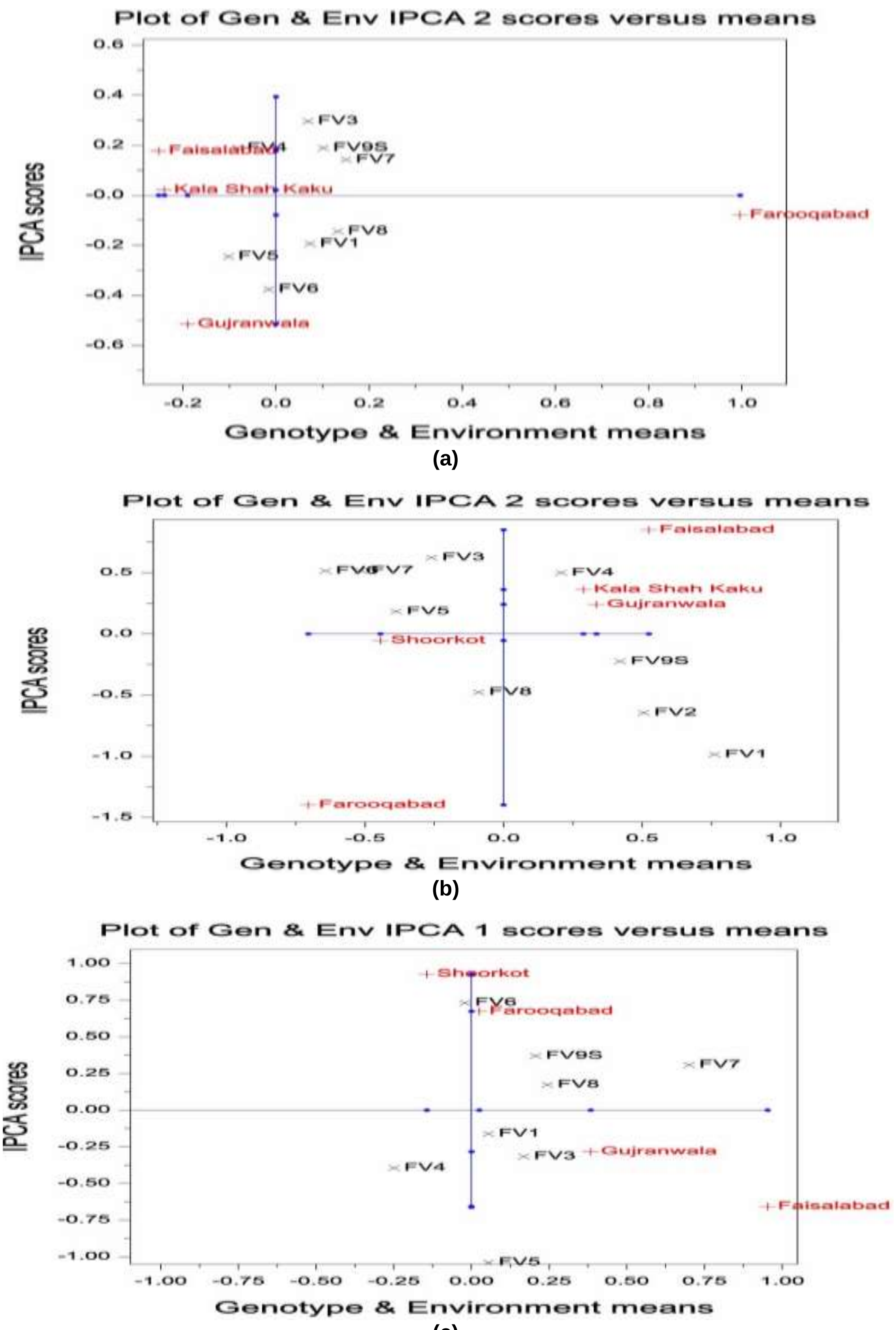
AMMI-1 biplot display

To further examine the main and interaction effects across genotypes and environments, biplots were constructed (Figure 1). The genotype and environment means are plotted on the x-axis, while the IPCA1 scores for the same genotypes and environments are on the y-axis. Displacement along the x-axis shows differences in the main effects, whereas displacement along the y-axis reflects differences in the interaction effects. When a cultivar and an environment have the same sign on IPCA1, their interaction is positive; if the sign is different, their interaction is negative. Genotypes with dissimilar interaction scores have dissimilar interaction effects across environments, while genotypes with interaction scores close to zero have negligible interaction effects. FV4 was found more suitable for the Faisalabad environment along with FV3, FV9 and FV7 with the strong positive interaction. In Gujranwala, FV5, FV8, FV6 and FV1 interacted positively and strongly. While in Farooqabad, FV6, FV7, FV8, FV9 performed at their suitable level of amylose content. Gujranwala, Kala Shah Kaku and Shorkot are the best suited genotype locations (Table 2). For protein and moisture content, the mean and variances of genotype and environment in AMMI ranking were studied and found to be the best suited environment for all the variants (Tables 4, 5 and 6).

DISCUSSION

Before releasing a new variety on a commercial basis, plant breeders grow different varieties in different environments over several years to evaluate the magnitude of G × E interactions for confirming the stability of the variety across various environments (Sabaghnia et al*.,* 2008). The AMMI model is suitable for the analysis of the G × E interaction different location trials (Zobel et al*.,* 1988). The analysis of variance of the AMMI model showed that G × E interactions were highly significant for all traits. Firmness and fluffiness of rice grain on cooking depends upon amylose content whether it will be, or it will turn sticky and glutinous. The average amylose content of rice grown in five diverse environments was high under the present study, which outcomes in elongation during cooking and cooked rice showed soft texture (Juliano and Pascual, 1980). The rice grain quality traits such as amylose and protein content were readily affected by various environmental factors including solar radiation, temperature and location of the field in various studies (Sharifi et al*.,* 2010; Bao et al*.,* 2002; Tian et al*.,* 2005). Comparable to the grain yield, the confirmed grain quality parameters were entirely significantly influenced by genotype, environment and G × E interaction by Nagarajan et al. (2010). The AMMI analysis produced highly significant principal components for protein content and amylose content (Table 3). Variable properties of growing temperatures on amylose content of the rice cultivars had been described (Singh et al*.,* 2014). However, rice has a low quantity of protein content (that is, between 5.8 and 9.4%) in the milled rice, though rice is used as the main source of protein in numerous rice-consuming countries of world. Therefore, protein content is significant from a dietary perspective.

In this study, protein content was quite high (> 8%) for all the genotypes. Protein content was affected by



(a)

(b)

(c)

Figure 1. AMMI-1 biplot showing the means of Genotypes (G) and Environments (E) against their respective IPCA1 scores. a) Amylose content %, b) Protein content %, c) Moisture Content.

