

OPEN ACCESS



African Journal of
Agricultural Research

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

Indexing

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

Open Access Policy

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

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

Article License

All articles published by African Journal of Agricultural Research are licensed under the [Creative Commons Attribution 4.0 International License](#). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited. Citation should include the article DOI. The article license is displayed on the abstract page the following statement:

This article is published under the terms of the [Creative Commons Attribution License 4.0](#) Please refer to <https://creativecommons.org/licenses/by/4.0/legalcode> for details about [Creative Commons Attribution License 4.0](#)

Article Copyright

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

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

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

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

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

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

Self-Archiving Policy

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

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

Digital Archiving Policy

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

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

Metadata Harvesting

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

Memberships and Standards



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



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



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

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

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



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

Contact

Editorial Office: ajar@academicjournals.org

Help Desk: helpdesk@academicjournals.org

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

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

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor, Kenyatta Avenue, Nairobi, Kenya

Editors

Prof. N. Adetunji Amusa

Department of Plant Science and Applied Zoology
Olabisi Onabanjo University
Nigeria.

Dr. Vesna Dragicevic

Maize Research Institute
Department for Maize Cropping
Belgrade, Serbia.

Dr. Abhishek Raj

Forestry, Indira Gandhi Krishi Vishwavidyalaya,
Raipur (Chhattisgarh) India.

Dr. Zijian Li

Civil Engineering, Case Western Reserve
University,
USA.

Dr. Tugay Ayasan

Çukurova Agricultural Research Institute
Adana,
Turkey.

Dr. Mesut YALCIN

Forest Industry Engineering, Duzce
University,
Turkey.

Dr. Ibrahim Seker

Department of Zootecny,
Firat university faculty of veterinary medicine,
Türkiye.

Dr. Ajit Waman

Division of Horticulture and Forestry, ICAR-
Central Inland Agricultural
Research Institute, Port Blair, India.

Dr. Mohammad Reza Naghavi

Plant Breeding (Biometrical Genetics) at
PAYAM NOOR University,
Iran.

Editorial Board Members

Prof. Hamid Ait-Amar

University of Science and Technology
Algiers,
Algeria.

Dr. Sunil Pareek

Department of Horticulture
Rajasthan College of Agriculture
Maharana Pratap University of Agriculture &
Technology
Udaipur,
India.

Prof. Osman Tiryaki

Çanakkale Onsekiz Mart University,
Plant Protection Department,
Faculty of Agriculture, Terzioğlu Campus, 17020,
Çanakkale,
Turkey.

Prof. Panagiota Florou-Paneri

Laboratory of Nutrition
Aristotle University of Thessaloniki
Greece.

Prof. Dr. Abdul Majeed

Department of Botany
University of Gujrat
Pakistan.

Prof. Mahmoud Maghraby Iraqi Amer

Animal Production Department
College of Agriculture
Benha University
Egypt.

Prof. Irvin Mpofo

University of Namibia
Faculty of Agriculture
Animal Science Department
Windhoek,
Namibia.

Dr. Celin Acharya

Dr. K.S. Krishnan Research Associate
(KSKRA)
Molecular Biology Division
Bhabha Atomic Research Centre (BARC)
Trombay,
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.

Prof. Suleyman Taban

Department of Soil Science and Plant Nutrition
Faculty of Agriculture
Ankara University
Ankara, Turkey.

Dr. Abhishek Raj

Forestry, Indira Gandhi Krishi
Vishwavidyalaya,
Raipur (Chhattisgarh) India.

Dr. Zijian Li

Civil Engineering,
Case Western Reserve University,
USA.

Prof. Ricardo Rodrigues Magalhães

Engineering,
University of Lavras,
Brazil

Dr. Venkata Ramana Rao Puram,

Genetics And Plant Breeding,
Regional Agricultural Research Station, Maruteru,
West Godavari District,
Andhra Pradesh,
India.

Table of Content

Impact of shade on morpho-physiological characteristics of coffee plants, their pests and diseases: A review Biruk Ayalew	2016
The use of Information Communication and Technology in advancement of African agriculture Dionysious Kiambi	2025
Use of renewable energy resources in agriculture the case of Turkey Bekir Yelmen	2037
Agronomic effectiveness of water hyacinth-based composts Dennis Beesigamukama, Alice Amoding-Katusabe, John Baptist Tumuhairwe, John Muoma, John M. Maingi, Omwoyo Ombori, Josephine Nakanwagi and Dative Mukaminega	2055
Bioactivity and phenolic composition of extracts of noni (<i>Morinda citrifolia</i> L., Rubiaceae) in tomato moth (<i>Tuta absoluta</i> Meyrick, 1917) (Lepidoptera: Gelechiidae) Rubens Pessoa de Barros, Ligia Sampaio Reis, João Gomes da Costa, Amanda Cunha Lima, Isabelle Cristina Santos Magalhães, Claudio Galdino da Silva, Aldenir Feitosa dos Santos, Jhonatan David Santos das Neves, Adriana Guimarães Duarte, Gabriela Souto Vieira de Mello, Jhonnatan Duarte de Freitas, Jonas dos Santos Sousa and Simone Paes Bastos Franco	2063
Determination of tomato drying conditions with solar energy family type shelf dryer Bekir YELMEN	2070
Effects of seed tuber size on growth and yield performance of potato (<i>Solanum tuberosum</i> L.) varieties under field conditions Sadik Ebrahim, Hussien Mohammed and Tewodros Ayalew	2077

Review

Impact of shade on morpho-physiological characteristics of coffee plants, their pests and diseases: A review

Biruk Ayalew

School of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, P. O. Box: 05, Hawassa, Ethiopia.

Received 23 July, 2018; Accepted 20 August, 2018

Traditionally, coffee plant has been considered as a shade demanding species and intolerant of direct sunlight, although it performs well without shade. Still controversy result and recommendation have been reported among investigators in the optimal shading level for coffee growth. This controversy will probably continue endlessly until the effects of shade up on the performance of morphology and physiology of the plant is known better. This review discusses the advantages of shade for coffee production, the responses of coffee plants to shade in morphology, physiology, and effects on coffee pest and diseases and finally, the effect of shade on coffee pest and diseases are discussed.

Key words: Coffee, shade, morphology, physiology, coffee pest, disease.