Table 2. Combine analysis of variance from AMMI model for evaluated traits in experimental environments.

Source	df	Protein Content		Amylose Content		Moisture Contents	
		SS	MS	SS	MS	SS	MS
Total	134	134.00	1.000	134	1	134.00	1.000
Treatments	44	129.93	2.953**	38.9	0.884**	126.93	2.885**
Genotypes	8	29.40	3.676**	2.78	0.347**	30.55	3.818**
Environments	4	31.45	7.862^{ns}	33.74	8.435**	69.25	17.313**
Block	10	0.45	0.045**	94.56	9.456^{ns}	0.46	0.046**
Interactions	32	69.07	2.159**	2.38	0.074**	27.13	0.848**
IPCA1	11	28.56	2.596**	1.49	0.135**	15.41	1.401**
IPCA2	9	24.64	2.738**	0.63	0.07**	7.84	0.871**
Residuals	12	15.87	1.322	0.26	0.022	3.89	0.324
Error	80	3.62	0.045	0.54	0.007	6.60	0.083

ns = Non-significant; ** = highly significant at 0.01 and 0.05 levels of significance,

Table 3. Environment means and variances and AMMI ranking for Amylose contents.

Environment	NE	Em	Variances	IPCAe [1]	IPCAe [2]	1	2	3	4
Faisalabad	1	-0.2515	0.0286	0.06976	0.17793	FV7	FV3	FV9	FV8
Farooqabad	2	0.9966	3.7499	-0.73783	-0.07846	FV8	FV9	FV6	FV7
Gujranwala	3	-0.1893	0.0287	0.28991	-0.51480	FV1	FV5	FV8	FV6
Kala Shah Kaku	4	-0.2394	0.0241	0.18796	0.02120	FV7	FV1	FV8	FV3
Shorkot	5	-0.3164	0.0249	0.19019	0.39414	FV7	FV3	FV9	FV4

Table 4. Genotypes means and scores for proteins content, amylose content and moisture.

Genotype	NG	Protein Content			Amylose Content			Moisture Content		
		Gm	IPCAg[1]	IPCAg[2]	Gm	IPCAg[1]	IPCAg[2]	Gm	IPCAg [1]	IPCAg [2]
FV1	1	0.7611	-0.42362	-0.98562	0.0734	0.12467	-0.19334	0.0549	-0.16100	0.64036
FV2	2	0.5058	0.33768	-0.64551	-0.3271	0.11957	0.14119	-1.1603	0.32778	-0.00470
FV3	3	-0.2600	-0.45738	0.62233	0.0690	-0.06908	0.29623	0.1688	-0.31622	0.07503
FV4	4	0.2080	-0.81184	0.49833	-0.0829	0.37584	0.18890	-0.2489	-0.39415	-0.68147
FV5	5	-0.3876	0.75400	0.18206	-0.1018	0.46073	-0.24477	0.0549	-1.03944	0.11592
FV6	6	-0.6429	0.63324	0.51417	-0.0156	-0.25733	-0.37567	-0.0211	0.73201	-0.07951
FV7	7	-0.5153	0.21064	0.51631	0.1502	-0.05074	0.14228	0.7004	0.30879	-0.54460
FV8	8	-0.0898	0.54213	-0.47701	0.1330	-0.33957	-0.14410	0.2447	0.17283	-0.15103
FV9	9	0.4207	-0.78485	-0.22506	0.1018	-0.36410	0.18929	0.2067	0.36939	0.63000

Table 5. Environment means and variances and AMMI ranking for protein contents.

Environment	NE	Em	Variances	IPCAe[1]	IPCAe[2]	1	2	3	4
Faisalabad	1	0.5247	0.3945	-0.50365	0.84972	FV4	FV9	FV3	FV1
Farooqabad	2	-0.7044	1.4911	0.01375	-1.39726	FV1	FV2	FV9	FV8
Gujranwala	3	0.3356	0.4943	1.31372	0.24044	FV2	FV5	FV8	FV6
Kala Shah Kaku	4	0.2884	0.3249	0.20714	0.36176	FV2	FV1	FV4	FV9
Shoorkot	5	-0.4444	1.2393	-1.03097	-0.05466	FV1	FV9	FV4	FV2

Table 6. Environment means, variance and AMMI ranking for moisture contents.

Environment	NE	Em	Variance	IPCAe[1]	IPCAe[2]	1	2	3	4
Faisalabad	1	0.9536	0.3910	-0.65675	0.28970	FV5	FV3	FV1	FV7
Farooqabad	2	0.0253	0.5972	0.67430	0.73315	FV9	FV7	FV1	FV6
Gujranwala	3	0.3840	0.2773	-0.28332	0.31474	FV7	FV5	FV1	FV9
Kala Shah Kaku	4	-1.2194	0.5861	-0.66243	-0.64542	FV7	FV5	FV4	FV3
Shoorkot	5	-0.1435	0.6388	0.92820	-0.69217	FV7	FV6	FV8	FV9

different factors, e.g. fertilizing and soil salinity or alkalinity (Fasahat et al*.,* 2012; Eggum and Juliano, 1975; Juliano, 1985), short growth periods. A great quantity of the whole variability in protein content is nonetheless to be accredited to environment (Shobha et al*.,* 2006). As a result, brown rice becomes more unaffected to cracking and breakage during abrasive milling due to the high grain protein than low protein rice of the same variety (Hatfield and Follett, 2008). The impact of different environments on protein and amylose was also studied on different transplanting date (Kaur et al*.,* 2016). Climate fluctuations caused severe deviations in rainfall patterns, with increasing temperatures and critical growing conditions. Rice yield and quality are considerably affected by weather circumstances. Studies carried out on rice established the adverse influence of such (Oteng-Darko et al*.,* 2013).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Aluko G, Martinez C, Tohme J, Castano C, Bergman C, Oard JH (2004). QTL mapping of grain quality traits from the interspecific cross *Oryza sativa* × *Oryza. glaberrima*. Theoretical and Applied Genetics, 109:630-639.

Bao JS, Sun M, Corke H (2002). Analysis of genetic behavior of some starch properties in indica rice (*Oryza sativa* L.): thermal properties, gel texture, swelling volume. Theoretical and Applied Genetics, 104:408-413.

Beckles DM, Thitisaksakul M (2014). Review: how environmental stress affects starch composition and functionality in cereal endosperm. Starch/Starke, 66:58-71.

Champagne E T, Lyon, BG, Min B K, Vinyard BT, Bett KL, Barton FE, (1998). Effects of postharvest processing on rice texture profile analysis. Cereal Chemistry Journal, 75:181-186.