INTRODUCTION

All commercial coffee species are originated from Africa and belong to the family Rubiaceae which consists of more than 500 genera, of which *Coffea* is economically the most important one (Diby et al., 2016). Of the approximately 124 species, only *Coffea arabica* L. (Arabica coffee) and *Coffea canephora* Pierre ex A. Froehner (Robusta coffee) are economically important worldwide, accounting for approximately 99% of the global bean production (DaMatta, 2017; Bote et al., 2018a). Almost all the coffee species are diploid ($2n = 2x = 22$) and generally self-incompatible except *C. arabica* which is a natural allotetraploid ($2n = 2x = 44$) self-fertile species (Diby et al., 2016).

Coffee, a major export commodity, is a tropical crop grown in approximately 80 countries. It is estimated that more than 20 million people throughout the world earn their living from coffee, the majority of them involved in its production (Toledo and Moguel, 2012). The montane rainforests in South-Western Ethiopia are the only place in the world where coffee naturally grows in its original habitat (Stellmacher and Mollinga, 2009). Until today, Ethiopian coffee is mainly produced in traditional coffee production systems. This means wild coffee is simply picked inside the forest, or managed inside the forest by removing competing under growth vegetation and some canopy trees (Demel, 1999). In early plantations, coffee

E-mail: biruk.ayalew2@gmail.com.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

bushes were planted under shade canopy in order to simulate their natural habitat accounting for the fact that it has evolved as an understory shrub and showing all physiological and morphological characteristics of a shade adapted plant (Wexler, 2003; DaMatta, 2004; Grades, 2007). But, evidence from different part of the world indicates that satisfactory coffee crops may be produced under shade, as well as without shade, depending up on environmental and cultural practices (Fahl et al., 1994; DaMatta, 2004).

The knowledge of effects of shade (radiation) levels on the growth, morphology and physiology of coffee plants are the most important because, it helps to determine the optimum levels of radiation, as well as to add information on the existing knowledge on the performance of plants grown under shaded conditions. In addition, understanding shade effects on the morphology and physiology of coffee plants is useful for establishing the best management practices as well as for designing coffee production systems (Da Matta, 2004). However, there is still an open controversy among investigators, in what is the optimal shading level for coffee growth. This controversy will probably continue endlessly until the effects of shade up on the performance of morphology and physiology of the plant is known better. This review focuses on impact of both shaded and unshaded coffee on morpho-physiological characteristics and coffee pest and disease. The review is organized into dealing with the advantages of shade for coffee production, the responses of coffee plants to shade (morphological and physiological) and finally about the effect of shade as on coffee pests and diseases.

ADVANTAGES OF SHADE FOR COFFEE PRODUCTION

Production systems of coffee vary from multi-strata agroforestry systems to full-sun monocultures. In agroforestry coffee production systems, coffee trees are planted together with forest trees or within leguminous trees, fruits, timbers, and fire woods. The question of whether the coffee tree benefits or not from shelter trees has not been clear for more than a century (Beer, 1987; Damatta, 2004). Yield potential, competition for water and nutrients, and pest/disease incidence are central issues in this controversy. During the mid-twentieth century, farmers were encouraged to grow coffee in full sun to improve yields and reduce fungal infection; however, widespread acceptance of this practice did not take place until the 1970's (Perfecto et al., 1996).

Shading plantation can provide a number of important benefits to coffee. It has been found to reduce air temperature, soil, and leaf surface temperature as well as the thermal amplitude (Da Silva Neto et al., 2018). It also protects coffee plants from strong winds, rains, or hail and reduces the effect of biennial bearing, and improve and maintain soil fertility by way of returning large

amounts of leaf litter to the underneath soil, that is, shade trees can be a valuable source of organic matter, nitrogen fixation, while retaining soil moisture (Beer et al., 1998). Though, its major benefit is the actual reduction in light transmission to coffee crops which softening the effect of biennial bearing and excessive vegetative growth (Beer et al., 1998; DaMatta, 2004). Aranguren et al. (1982) showed that N input from shade tree litter fall alone was approximately $95 \text{ kg-N}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$. Fallen leaves from *Erythrina poeppigiana* and the debris provided by pollarding added 330.5, 269.3, and 173 $\text{kg-N}\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$, depending on whether trees were trimmed one, two or three times a year, respectively (Russo and Budowski, 1986). On the other hand, Babbar and Zak (1995) found that N lost by leaching in modern systems exceeded that in traditional systems by almost three-fold. In addition, shaded plantations have various beneficial features, including less sun scorch damage to the berries, greater natural resource conservation, increased biodiversity and greater stability in coffee production. Likewise, shaded plantations require less input and provide a more stable income due to cash income supplement provided by fruits or timber from the shelter trees (Beer et al., 1998) and a number of initiatives, such as local and national programmes for payment of ecosystem services and coffee certification schemes, have provided incentives for coffee farmers to provide a range of ecosystem services in addition to producing coffee (LeCoq et al., 2011). These characteristics of shaded coffee have stimulated renewed interest in the use of shade trees (Beer et al., 1998) and can significantly increase crop production stability.

On the other hand, unshaded plantations generally require high levels of external inputs to maximize crop yield and are often associated with soil degradation and environmental pollution. In addition, small holder producers of unshaded coffee face serious economic risks related to high variable costs and during unstable market prices. Also, sun plantations typically experience greater run-off and nutrient leaching and remain productive for only one-third to one-half as long as comparable shaded plantations (Perfecto et al., 1996). However, in many situations, coffee grows well without shade and even out yields shaded coffee (Fournier, 1988; Beer et al., 1998). Production of coffee in full sunlight has been highly successful due to the high acclimation capacity of coffee plants to different irradiance regimes, involving changes in physiological, anatomical and ultrastructural characteristics (Fahl et al., 1994; Ramalho et al., 2000; Pompelli et al., 2012).

RESPONSES OF COFFEE PLANTS TO SHADE

Among the many environmental factors, light is the most influential factor involved in the survival, growth and reproduction of tropical species. Light responses usually

provoke morphological and physiological alterations, which are determinant for CO₂ assimilation and optimization of gas exchange (Sands, 1995; Gonçalves et al., 2005). When plants grow under either shade or high irradiance, the photosynthesis processes could be inhibited, simply because of the presence of too little or too much light which creates a stressful environment to the system (Goncalves et al., 2005). Some plants show sufficient developmental plasticity to respond to a range of light regimes, growing as sun plants in sunny areas and as shade plants in shady habitats. However, other plant species are adapted to either a sunny or a shaded environment (Valladares et al., 2005) and show different levels of tolerance to high illumination. Generally, sun plants are better able to sustain exposure to high light than shade plants, which experience photo inhibition (Goldstein and Durand, 2001). However, extensive comparative studies indicate that there are few extremely shade tolerant plants and few extremely light-demanding species, with most species having intermediate, and thus overlapping, light preferences (Wright et al., 2003).