Champagne ET, Bett KL, Vinyard BT, McClung AM, Barton FE, Moldenhauer K, Linscombe SA, McKenzie K (1999). Correlation between cooked rice texture and Rapid Visco Analyses measurements. Cereal Chemistry Journal, 76:764-771.

Champagne ET, Bett-Garber KL, McClung AM, Bergman C (2004). Sensory characteristics of diverse cultivars as influenced by genetic and environmental factors. Cereal Chemistry Journal, 81:237243.

Fitzgerald MA, Sackville-Hamilton NR, Calingacion MN, Verhoeven HA, Butardo VM (2008). Is there a second gene for fragrance in rice? Plant Biotechnology Journal, 6:416-423.

Eggum BO, Juliano BO (1975). Higher protein content from nitrogen fertilizer application and nutritive value of milled rice protein. Journal of the Science of Food and Agriculture, 26:425-427.

Fasahat P, Muhammad K, Abdullah A, Wickneswari R (2012a). Identification of introgressed alien chromosome segments associated with grain quality in *Oryza rufipogon* × MR219 advanced breeding lines using SSR markers. Genetics and Molecular Research, 11:3534-3546.

Juliano B (1971). A simplified assay for milled-rice amylose. Cereal Science Today, 16:334-340, 360.

Juliano BO, Pascual CG (1980). Quality Characteristics of Milled Rice Grown in Different Countries, p: 25. IRRI Research Paper Series No. 48: International Rice Research Institute Los Banos: Laguna, Philippines.

Juliano B (1982). An International Survey of methods used for evaluation of the cooking and eating qualities of milled rice. IRRI Research paper series number 77. Los Baños, Laguna, Filipinas pp. 1-27.

Juliano B (1985). Criteria and tests for rice grain qualities. In: Rice Chemistry and Technology, Chapter 12. Minnesota: AACC pp. 443-514.

Mahajan G, Sharma N, Kaur R, Chauhan BS (2015). Comparison of photoperiod-sensitive and photoperiod-insensitive basmati cultivars for grain yield, water productivity, and quality traits under varied transplanting dates in northwest India. Crop and Pasture Science, 66:793-801.

Nagarajan S, Jagadish SVK, Prasad ASH, Thomar AK, Anand A, Pal M, Agarwal PK (2010). Local climate affects growth, yield and grain quality of aromatic and nonaromatic Rice in northwestern India. Agriculture, Ecosystems and Environment, 138:274-281.

Oteng-Darko P, Kyei-Baffour N, Ofori E (2013).Yield of rice as affected by transplanting dates and plant spacing under climate change simulations. Journal of Agricultural Reseach, 12:55-63.

Kaur P, Pal P, Virdi AS, Kaur A, Singh A, Mahajan M (2016). Protein and starch characteristics of milled rice from different cultivars affected by transplantation date. Journal of Food Science and Technology, 53(8):3186-3196

Sabaghnia N, Dehghani H., Sabaghpour SH (2008). Graphic analysis of genotype by environment interaction for lentil yield in Iran. Agronomy Journal, 100:760-764.

Shobha RN, Subba RLV, Viraktamath BC (2006). National guidelines for the conduct of tests for distinctness, uniformity, and stability: rice (*Oryza sativa* L.). Directorate of Rice Research, Rajendranagar, Hyderabad.

Sharifi P, Dehghani H, Moumeni A, Moghaddam M (2010). Genetic main effect and genotype × environment interaction for cooking quality traits in a diallel set of Indica rice (*Oryza sativa* L.) varieties. Crop and Pasture Science, 61:475-482

Septiningsih EM, Trijatmiko KR, Moeljopawiro S, McCouch SR (2003). Identification of quantitative trait loci for grain quality in an advanced backcross population derived from the Oryza sativa variety IR64 and the wild relative O. rufipogon. Theoretical and Applied Genetics, 107(8):1433-41.

Singh N, Paul P, Virdi AS, Kaur P, Mahajan G (2014). Influence of early and delayed transplantation of paddy on physicochemical, pasting, cooking, textural and protein characteristics of milled rice. Cereal Chemistry, 91:389-397.

Szczesniak AS (1968). Correlations between objective and sensory texture measurements. Food Technology, 22:981-985.

Thomson MJ, Tai TH, McClung AM, Lai XH, Hinga ME, Lobo KB, Xu Y, Martínez R, McCouch SR (2003). Mapping quantitative trait loci for yield, yield components and morphological traits in an advanced backcross population between *Oryza rufipogon* and the *Oryza sativa* cultivar Jefferson. Theoretical and Applied Genetics, 107:479-493.

Tian R, Jiang GH, Shen LH, Wang LQ, He YQ (2005). Mapping quantitative trait loci underlying the cooking and eating quality of rice using a DH population. Molecular Breeding, 15:117-124.

Webb BD (1991). Rice quality and grade. Pages 89-119 in: Rice: Volume 2, Utilization. B. S. Luh, ed. Van Nostr and Reinhold: New York.

Wu P, Zhang G, Huang N (1996). Identification of QTLs controlling quantitative characters in rice using RFLP markers. Euphytica, 89:349-354.

Xie LH, Chen N, Duan BW, Zhu ZW, Liao XY (2008). Impact of proteins on pasting and cooking properties of waxy and non-waxy rice. Journal of Cereal Science, 47:372-379.

Xiao J, Li J, Grandillo S, Ahn SN, Yuan L, Tanksley SD, McCouch SR (1998). Identification of trait-improving quantitative trait loci alleles from a wild rice relative, Oryza rufipogon. Genetics, 150:899-909.

Zhuang JY, Lin HX, Lu J, Qian HR, Hittalmani S, Huang N, Zheng KL (1997). Analysis of QTL × environment interaction for yield components and plant height in rice. Theoretical and Applied Genetics, 95:799-808.

Zobel RW, Wright MS, Gauch HG (1988). Statistical analysis of a yield trial. Agronomy Journal, 80:388-393.

Vol. 13(23), pp. 1220-1226, 7 June, 2018
DOI: 10.5897/AJAR2018.13144
Article Number: C5B167057320
ISSN: 1991-637X
Copyright ©2018
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

An agronomic approach to screen sugar and energy cane genotypes for drought tolerance

S. Elsayed-Farag[1*], M. De Almeida Silva[2], N. Solis-Garcia[1], J. Enciso[1] and J. Da Silva[1]

[1]Texas A&M AgriLife Research and Extension Center, Texas A&M University System, Weslaco, TX 78596, USA.
[2]School of Agricultural Sciences, UNESP-São Paulo State University, P. O. Box 237, Botucatu, SP 18603-970, Brazil.