Leaves adjust (anatomically, morphologically, and physiologically) to the light environment under which they expand and develop (Abrams and Kubiske, 1990). This ability is a highly important feature of plants because it takes into account, on a spatial and temporal scale, the ability of plants to perceive and respond to different characteristics of different ecosystems. On a temporal scale, this plasticity facilitates survival and a potential specialization of species (Ackerly, 2003). On the individual level, the expression of phenotypic plasticity is accompanied by the potential for discriminating between environmental qualities that are most suitable for growth (Rubio de Casas et al., 2007).

Arabica and Robusta coffees have evolved in the forest as understory trees; therefore, they are considered to be a shade demanding species (DaMatta, 2004). Most cultivars were derived from wild Arabica populations, such as the germplasm collections of Ethiopia, and they become severely stressed when grown without overhead shade and provide low yields (Van Der Vossen, 1985). However, according to van Der Vossen (2005), almost all current cultivars are descendants of early coffee introductions from Ethiopia to Yemen, where they were subjected to a relatively dry ecosystem without shade for a thousand years before being introduced to Asia and Latin America. Most of these cultivars have retained the physiological attributes as shade tolerant plants and can respond to various conditions, such as a mild drought and full sunlight. However, some cultivars (e.g. 'Typica') are not suited to the open, showing excessive symptoms of photo-damage when grown at full exposure. In any case, modern high-yielding coffee cultivars have been selected in test trials with high external inputs conducted under full sunlight and wide spacing. Hence the performance of Arabica coffee cultivars in full sunlight is likely to have been improved (DaMatta, 2004). Therefore,

under intensive crop management, coffee will often produce much higher yields in sunlight than under shade. However, cultivation of coffee in open sun is common in most coffee producing countries, though its sustainability is questionable (Beer et al., 1998; Kufa et al., 2007; Rodríguez et al., 2001).

According to Fahl et al. (1994), coffee plants are classified as a shade-facultative species, because they have some characteristic features of sun-adapted plants, such as increased growth and photosynthesis capacity, high light saturation under full irradiance and relatively constant quantum yield when coffee is grown in both shade (lower radiation) and full sunlight environments. In addition, coffee displays several shade-acclimation characteristics, including a low chlorophyll a/b ratio and structural change such as higher specific leaf area (Rodríguez et al., 2001).

Generally, different light intensities promote changes in both the physiology and morphology of them; which are features that results from the interaction between gene expression and the environment (Nunes et al., 1993). The ability of an individual species to successfully grow in a low or high light environment (holding quality constant) can be based on how rapidly and how efficiently allocation patterns and physiological behavior are adjusted in order to maximize resource acquisition in that particular environment (Dias-Filho, 1997).

Shade effect on anatomical and morphological characteristics of coffee plants

Fahl et al. (1994), Luiza et al. (1999) and Paiva et al. (2003) observed that the highest shading levels reduced the growth of coffee plants. Excessive shading by upper two to three canopy strata of various tree species under forest environment is reported to reduce growth and productivity of coffee plant (Tesfaye et al., 2002; DaMatta et al., 2007). This excessive shading reduces both the quantity (photosynthetic photon flux density) and the quality (e.g. decreased red: far-red ratio) of the transmitted radiation, which affects the morphological and physiological processes of the plant such as photosynthesis and growth (Morais et al., 2003). In such conditions, the plant spends much of its photosynthetic activities for maintenance purposes (DaMatta et al., 2007). Heavy shading due to reduced light penetration by the upper canopy strata can result in increased competition for light for photosynthesis which, in turn, leads to undesirable growth of single stemmed coffee trees with thin leaves and reduced reproductive efficiency. In addition to this, shading reduces flower bud formation and can also reduce the whole tree carbon assimilation (DaMatta, 2004; DaMatta et al., 2007). This may result in reduced yield as a result of death of heavily shaded productive middle and bottom primary branches (Kufa and Burkhardt, 2013). Furthermore, dense shading

also results in reduced coffee fruit load through its effects on coffee morphology and physiological changes, such as longer internodes, fewer nodes formed per branch and less flower buds at existing nodes (DaMatta et al., 2007; Kanten and Vaast, 2006). Because the fruit load is the key component of coffee production, its reduction results in decreased productivity (DaMatta et al., 2007).

A study conducted by Baliza et al. (2012) showed that coffee plants grown under 90% shading level (10% solar radiation) showed the smallest mean plant height than plants grown under 35, 50 and 65% shading levels. In addition, the plant diameter and number of plagiotropic branches were also small in the 90% shading level with thinner diameters and fewer branches. Similarly, Braun et al. (2007) observed that there was a higher plant height in *C. canephora* seedlings exposed to 75% shading as compared to coffee plants grown under shade levels of 30% or in full sun. Similarly, Bote et al. (2018a) reported that Arabica coffee plants grown under 70% shade scored the highest plant height as compared to coffee plants grown under 50%, 30% and a coffee plants grown under open sun (0% shade). Moreover, these authors reported that coffee plants grown under open field conditions scored the minimum plant height. Kohyama and Hotta (1990) and Lakshamma and Rao (1996) also reported that there is a tendency for increasing height by shade adapted species for better exploitation of light penetrating from the higher stories in the canopy. In addition, these authors reported that densely shaded coffee plants undergo inter-plant competition for sunlight and other growth factors, resulting in tall, but slim plants. Generally, these results indicate that the increase in plant height under shade was probably due to a possible adaptation mechanism of the coffee plant for maximization of light interception by individual leaves. And this is evidence that the coffee plants showed shade avoidance syndrome (SAS) which is typically common in sun loving crops that are grown in less than optimum light intensities.

As reported by Fahl et al. (1994), coffee plants possess a fairly high acclimation capacity with respect to the level of irradiance during growth. These authors explained that, coffee plants grown under shade develop thinner leaves and a larger leaf area which allow more efficient capture of light energy. In contrast, unshaded cultivation increases leaf thickness which presumably leads to larger internal volume for CO₂ diffusion and a greater cellular volume to hold photosynthetic apparatus (Björkman, 1981). The increase in leaf thickness is due to larger palisade and spongy cells and to the presence of a second cell layer in the palisade parenchyma. Chloroplast ultrastructure also is affected by irradiance, and chloroplasts from shaded plants possessed a more robust granum system with more thylakoids per granum than those from full sun grown plants. Generally, structural modification of the leaf induced by irradiance would not be physiologically significant unless net

photosynthetic rate increased accordingly, a response that does not occur in shade obligatory species (Fahl et al., 1994).

Effects of shade on photosynthesis of coffee

Photosynthetic rate is the rate at which CO₂ is assimilated in order to increase biomass (Gulmon and Chu, 1981). According to these authors, high rates of photosynthesis mean that there is high biochemical and physiological potential for high carbon fixation capacity. However, different factors affect the photosynthetic rate of a given plant of which light intensity is one. Plants of the same species perform differently if they are grown under different light regimes (Bote and Struik, 2011). It is possible to select the most productive trees based on photosynthetic rates of plants at the initial stage of development (Mazzafera and Warrior, 1991).

The effect of irradiance regimes on photosynthetic gas exchange of coffee trees seems to be contradictory. Cannell (1985) reported that the maximal photosynthetic rates of sun leaves of coffee are lower around 7 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-2}$, but according to the work of Kumar and Tieszen (1980) are higher for shade leaves up to 14 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-2}$ than for sunlit leaves. Similarly, Bote et al. (2018b) reported that Arabica coffee grown under full sunlight scored a lower rate of photosynthesis as compared to coffee plants grown under shade (50 and 70%). Bote and Struik (2011) discussed that Arabica coffee plants exposed to direct sun light, increased air temperature which resulted in subsequent lowering of stomatal conductance which in turn imposed a large limitation on the rate of CO₂ assimilation. Kumar and Tieszen (1980) and Rodrigues et al. (2018) also reported that Arabica coffee is prone to photoinhibition of photosynthesis when exposed to full solar irradiance as coffee net photosynthetic rate saturates at low irradiance. These authors also discussed that many of the physiological processes of plants are temperature dependent; under high temperature crops have greater difficulty in maintaining photosynthetic activities. Kumar and Tieszen (1980), Kanечи et al. (1995), and Paiva et al. (2003) showed higher photosynthetic rate under shade than under full sun, a lower stomatal conductance for sunlight leaves may at least partially explain that pattern. Kumar and Tieszen (1980) pointed out that shade grown plants photosynthesized at nearly twice the rate of those grown in the sun, with corresponding changes in leaf conductance. Since stomatal aperture is greater under shade or on cloudy/rainy days (Fanjul et al., 1985), it is may be suggested that under full sun photosynthesis would be largely restricted by low stomatal conductance.

There are also considerable information that contradicts the observations of Kumar and Tieszen (1980), Cannell (1985), and Bote et al. (2018b). For example, Gutiérrez

and Meinzer (1994) observed in Arabica coffee a higher rate of photosynthesis in sun leaves from the upper canopy than in shade leaves from the middle canopy. Contrary to photosynthetic rate, these authors also reported that stomatal conductance to water vapor (gs) was lower in sun than in shade leaves. As a whole, these results indicate that photosynthetic rate of shade leaves was limited by the low light availability, rather than by stomatal conductance. Friend (1984) and Fahl et al. (1994) also observed higher photosynthetic rate in sun-grown than in shade grown Arabica coffee plants. By contrast, Luiza et al. (1999) did not find differences in photosynthetic rate and stomatal conductance from plants of Arabica and Robusta coffee grown either under full sunlight or under 50% artificial shade, although photosynthetic rate and stomatal conductance strongly decreased in both species when grown under 80% shade. On the other hand, Matos et al. (2009) conducted a study and documented the light responses in coffee by sampling leaves from both sun-exposed and self-shaded leaves on coffee plants under full sun. This allowed for observation of differences between leaves on the same plant growing at different light levels. These researchers observed adaptations under shaded conditions including increased leaf area, lower respiration rates and light compensation points and lower stomatal densities. This study suggests that physiological and biochemical adaptations play an important role in coffee adaptation to shaded conditions, and that morphological or anatomical plasticity may play a secondary role.

Similarly, DaMatta et al. (2007) pointed out that shade can result in net photosynthesis limitations due to insufficient light interception. Although, coffee leaves exhibit typical shade acclimation features, theoretically allowing them to maintain net photosynthesis in low light. In addition, Araujo et al. (2008) reported that a low physiological plasticity to low light in coffee leaves located inside the canopy, resulting in reduced net photosynthesis as compared to exposed leaves. Limitation of photosynthesis by low light availability has been proposed as one of the main reasons for lower yields of coffee grown in agroforestry systems in optimal coffee production areas (Beer et al., 1998; DaMatta et al., 2007). Nevertheless, DaMatta et al. (2007) have emphasized that, under optimal or near-optimal edapho-climatic conditions, shade provides little, if any, benefit to the crop.

Generally, these contradictory results might be due to the methodological differences between the conducted works. For studies of this nature, some factors that affect the physiological processes of coffee plants should be considered, such as climatic conditions (temperature and radiation), experimental conditions (pot or field), plant age, genotype and its adaptability to the local climate, shading type (natural or artificial), species that were studied, and shading density (Luiza et al., 1999; Morais et al., 2003).

Effects of shade on stomatal conductance of coffee

Stomatal regulation is a key process in the physiology of *C. arabica*, as well as many other plant species, and hence it is a key parameter in many ecological models (Bote and Struik, 2011). Stomatal conductance is intrinsically linked to photosynthesis and water relations, it provides insights into the plant's adaptive capacity, survival and growth (Craparo et al., 2017). Stomatal movements can be affected by various environmental factors, including plant water status, CO₂ concentration, and light. For example, bright light and low concentrations of CO₂ stimulate opening, while high CO₂ concentration even in bright light, cause closure (Kim et al., 2004). This means that various environmental and endogenous factors control stomatal movements, but from McDonald (2003) observation light is of major importance.