Received 26 March, 2018; Accepted 30 April, 2018

Sugarcane production can be affected by extreme environmental conditions, such as drought stress. This study focused on establishing a screening method to evaluate and select drought tolerant germplasm of *Saccharum* species. A new drought screening methodology is presented in this paper. A randomized block design experiment was conducted under greenhouse conditions with 2 months old seedlings of five genotypes of *Saccharum spontaneum* (IRAN 28, JW43, TUS12-72, TUS12-23, X08-0299) and one genotype of a commercial cultivar (*Saccharum* spp. CP72-1210), under well-irrigated and water stress conditions. Three treatments were established with irrigation intervals at 3, 6, and 9 days, with four replicates per each genotype in each treatment. Evapotranspiration, stomatal conductance, total biomass, leaf death rate, rate of new tillers and shoot growth were evaluated during the experiment. JW43 and CP72-1210 presented the highest values of stomatal conductance with non-significant differences. Accumulated water used by all the genotypes was significantly different among the three treatments. Also, significant differences were found in the total dry biomass among all the treatments. Results showed that TUS12-23 genotype can be classified as very tolerant to drought stress and JW43 is the less tolerant, whereas the other genotypes could be susceptible and may survive under mild drought conditions. Results also indicated that the methodology used, and the parameters measured are effective in identifying sugarcane germplasm with extreme reaction to drought stress.

Key words: Drought stress, *Saccharum* species, biomass, stomatal conductance, agronomic parameters.

INTRODUCTION

Sugarcane (*Saccharum* species) is a crop of economic importance worldwide for producing sugar and considered as an essential renewable source of biofuel (Prabu et al., 2011). It's a tall growing monocotyledonous crop that belongs to the genus *Saccharum* L., of the tribe Andropogoneae in the grass family (Poaceae) which is cultivated in the tropical and subtropical regions of the world. The *Saccharum* complex comprises of *Saccharum*, *Erianthus* section *Ripidium*, *Miscanthus* section *Diandra*, *Narenga* and *Sclerostachya* (Daniels and Roach, 1987). Modern sugarcane varieties that are cultivated for sugar production are founded on

*Corresponding author. E-mail: Sheren.Farag@ag.tamu.edu.

interspecific hybrids between *Saccharum spontaneum* and *Saccharum officinarum* (*Saccharum* spp.). This specie can be adapted to different environmental conditions; however, drought stress can limit the amount of sugarcane establishment and growth in many world regions because sugarcane requires substantial amounts of water during early stages (Wiedenfeld, 2008).

The limitation of drought stress on sugarcane productivity has been the subject of several studies (Inman-Bamber and Smith, 2005; Smit and Singels, 2006; Silva et al., 2008; Singels et al., 2010). Generally, water shortage results in a negative impact on establishment of the crop, especially if the drought duration exceeds the capacity of drought tolerance of the plant species (Smit and Singels, 2006). Under soil water-deficit conditions, plants show adaptive mechanisms and/or responses that allow them to survive. One alternative to mitigate water deficit in sugarcane is irrigation (Inman-Bamber, 2004); however, water is limited in some regions, and equipment costs make this strategy expensive (Silva et al., 2007). Therefore, studies aimed at selecting drought-tolerant cultivars are a viable alternative to increase productivity and a necessity for the future (Prabu et al., 2011).

Water-deficit stress at early stage alters a variety of growth and physiological processes in sugarcane, which cause decreased yields (Zhang et al., 2001; Silva et al., 2007). Water deficit during establishment can trigger a negative impact upon growth and development of the crop, compromising plant productivity (Inman-Bamber, 2004). Moderate water deficit causes significant morphological and physiological changes in sugarcane establishment (Creelman et al., 1990) while severe deficit may lead to plant death (Cheng et al., 1993). Despite the existence of a significant amount of research on these physiological variables such as stomatal conductance, and others (Silva et al., 2014), little have focused on their interaction with agronomic parameters such as crop productivity and growth rate. Such traits can be measured as an alternative method of characterizing tolerant and susceptible genotypes in sugarcane breeding programs. Silva et al. (2008) found differences in productivity and yield components of 80 sugarcane genotypes grown under two water regimes, with and without water deficit stress. Under stress, the authors found that some varieties, considered drought-tolerant, showed a higher productivity, greater stem mass than sensitive varieties, showing a positive correlation between these morphological variables and total biomass production.

Generally, the drought tolerance is assessed by the combination of physiological and agronomic parameters response to water stress (Ferreira et al., 2017). Additionally, assessing the biomass production per water unit could give an idea about the plant survival under water deficit. The development of screening methodologies for tolerance of *S. spontaneum* for abiotic stresses, such as drought is very important for breeding of bioenergy crops (Da Silva, 2017). Sugarcane biomass yields per hectare vary widely (25 to 35 dry t·ha^{-1}). Newly-developed energy canes and wide hybrids involving *Saccharum* spp. have shown even higher biomass yield potentials, 30 to 45 dry t·ha^{-1} (Da Silva, 2017) and higher water productivities under the long growing season conditions in parts of the Southeast U.S. The objective of this study was to develop an agronomic screening approach to evaluate and select drought tolerant genotypes of *Saccharum* spp.

MATERIALS AND METHODS

A greenhouse experiment was conducted at Weslaco, Texas, USA (26°12′N, 97°57′W), from August to October 2016 to evaluate one commercial sugarcane cultivar (*Saccharum* interspecific hybrid, CP72-1210) and five genotypes of energy cane *S. spontaneum* (IRAN 28, TUS12-72, TUS12-23, X08-0299, and JW43) under drought conditions. The plant materials selected for the experiments were 2 months old seedlings with uniform height and crop development. A randomized block design experiment was conducted with three treatments and four replications per each genotype. The treatments denoted as A, B, and C consisted in applying irrigation to field capacity at intervals of 3, 6, and 9 days, respectively. The treatments represented a well irrigated treatment (treatment A) and water stress conditions (treatments B and C).

The water used by the crop (crop evapotranspiration) was calculated by the difference in pot weight before and after each irrigation event. To intensify the drought stress in the plants, at the sixth weeks of the experiment, treatments A, B, and C were adjusted to replace 50, 25 and 10% of the amount of water by the plants which was calculated from the average of the evapotranspiration data recorded during the first experimental six weeks, by which 250, 150, and 100 mL of water were added every 3 days to the treatments A, B, and C, respectively. Accumulated crop evapotranspiration (the total water used for each treatment), was estimated at the end of the season by summing the water used during all the irrigation intervals. Several methods and measurements were used to screen the plants for drought stress. Other agronomic measurements were rate of tillers and plant height that used to estimate the growth rate per week. A measure stick was used to measure plant height from the base until the top of the main stalk.

Total fresh and dry biomass was calculated at the end of the experiment from the difference in the fresh and dry weight of the shoots and roots. At the end of the experimental period, the numbers of dead leaves were counted to calculate the percent of dead leaves in each plant. Moreover, the plants were collected and separated by stems, leaves, and roots at the end of the experimental period and oven-dried for three days at 110°C to measure dry matter. The physiological parameter of stomatal conductance (g_s) was measured once per week during the experimental period, in one young adult leaf per pot. The leaf measurements were taken with a leaf porometer (SC-1, Decagon Devices Inc., Pullman, WA) between 9:00 and 11:00 h to avoid the high temperatures and low relative humidity of the afternoon that can cause a high leaf-to-air vapor pressure deficit that close stomata (Hu et al., 2009). All the biomass data were analyzed using a two-way variance (Analysis of Variance, ANOVA), StatPlus statistical packages, StatPlus, and AnalystSoft Inc.-Statistical analysis program, Version 6 (http://www.analystsoft.com/en/) were analyzed using Tukey's test for mean separations ($P \leq 0.05$) when a significant F-test was observed.

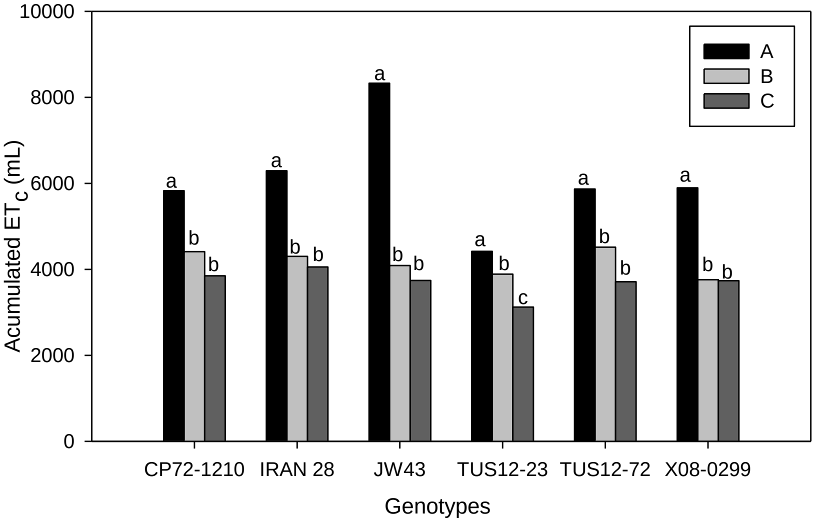


Figure 1. Cumulative crop evapotranspiration ET_c, mL (water use per each genotype) for the three treatments A, B, and C during the first six weeks of the experimental period. For each genotype,different letters indicate significant differences among water treatments at P≤0.05.

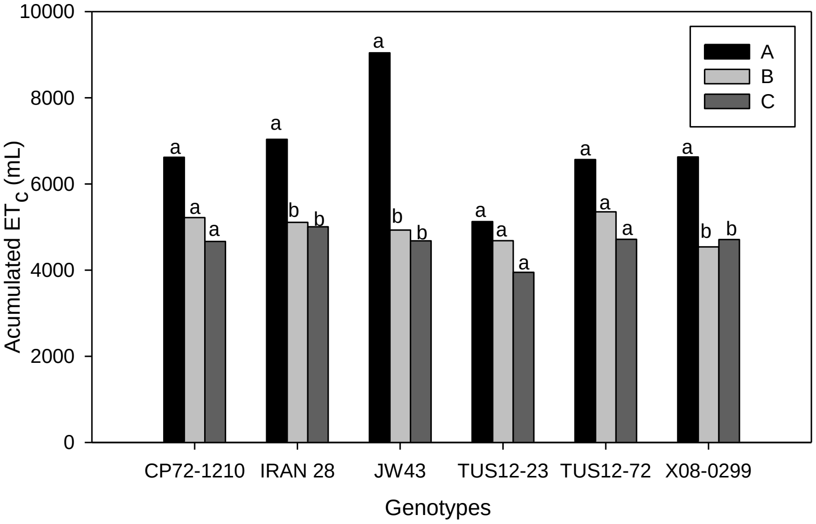


Figure 2. Cumulative crop evapotranspiration ET_c, mL (water use per each genotype) for the three treatments, A, B, and C during the whole experimental period (twelve weeks). For each genotype, different letters indicate significant differences among water treatments at P≤0.05.

RESULTS

Total water used by the different genotypes

The evapotranspiration rate recorded in the studied genotypes during the first experimental six weeks is shown in (Figure 1). Among all genotypes, TUS12-23 consistently presented the lowest evapotranspiration rate under well-watered (treatment A, irrigation every 3 days) and drought stress conditions (treatment B and C, irrigation every 5 and 9 days, respectively). In contrast, JW43 presented the highest evapotranspiration rate under well-watered conditions, whereas no significant differences were found under drought conditions. Cumulative amounts of water use per each genotype during the whole experimental period (twelve weeks) are shown in (Figure 2).