The stomatal limitations in coffee species are associated with a strong stomatal sensitivity to increasing leaf-to-air vapor pressure deficit (VPD) during the day (Vaast et al., 2006) and result in large reductions of photosynthesis, particularly in the afternoon (DaMatta and Ramalho, 2006). For example, when a coffee is grown in suboptimal (hotter and drier) growing conditions, and in full sun, the photosynthesis is lower than in the shade (Kanten and Vaast, 2006); which has been related to the high sensitivity of coffee stomatal conductance to VPD (DaMatta and Ramalho, 2006; Vaast et al., 2006). Shade trees reduce wind speed and leaf temperature while increasing air humidity, and hence reduce VPD and the stomatal limitations of coffee photosynthesis; therefore, agroforestry production systems have been recommended for suboptimal growing conditions (DaMatta, 2004; DaMatta et al., 2007; Vaast et al., 2006).

Barros et al. (1999) reported that the maximum rate of net photosynthesis in coffee was 4.5 mg CO₂ dm⁻² h⁻¹ and photosynthesis rate was decreased at the midday. This is associated to stomatal closure induced by direct action of sunlight, but not by leaf water relations (Franck et al., 2006; Ronquim et al., 2006); and also circumstantially with photoinhibition of photosynthesis and feedback inhibition coupled to an accumulation of soluble sugars in coffee leaves (Franck et al., 2006; Ronquim et al., 2006). Kanechi et al. (1995) also observed that stomatal conductance decreases logarithmically with increasing leaf temperature and vapor pressure deficit. Parallel to this, stomatal and mesophyll conductances are decreased sensitively with decreasing water potential, indicating that both conductances contribute to decline in the leaf photosynthetic rate. Moreover, this species is prone to photoinhibition of photosynthesis when exposed to full solar irradiance as coffee photosynthesis saturates at low irradiance (Ramalho et al., 2000). However, according to Chaves et al. (2008), photoinhibitory limitations of photosynthesis in full sun have been shown to be of secondary importance as compared to stomatal

conductance limitations in commercial Arabica coffee varieties and they attributed this feature to an acclimation to high irradiance in order to prevent photoinhibition. Moreover, Cannell (1985) noted that even with the light-adapted sun leaves of coffee, the photosynthetic apparatus seems to be physically damaged by continued exposure to high irradiances, perhaps by disruption of Photosystem II and exposed leaves of coffee exhibit chlorotic symptoms.

Effect of shade in leaf temperature

Caramori et al. (1996), studying frost protection provided by *Mimosa scabrella* Benth, showed leaf and air temperatures remained 2 to 4 and 1 to 2°C warmer at night, respectively, in shaded plots and reduced damage from cool temperatures. In Mexico, air temperature was 5.4°C higher and the minimum 1.5°C lower in sun as compared to shade plantations (Barradas and Fanjul, 1986). Soil temperature and vapor pressure deficits also were lower under shade trees. Over story, trees also reduced wind speed below their canopies (Caramori et al., 1996).

The negative effect of temperature on coffee photosynthesis has been reported early in the past century with net CO₂ assimilation decreasing at temperature above 24°C. This temperature effect was confirmed by several authors (Kumar and Tieszen, 1980) in studies where plants experienced a decrease in net CO₂ assimilation due to a reduction in stomatal conductance for temperatures in the range of 25 to 35°C. For this reason, it is assumed that CO₂ assimilation may be reduced in leaves completely exposed to high irradiance due to the high temperatures reached in tropical regions, which are in the order of 10 to 15°C above the air temperature (Cannell, 1985). Generally, shade trees have a pivotal role on creating a favorable ambient micro-climate for coffee plantations in particular and for the integral ecological system of the coffee tracts in general. Tree shades basically help to reduce the amount of heat reaching the coffee plant during the day time and protects the coffee plants from the evening and night low temperatures as the trees will serve as a cover and protection, hence contribute for the creation of an ambient micro-climate, which suits well for the growth and development of coffee bush (Alemu, 2015).

Effect of shade on coffee pest and diseases

Shade trees have been shown to alter the micro-environment around coffee. These changes likely explain why some pests and diseases are less successful under shade (Sarnayoa-Juarez and Sanchez-Garita, 2000). Beer et al. (1998) reported that there is a lack of agreement among farmers and scientists as to whether

shade trees reduce or increase diseases and pests of economic importance, such as leaf rust (*Hemileia vastatrix*) and the coffee berry borer (*Hypothenemus hampei*). Perfecto et al. (1996) reported that shade coffee systems, especially those that maintain a dense natural shade have been found to maintain a high level of biodiversity. Because of the potential of shade coffee as a refuge of biodiversity, coffee producers have been encouraged to maintain a dense, high diversity shade in their plantations. Shade provides an efficient biological management tool for the control of major pests and diseases like coffee white stem borer and leaf rust in Arabica coffee. It is also well documented that white stem borer is active in open patches and these open patches provide ideal conditions for spread of the pest to the neighboring plants. The activity of borer beetles is stifled at cooler temperatures. Thus, providing uniform shade is one of the major mechanisms for the effective management of the white stem borer. Besides providing unfavorable conditions for this pest, the shade trees are also reported to harbor a variety of predatory birds and natural enemies of it, thus contributing towards natural and biological control of the pest (Alemu, 2015).

Similarly, several papers have been reported on effects of shade on coffee berry borer. For example, for the first time, the effects of shade on the coffee berry borer were reported by Hargreaves (1926, 1935, 1940) in Uganda and by Jervis (1939) in Tanzania (Vega et al., 2015). These authors ascribed that the reduced damage was observed in coffee plants grown under full sun and shade; explaining that coffee berry borer damage is higher in unpruned trees and when large trees provide dense shade to the coffee plant. In general, higher coffee berry borer infestation levels have been reported in a coffee grown under shade (Baker et al., 1994). According to these authors, these would be due to two major reasons: first, since the insect evolved in the shade of forests, it is better adapted to that environment and not to the lower to the lower relative humidity (RH) of sun-exposed plantation. The second reason is shade has a negative effect on parasitoids, that is, adult coffee berry borers are very sensitive to high RH with an optimum range for survival and development at 90 to 95% of RH at and 25°C (Baker et al., 1994). These high humidity conditions would be more likely to be encountered in shaded plantations. In addition, Feliz Matos (2004) examined coffee berry borer infestation levels under three shade levels in Nicaragua: no shade, medium shade (40 to 50%) using *Gliricidia sepium* (Jacq.) Walp. (Fabaceae), and dense shade (60 to 70%) using *Eugenia jambos* L. Percent infestation was significantly higher (17 to 25%) in dense shade as compared to <2% under no shade and medium shade. Infestation levels for no shade and medium shade were not significantly different.