Total amounts of water use were not significantly

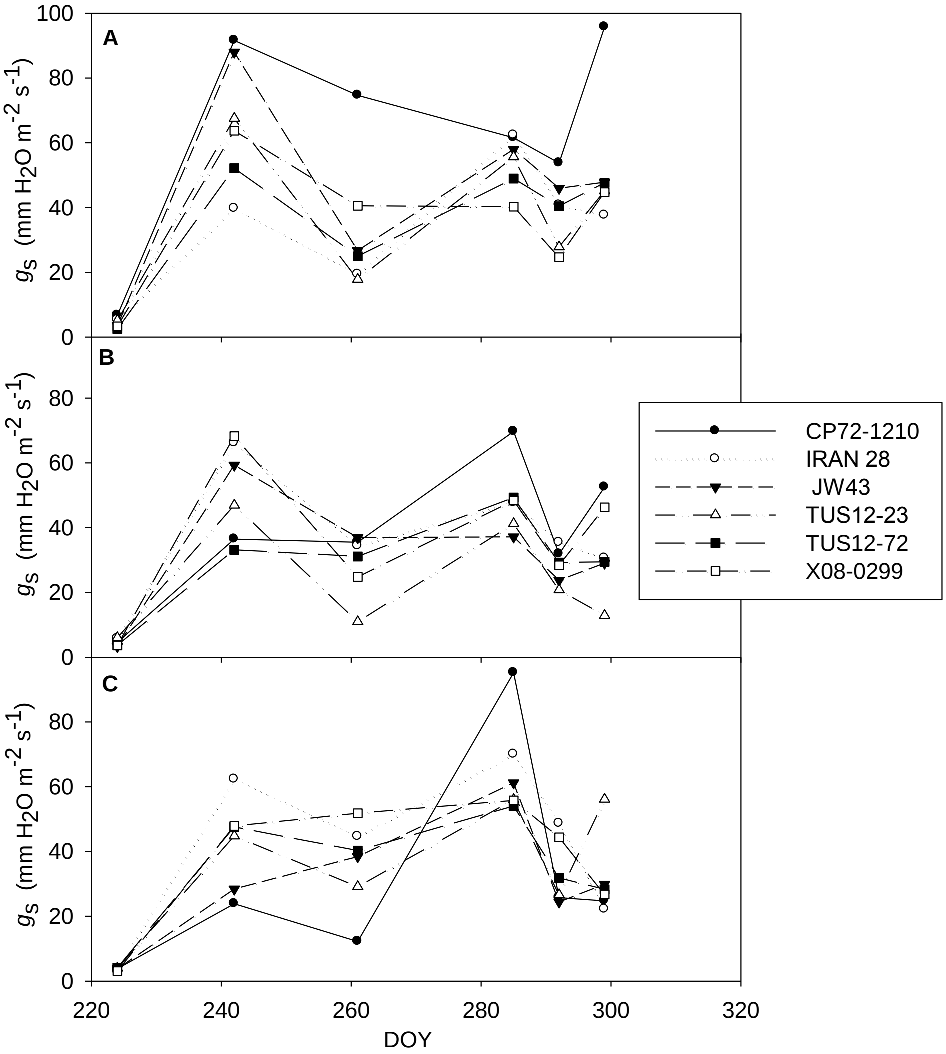


Figure 3. Stomatal conductance (g_s) measured in all the genotypes for each irrigation treatment A, B and C. Each point represents the average of four leaves per genotype. DOY=day of year; (220=August 7). Statistical differences were found in CP72-1210 and JW43 at P≤0.05, whereas, no statistical differences were found in the other genotypes.

different among the three irrigation treatments A, B, and C for genotypes TUS 12-23, CP72-1210, and TUS 12-72. No statistical differences among treatments B and C were observed for genotypes IRAN 28, JW43, and X08-0299. Considering the whole experimental period of twelve weeks (Figure 2), the genotype JW43 showed the highest amount of water use in treatment A with approximately 9043 mL, followed by IRAN28, CP72-1210, TUS12-72, X08-0299, and TUS12-23, respectively, whereas the lowest amount of water use for the same treatment A was observed for TUS12-23 with approximately 5124 mL (Figure 2). Non-significant differences on total water use for each genotype were observed for treatments B and C. There was a slight numerically decrease in water use between treatment B and C among all genotypes except in genotype X08-299.

Stomatal conductance

The range of stomatal conductance values observed for all genotypes during the experiment varied from 3 to 90 mm H_2O m^{-1}. Overall the experimental period, there was not any observable trend (Figure 3) that reflects variation changes in stomatal conductance between genotypes and treatments. However, analyzing the measurements of each individual date showed significantly higher values of stomatal conductance (92 and 88 mm H_2O m^{-1}) in CP72-1210 and JW43 in some days, compared with the other genotypes that gave values less than 68 mm H_2O m^{-1}. These same varieties (CP72-1210 and JW43) were among the varieties that resulted in the highest cumulative evapotranspiration. Lower numerically stomatal conductance with non-statistical differences was observed

Table 1. Agronomic parameters measured at the end of the experimental period in the three irrigation treatments (A, B, and C). Data represent the mean of four plants per each genotype (n=4). The abbreviations represent the following parameters; SDW: Shoot dry weight; RDW: roots dry weight; TDW: total dry weight (total dry biomass), θ_{leaf}: leaf water content, % of dead leaves, rate of new tillers, and S/R ratio: shoots/roots ratio. For each genotype, different letters indicate significant differences among irrigation treatments at P≤0.05.

Variable	CP72-1210	IRAN 28	JW43	TUS12-23	TUS12-72	X08-0299
SDW (g)						
A	33.8	27.9	37.0^{a}	20.5	24.0	36.0^{a}
B	32.8	26.0	24.1^{b}	20.9	28.0	20.6^{b}
C	24.8	20.5	17.9^{b}	15.1	17.9	15.1^{b}
RDW (g)						
A	6.6^{ab}	18.5^{a}	15.4^{a}	5.7	13.1	11.4
B	12.0^{a}	12.6^{b}	8.9^{b}	10.6	11.8	6.7
C	5.7^{b}	7.4^{b}	8.0^{b}	7.0	9.2	7.0
TDW (g)						
A	40.5	46.4^{a}	52.5^{a}	26.2	37.1	47.4^{a}
B	44.9	38.5^{ab}	33.0^{b}	31.5	39.7	27.3^{b}
C	30.6	27.6^{b}	25.8^{b}	22.2	27.1	22.2^{b}
θ leaf (%)						
A	78.2	74.1	74.2^{ab}	77.7	76.8	65.7
B	75.1	70.4	71.3^{a}	78.4	76.1	69.3
C	76.6	75.7	79.4^{b}	81.5	81.6	73.5
Dead leaves(%)						
A	22.4^{a}	61.9	67.4	63.5	60.9	74.7
B	73.6^{b}	62.8	74.2	55.1	73.1	74.3
C	61.9^{b}	65.8	82.8	60.9	67.6	76.9
Rate of new tillers						
A	0.3	7.5	7.5^{a}	2.0	5.3	7.5
B	1.0	6.8	3.8^{b}	3.0	5.5	5.8
C	0.3	6.8	4.5^{ab}	2.0	2.8	7.0
S/R ratio						
A	5.1	1.5	2.4	3.6	1.8	3.2
B	2.7	2.1	2.7	2.0	2.4	3.1
C	4.3	2.8	2.2	*2.2*	1.9	2.1

for all the genotypes under irrigation treatments B and C.

Growth rate and yield production

Shoots dry weight (SDW) values of CP72-1210 were not significantly affected by drought stress (Table 1), the reduction of SDW from the control treatment to drought treatments was very low, similar results observed in IRAN 28, TUS12-23 and TUS12-72 genotypes. The greatest of SDW reduction from treatment A to treatment B were observed for the JW43 and X08-0299 genotypes (35.14 and 42.78%, respectively). Statistical differences were found in roots dry weight (RDW) in CP72-1210, IRAN 28, and JW43. The reduction of RDW from treatment A to B was 31.9 and 41.1% for the IRAN 28 and X08-229 genotypes.