Wegbe et al. (2007) in Togo have also reported significantly higher coffee berry borer infestation levels in densely shaded coffee plantations. In Colombia,

Bosselmann et al. (2009) reported a trend towards higher infestation levels under shade.

On the other hand, several papers have reported on the effects of shade on different ant species. For example, Armbrrecht and Perfecto (2003) reported significantly different levels of litter and twig-nesting ants like *Pheidole*, *Solenopsis*, *Hypoconera* and *Wasmannia* in Mexico when distance from the forest was compared for shaded monocultures (that is, coffee under *Inga*, common name Shimbillo) and shaded polycultures (coffee shaded with various tree species). For the shaded monoculture, ant species decreased with increased distance from the forest, while an increase in ant species was reported for the shaded polyculture with increased distance from the forest. Thus, even within one system (that is, shaded coffee), various levels of different ant species can be found. This has important implications for the coffee berry borer, because one particular shaded habitat may be more favorable towards ant species that might potentially prey on the insect when compared with a different habitat. Roberts et al. (2000) and Philpott and Armbrrecht (2006) have also reported increased ant diversity in shaded coffee habitats.

CONCLUSIONS

Shading a plantation can provide a number of important benefits to the coffee plant by reducing air and soil temperature extremes, buffer high wind speed and improve and maintain soil fertility by returning large amounts of leaf litter to the underneath soil. It also softens the effect of biennial bearing, but it has to be considered in open plantations. Generally, the overall effect of the different interactions between shade trees and coffee are dependent upon climate and soil condition, and coffee species and varieties. In general, on optimal sites, coffee can be grown without shade using high agrochemical inputs; but at the expense of environmental degradation. On the other hand, shade tree may increase the incidence of some commercially important pests such as coffee berry borer and decrease the incidence of others like coffee leaf rust and coffee white stem borer.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

- Abrams MD, Kubiske ME (1990). Leaf Structural characteristics of 31 hardwood and conifer tree species in Central Wisconsin: influence of light regime and shade tolerance rank. *Forest Ecology Management* 31:245-253.
- Ackerly DD (2003). Community assembly, niche conservatism, and adaptive evolution in changing environments. *International Journal of Plant Science*, Chicago 164(1):165-S184.
- Alemu MM (2015). Effect of Tree Shade on Coffee Crop Production. *Journal of Sustainable Development* 8(9):66.
- Aranguren J, Escalante G, Herrera R (1982). Nitrogen cycle of tropical perennial crops under shade trees: Coffee Plant and Soil 67:247-258.
- Araujo WL, Dias PC, Moraes GABK, Celin EF, Cunha RL, Barros RS (2008). Limitations to photosynthesis in coffee leaves from different canopy positions. *Plant Physiology and Biochemistry* 46:884-890.
- Armbrrecht I, Perfecto I (2003). Litter-twig dwelling ant species richness and predation potential within a forest fragment and neighboring coffee plantations of contrasting habitat quality in Mexico. *Agriculture, Ecosystems and Environment* 97:107-115.
- Babbar LI, Zak DR (1995). Nitrogen loss from coffee agroecosystems in Costa Rica: leaching and denitrification in the presence and absence of shade trees. *Journal of Environmental Quality* 24:227-233
- Baker PS, Rivas A, Balbuena R, Ley C, Barrera JF (1994). Abiotic mortality factors of the coffee berry borer (*Hypothenemus hampei*). *Entomologia Experimentalis et Applicata* 71:201-209.
- Baliza DP, Cunha RL, Guimarães RJ, Barbosa JPRAD, Ávila FW, Passos AMA (2012). Physiological characteristics and development of coffee plants under different shading levels. *Revista Brasileira de Ciências Agrárias* 7(1):37-43.
- Barradas VL, Fanjul L (1986). Microclimatic characterization of shaded and open-grown coffee (*Coffea arabica* L.) plantations in Mexico. *Agricultural and Forest Meteorology* 38:101-112.
- Barros R, Maestri M, Rena A (1999). Physiology of growth and production of the coffee tree: A review. *Journal of Coffee Research* 27(1):1-54.
- Beer J (1987). Advantages, disadvantages and desirable characteristics of shade trees for coffee, cacao and tea. *Agroforestry Systems* 5:3-13.
- Beer J, Muschler R, Kass D, Somarriba E (1998). Shade management in coffee and cacao plantations. *Agroforestry System* 38:139-164
- Björkman O (1981). Responses to different quantum flux densities. In 'Physiological Plant Ecology. I. Responses to the Physical Environment'. (Eds O.L. Lange, P. S. Nobel, C. B. Osmond and H. Ziegler.) *Encyclopedia of Plant Physiology* 12:57-107.
- Bosselmann AS, Dons K, Oberthur T, Olsen CS, Raebild A, Usma H (2009). The influence of shade trees on coffee quality in small holder coffee agroforestry systems in Southern Colombia. *Agriculture, Ecosystems and Environment* 129:253-260.
- Bote AD, Ayalew B, Ocho FL, Anten NPR, Vos J (2018a). Analysis of coffee (*Coffea arabica* L.) performance in relation to radiation levels and rates of nitrogen supply I. Vegetative growth, production and distribution of biomass and radiation use efficiency. *European Journal of Agronomy* 92:115-122.
- Bote AD, Struik PC (2011). Effects of shade on growth, production and quality of coffee (*Coffea arabica*) in Ethiopia. *Journal of Horticulture and Forestry* 3(11):336-341.
- Bote AD, Zana Z, Ocho FL, Vos J (2018b). Analysis of coffee (*Coffea arabica* L.) performance in relation to radiation level and rate of nitrogen supply II. Uptake and distribution of nitrogen, leaf photosynthesis and first bean yields. *European Journal of Agronomy* 92:107-114.
- Braun H, Zonta JH, Lima JSS, Reis EF (2007). Production of conilon coffee seedlings propagated at different levels of shading. *IDESIA* 25(3):85-91 <http://www.idesia.com.ph/>
- Cannell MGR (1985). Physiology of coffee crop. In: Clifford, M.N., Willson, K.C. (Eds.), *Coffee, Botany, Biochemistry and Production of Beans and Beverage*. Croom Helm, London pp. 108-134.
- Caramori PH, Androcioli Filho A, Leal AC (1996). Coffee shade with *Mimosa scabrella* benth. for frost protection in southern Brazil. *Agroforestry Systems* 33(3):205-214.
- Chaves ARM, Ten-Caten A, Pinheiro HA, Ribeiro A, DaMatta FM (2008). 'Seasonal changes in photoprotective mechanisms of leaves from shaded and unshaded field-grown coffee (*Coffea arabica* L.) trees'. *Trees* 22:351-361.
- Craparo ACW, Steppe K, Asten PJA, Van Läderach P, Jassogne LTP, Grab SW (2017). Application of thermography for monitoring stomatal conductance of *Coffea arabica* under different shading systems. *Science of the Total Environment* 609:755-763.
- Da Silva Neto FJ, Morinigo KPG, De França Guimarães N, De Souza Gallo A, De Souza MDB, Stolf R, Fontanetti A (2018). Shade Trees