The RDW increase of genotype CP71-1210 from treatment A to B was probably caused by the variability of the genotypes characteristics. Small numerical reductions were observed in the RDW of TUS12-72. Statistically significantly reduction of total dry weight (TDW) was observed for the IRAN 28 (16.91%), JW43 (37.02%), and X08-299 (42.44%) genotypes from the well-water treatment (3 days interval) to the drought treatment (6 days interval). TDW values showed that the IRAN 28 was less affected by drought conditions than the other genotypes, and the most affected genotypes for TDW drought tolerance was X08-299. The percent of dead leaves at the end of the experiment showed that the CP72-1210 was the least affected treatment under the well-watered conditions. However, it statistically increased under drought conditions. It is important to mention that all of the genotypes, except CP72-1210 under treatment A, presented a high percent of dead leaves.

The highest numerical percent value of dead leaves was observed for the drought treatments of genotypes JW43 and X08-299 for treatment C (irrigation interval of 9 days). The rate of new tillers decreased significantly under drought conditions for the JW43 genotype. For the other genotypes, the rate of tillers of the well-water treatments (A) was compared with the drought treatments (B and C), and no statistically differences were observed. However, numerically higher rate of tillers was observed for genotypes IRAN28 and X08-0299 under the drought treatment (treatment C). No statistical differences on growth rate were observed among genotypes of the three treatments.

DISCUSSION

The aim of this study was focused on establishing a screening method to evaluate and select drought tolerant genotypes of *Saccharum* spp. during the early growth phase. The data showed that there were statistical differences in the amount of water use among the studied genotypes. TUS12-23 consistently showed the lowest water consumption under well-watered and drought conditions, and there was not significant reduction in biomass, new tillers produced, and percent of dead leaves. On the other hand, JW43 genotype was the highest consumer of water for the well irrigated treatment A followed by IRAN 28, X08-0299, CP72-1210, TUS12-72, and TUS12-23, respectively. This same genotype resulted in the highest total biomass for the irrigation treatment A, but when it was submitted to drought conditions led to high reduction of the total dry biomass which was approximately 51%. Water consumption for IRAN 28, X08-0299, CP72-1210, and TUS12-72 resulted in intermediate values between the two extreme values of the TUS12-23 and JW43 genotypes. For the IRAN 28 genotype, the reduction of total dry biomass from the well-water treatment A to the drought treatment C was approximately 40%. There was a significant difference of the amount of water used between well-watered and drought conditions in the X08-0299 genotype, and the reduction of yield was reduced 53.3% of the total produced biomass. Whereas, the reduction of water use under drought treatments in TUS12-72, CP72-1210, and TUS12-23 genotypes resulted in non-significant differences in the total dry biomass; however there were slightly numerical differences.

Results showed that JW43 and X08-0299 were the lowest total dry biomass and the highest percent of dead leaves which indicate that these genotypes cannot be adapted to drought conditions either moderate or severe water stress conditions as in treatments B and C, respectively. The rate of new tillers decreased significantly under drought conditions for the JW43 genotype. For the other genotypes, the rate of tillers of the well-water treatments (A) was compared with the drought treatments (B and C), and no statistical differences were observed. However, numerically higher rate of tillers was observed for genotypes IRAN28 and X08-0299 under the drought treatment (treatment C). The JW43 and IRAN 28 varieties that produced more biomass under well-water conditions, they were also the ones that suffered the greatest reductions of biomass, and the greatest reductions of the number of tillers. The reduction in the number of tillers due to water stress was reported by Robertson et al. (1999); Silva and Costa (2004); Singh and Reddy (1980) and Soares et al. (2004). Ramesh and Mahadevaswamy (2000) reported that the formation of tillers in sugarcane is important because of the contribution they make to the crop yield by acting as a storage sink. Joshi et al. (1996) also reported that the tillering ability and subsequent growth efficiency largely determine the yield of a given cultivar.

The obtained results give an indication that JW43 and X08-0299 are intolerant drought genotypes and very sensitive to water shortage. Therefore, submitting these genotypes to severe water stress may lead to plant death, band could cause high reduction in the yield production. Sonia et al. (2012) reported that drought events can significantly decrease sugarcane productivity during the establishment stage. Several more studies have highlighted the effect of water stress on sugarcane (Jones and Ritchie, 1990). Ramesh and Mahadevaswamy (2000) also reported the reduction of biomass of these genotypes can be attributed to sucrose accumulation caused by water stress. On the other hand, TUS12-23 and CP72-1210 genotypes demonstrated high tolerance to drought stress, where the total dry biomass was slightly numerically reduced (less than 15.6 and 24.4%, respectively), as compared to well-watered conditions and non-significant differences were found in reduction rate of new tillers between drought and well-watered conditions. Whereas IRAN 28 genotype showed that it could be susceptible for drought stress, the reduction of total biomass under drought conditions was 40%, however the rate of new tillers was not affected by drought stress; similar results found in the percent of dead leaves which indicated that this genotype could tolerate moderate drought stress and sustain a rational production for prolonged periods.

According to Inman-Bamber and Smith (2005), plants may avoid or delay water stress by limiting transpiration through stomatal closure or by reducing exposed leaf area through leaf rolling. Statistical differences were found in stomatal conductance values among the well-watered and drought stress treatments in CP72-1210 and JW43 genotypes. However, no statistical differences were found in the other genotypes, which indicate that the studied genotypes may need prolonged stress periods to show differences in stomatal conductance and other physiological parameters. Therefore, as a preliminary study that bases on an agronomic approach for a rapid screening of drought tolerance, TUS12-23 genotype can be classified as very tolerant to drought stress and JW43 as the less tolerant genotype, whereas the other genotypes could be susceptible and may survive under mild drought conditions. The results of this study showed that *S. spontaneum* genotypes presented extreme reactions to drought stress, which is consistent with the great phenotypic variability presented by these species, which is found in environments with different and extreme conditions, including flood basins and deserts.

Conclusions

The physiological parameters such as stomatal conductance may provide reliable information on the impact of water stress on sugar and energy cane genotypes. However, it requires prolonged periods to obtain significant differences, which might not be a good option for some genotypes that cannot be submitted to prolonged stress conditions. Therefore, an agronomical approach could be a useful tool for rapid screening of sugar and energy cane genotypes for drought stress. The study showed significant differences were found in the response of sugar and energy cane genotypes to different drought stress levels under the evaluation of the total amounts of water use, total dry biomass, the rate of new tillers and percent of dead leaves.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Cheng Y, Weng J, Joshi CP, Nguyen HT (1993). Dehydration stress-induced changes in translatable RNAs in sorghum. Journal of Crop Science, 33:1397-1400.

Creelman RA., Mason HS, Bensen RJ, Boyer JS, Mullet JE (1990). Water Deficit and Abscisic Acid Cause Differential Inhibition of Shoot versus Root Growth in Soybean Seedlings: Analysis of Growth, Sugar Accumulation, and Gene Expression. Plant Physiology, 92:205-214.

Da Silva JA (2017). The Importance of the Wild Cane Saccharum spontaneum for Bioenergy Genetic Breeding. A Review. Sugar Technology DOI: 10.1007/s12355-017-0510-1.

Daniels J, Roach BT (1987). Taxonomy and evolution. Chapter 2. In: DJ Heinz, ed. Sugarcane improvement through breeding, Volume 11. Elsevier, Amsterdam, Netherlands, pp. 7-84.

Ferreira TH, Tsunada MS, Bassi D, Araújo P, Mattiello L, Guidelli GV, Menossi M (2017). Sugarcane water stress tolerance mechanisms and its implications on developing biotechnology solutions. Frontiers in Plant Science, 8:1077.

Hu MJ, Guo Y-P, Shen Y-G, Guo D-P, Li D-Y (2009). Midday depression of photosynthesis and effects of mist spray in citrus. Annals of Applied Biology, 154:143-155.

Inman-Bamber NG (2004). Sugarcane water stress criteria for irrigation and drying off. Field Crops Research, 89:107-122.

Inman-Bamber NG, Smith DM (2005). Water relations in sugarcane and response to water deficits. Field Crop Research, 92:185-202.

Jones JW, Ritchie JT (1990). Crop growth models In: (Hoffman G.J., Howell T.A., Solomon K.H. eds). Management of farm irrigation systems ASAS Monograph No 9 Michigan USA, pp. 80-86.

Joshi HC, Pathak H, Choudhary A, Kalra N (1996). Distillery effluents as a source of plant nutrient: Problems and prospects. Fert. News, 41(11):41-47.

Prabu G, Kawar PG, Pagariya MC, Prasad DT (2011). Identification of water deficit stress upregulated genes in sugarcane. Plant Molecular Biology Reporter, 29:291-304.

Ramesh P, Mahadevaswamy M (2000). Effect of formative phase drought on different classes of shoots, shoot mortality, cane attributes, yield and quality of four sugarcane cultivars. Journal of Agronomy Crop Sciences, 185:249-258.

Robertson MJ, Muchow RC, Donaldson RA., Inman-Bamber NG, Wood AW (1999). Estimating the risk associated with drying-off strategies for irrigated sugarcane before harvest. Australia Journal of Agricultural Research, 50:65-77.

Silva ALC, Costa WAJM (2004). Varietal variation in growth, physiology and yield of sugarcane under two contrasting water regimes. Tropical Agricultural Research, Peradeniya, 16:1-12.

Silva M de A, Jifon JL, Da Silva JAG, Dos Santos CM, Sharma V (2014). Relationships between physiological traits and productivity of sugarcane in response to water deficit. Journal of Agricultural Science, 152:104-118.

Silva MA, Silva JAG, Enciso J, Sharma V, Jifon J (2008). Yield components as indicators of drought tolerance of sugarcane. Science Agricola, 65:620-627.

Silva MDA, Jifon JL, Silva JAG, Sharma V (2007). Use of physiological parameters as fast tools to screen for drought tolerance in sugarcane. Brazilian Journal Plant Physiology, 19:193-201.

Singels A, Van Den Berg M, Smit MA, Jones MR, Van Antwerpen R (2010) Modeling water uptake, growth and sucrose accumulation of sugarcane subjected to water stress. Field Crop Research, 117:59-69.

Singh S, Reddy MS (1980). Growth, yield and juice quality performance of sugarcane varieties under different soil moisture regimes in relation to drought resistance. In: International Society of Sugar Cane Technologists Congress, 17, Manila. Proceedings... Manila: ISSCT, 1:541-555.

Smit MA, Singels S (2006). The response of sugarcane canopy development to water stresses. Field Crop Research, 98:91-97.

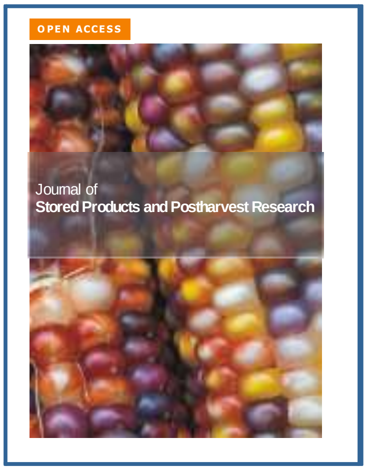
Soares RAB, Oliveira PFM, Cardoso HR, Vasconcelos ACM, Landell MGA, Rosenfeld U (2004) *Efeito da irrigação sobre o desenvolvimento e a produtividade de duas variedades de cana-de-acucar colhidas em inicio de safra*. STAB – Açúcar Álcool e Subprodutos, Piracicaba, 22(4):38-41.

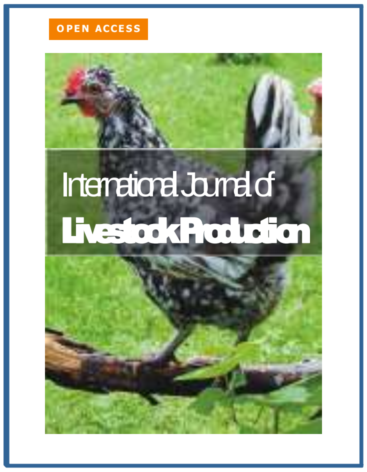
Sonia MZ, Fabiana AR, Jose PG, Livia MP, Mirian VL (2012). Sugarcane Responses at Water Deficit Conditions, Water Stress, Brazil, pp. 256-275.

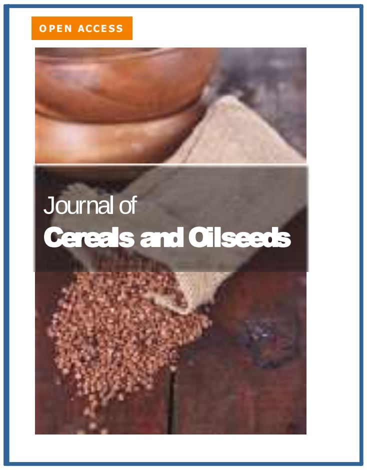
Wiedenfeld B (2008). Effects of irrigation water salinity and electrostatic water treatment for sugarcane production. Agricultural Water Management, 95:85-88.

Zhang MQ, Li GJ, Chen RK (2001). Photosynthesis characteristics in eleven cultivars of sugarcane and their responses to water stress during the elongation stage. Proceedings - International Society of Sugar Cane Technologists, 24:642-643.

Related Journals:







www.academicjournals.org