- Spatial Distribution and Its Effect on Grains and Beverage Quality of Shaded Coffee Trees. *Journal of Food Quality* 2018. <https://doi.org/10.1155/2018/7909467>
- DaMatta FM (2004). Ecophysiological constraints on the production of shaded and unshaded coffee: a review. *Field Crops Research* 86(2-3):99-114.
- DaMatta FM (2017). Coffee tree growth and environmental acclimation. In *Achieving sustainable cultivation of coffee: Burleigh Dodds Series in Agricultural Science* Number 07.
- DaMatta FM, Ramalho JDC (2006). Impacts of drought and temperature stress on coffee physiology and production: A Review. *Brazilian Journal of Plant Physiology* 18(1):55-81.
- DaMatta FM, Ronchi CP, Maestri M, Barros RS (2007). Ecophysiology of coffee growth and production. *Brazilian Journal of Plant Physiology* 19(4):485-510.
- De Carvalho Gonçalves JF, De Sousa Barreto DC, Dos Santos UM, Fernandes AV, Barbosa Sampaio PDT, Buckeridge MS (2005). Growth, photosynthesis and stress indicators in young rosewood plants (*Aniba rosaeodora* Ducke) under different light intensities. *Brazilian Journal of Plant Physiology* 17(3):325-334.
- Demel T (1999). History, botany and ecological requirements of coffee. *Walia* 20:28-50.
- Dias-Filho MB (1997). Physiological Response of *Solanum crinitum* Lam. To Contrasting Light Environments. *J. Pesquisa Agropecuária Brasileira* 32(8):789-796.
- Diby L, Kahia J, Kouamé C, Aynekulu E (2016). Tea, Coffee, and Cocoa. *Encyclopedia of Applied Plant Sciences* 3:420-425.
- Fahl J, Carelli MLC, Vega J, Magalhaes AC (1994). Nitrogen and irradiance level affect photosynthesis of coffee arabica. *HortScience* 69(1):161-169.
- Fanjul L, Arreola RR, Mendez CM (1985). Stomatal responses to environmental variables in shade and sun-grown coffee plants in Mexico. *Experimental Agriculture* 21:249-258.
- Fe'iz Matos D, Guharay F, Beer J (2004). Incidence of the berry borer (*Hypothenemus hampei*) in coffee plants in full sun and under the shade of *Eugenia jambos* and *Gliricidia sepium* in Marcos, Nicaragua. *Agroforesteria en las Américas* 42:56-61.
- Fournier LA (1988). The cultivation of coffee (*Coffea arabica* L.) in sun or shade: an agronomic and ecophysiological approach. *Agronomía Costarricense* 12:131-146.
- Franck N, Vaast P, Génard M, Dauzat J (2006). Soluble sugars mediate sink feedback down-regulation of leaf photosynthesis in field-grown *Coffea arabica*. *Tree Physiology* 26(4):517-525.
- Friend DJ (1984). Shade adaptation of photosynthesis in *Coffea arabica*. *Journal of photosynthesis research. The Netherlands* 5(4):325-334.
- Goldstein G, Durand LZ (2001). Photosynthesis, photoinhibition and nitrogen use efficiency in native and invasive tree ferns in Hawaii. *Oecologia, Heidelberg* 126(3):345-354.
- Goncalves JF, Barreto DC, Junior UM, Fernandes AV, Sampaio PT, Buckeridge MS (2005). Growth, photosynthesis and stress indicators of young rosewood plants (*Aniba rosaeodora* Duck) under different light intensities. *Journal of Plant Physiology* 17(3):325-334.
- Grades E (2007). Ecophysiological diversity of wild *Coffea arabica* populations in Ethiopia: Drought adaptation mechanisms. Doctoral Dissertation. Center for Development Research ZEF, Bonn.
- Gulmon SL, Chu CC (1981). The Effects of Light and Nitrogen on Photosynthesis, Leaf Characteristics, and Dry Matter Allocation in the Chaparral Shrub, *Diplacus aurantiacus*. Stanford, California 94305, USA.
- Gutiérrez MV, Meinzer FC (1994). Estimating water use and irrigation requirements of coffee in Hawaii. *Journal of the American Society for Horticultural Science* 119:652-657.
- Kanechi M, Uchida NU, Yasuda T, Yamaguchi T (1995). Water stress effects on leaf transpiration and photosynthesis of *Coffea arabica* L. under different irradiance conditions. In: *Proceedings of the 16th International Scientific Colloquium on Coffee, Kyoto*. Association Scientifique Internationale du Café, Paris pp. 520-527.
- Kanten RV, Vaast P (2006). Transpiration of arabica coffee and associated shade tree species in sub-optimal, low-altitude conditions of Costa Rica, 187–202. <https://doi.org/10.1007/s10457-005-3744-y>
- Kim HD, Goins RM, Wheeler KM, John CS (2004). Stomatal Conductance of Lettuce Grown Under or Exposed to Different Light Qualities. *Annals of Botany* 94:691-697.
- Kohyama T, Hotta M (1990). Significance of allometry in tropical saplings. *Functional Ecology* 4:515-521.
- Kufa T, Alemseged Y, Tesfaye S, Anteneh N, Endale T (2007). Yield performance of *Coffea arabica* cultivars under different shade trees at Jimma Research Center, Southwest Ethiopia. *Proceedings of the Second International Symposium on Multi-Strata Agroforestry Systems with Perennial Crops*, September 17-21, 2007, CATIE, Turrialba, Costa Rica.
- Kufa T, Burkhardt J (2013). Studies on root growth of *Coffea arabica* populations and its implication for sustainable management of natural forests. *Journal of Agricultural and Crop Research* 1:1-9.
- Kumar D, Tieszen LL (1980). Photosynthesis in *Coffea arabica*. I. Effects of light and temperature. *Experimental Agriculture* 16:13-19.
- Lakshamma P, Rao IV (1996). Response of black gram to shade and naphthalene acetic acid. *Indian Journal of Plant Physiology* 1(1):63-64.
- LeCoq JF, Soto G, González C (2011). PES and Eco-labels: a comparative analysis of their limits and opportunities to foster Environmental Services provision. In: *Rapidel, B., DeClerck, F., Le-Coq, J.F., Beer, J. (Eds.), Ecosystem Services from Agriculture and Agroforestry: Measurement and Payment*. Earthscan, London, UK. pp. 237-264.
- Luiza M, Carelli C, Fahl JI, Trivelin PCO, Queiroz-voltan RB (1999). Carbon isotope discrimination and gas exchange in coffee species grown under different irradiance regimes. *Revista Brasileira de Fisiologia Vegetal, Londrina* 11(2):63-68
- Matos FS, Wolgramm R, Gonçalves FV, Cavatte PC, Ventrella MC, DaMatta FM (2009). Phenotypic plasticity in response to light in the coffee tree. *Environmental and Experimental Botany* 67:421-427.
- Mazzafera P, Warrior S (1991). The coffee yield. Campinas: IAC, P 21.
- McDonald MS (2003). *Photobiology in higher plants*. Chichester: John Wiley and Sons. <https://www.wiley.com/en-us/Photobiology+of+Higher+Plants-p-9780470855232>
- Morais H, Marur CJ, Caramori PH, Ribeiro MA, Gomes JC (2003). Physiological characteristics and growth of coffee plants grown under shade of pigeonpea and unshaded. *Pesquisa Agropecuária Brasileira* 38:1131-1137.
- Nunes MA, Ramalho DC, Dias MA (1993). Effect of nitrogen supply on the photosynthetic performance of leaves from coffee plants exposed to bright light. *Journal of Experimental Botany* 44: 893-899.
- Paiva LC, Guimarães RJ, Souza AS (2003). Influence of different shading levels on coffee (*Coffea arabica* L.) seedlings growth. *Ciência e Agrotecnologia* 27:134-140.
- Perfecto I, Rice R, Greenberg R, Van der Voort M (1996). Shade coffee: a disappearing refuge for biodiversity. *BioScience* 46:598-608.
- Philpott SM, Armbrrecht I (2006). Biodiversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. *Ecological Entomology* 31:369-377.
- Pompelli MF, Cabrini EC, Claudjane M, Leite J (2012). Leaf anatomy, ultrastructure and plasticity of *Coffea arabica* L. in response to light and nitrogen Resumo. *Biotemas* 25(4):13-28.
- Ramalho JC, Pons TL, Groeneveld HW, Azinheira HG, Nunes MA (2000). Photosynthetic acclimation of high light conditions in mature leaves of *Coffea arabica* L.: role of xanthophylls, quenching mechanisms and nitrogen nutrition. *Australian Journal of Plant Physiology* 27:43-51.
- Roberts DL, Cooper RJ, Petit LJ (2000). Use of premontane moist forest and shade coffee agroecosystems by army ants in Western Panama. *Conservation Biology* 14:192-199.
- Rodrigues WP, Silva JR, Ferreira LS, Filho JAMH, Figueiredo FAMMA, Ferraz TM, Campostrini E (2018). Stomatal and photochemical limitations of photosynthesis in coffee (*Coffea* spp.) plants subjected to elevated temperatures. *Crop and Pasture Science* 69(3):317-325.
- Rodríguez L, Verdecia J, Arias L, Medina R, Velasco E (2001). Growth, relative water content, transpiration and photosynthetic pigment content in coffee trees (*coffea arabica* L.) growing at different sunlight regimes. *Cultivos Tropicales* 22(4):37-41.
- Ronquim JC, Prado CHBA, Novaes P, Fahl JI, Ronquim CC (2006). 'Carbon gain in *Coffea arabica* during clear and cloudy days in the wet season'. *Experimental Agriculture* 42:147-64.

- Rubio-De-casas R, Pérez-corona E, Manrique E, Quintana JR, García-Verdugo C, Balaguer L (2007). Field patterns of leaf plasticity in adults of the long-lived evergreen *Quercus coccifera*. *Annals of Botany*, Oxford 100(2):325-334.
- Russo RO, Budowski G (1986). Effect of pollarding frequency on biomass of *Erythrina poeppigiana* as a coffee shade tree. *Agroforestry Systems* 4:145-162
- Sands PJ (1995). Modeling canopy production. II. From single leaf photosynthesis parameters to daily canopy photosynthesis. *Australian Journal of Plant Physiology* 22:603-614.
- Sarnayoa-Juarez J, Sanchez-Garita V (2000). Leaf diseases on organic and conventional coffee. *Manejo Integrado de Plagas* 58:9-19.
- Stellmacher T, Mollinga PP (2009). The Institutional Sphere of Coffee Forest Management in Ethiopia: Local Level Findings From Koma Forest, Kaffa Zone. *International Journal of Social Forestry* 2(1):43-66.
- Tesfaye S, Taye K, Alemseged Y (2002). The effect of established shade trees on the growth and yield of Arabica coffee in two planting patterns. *Proceedings of the International Conference on Coffee Science (ASIC)*, May 14-18, 2001, Trieste, Italy.
- Toledo VM, Moguel P (2012). Coffee and sustainability: the multiple values of traditional shaded coffee. *Journal of Sustainable Agriculture* 36:353-377.
- Vaast P, Bertrand B, Perriot JJ, Guyot B, Génard M (2006). Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. *Journal of the Science of Food and Agriculture* 86:197-204.
- Valladares F, Arrieta S, Aranda I, Lorenzo D, Sanchez-Gomez D, Tena D, Suárez F, Pardos JA (2005). Shade tolerance, photoinhibition sensitivity and phenotypic plasticity of *Ilex aquifolium* in continental Mediterranean sites. *Tree Physiology*, Victoria 25(8):1041-1052.
- Van Der Vossen HAM (1985) Coffee Selection and Breeding. In: Clifford, M.N. and Wilson, K.C., Eds., *Coffee: Botany, Biochemistry and Production of Beans and Beverage*, Croom Helm, Westport, London pp. 48-96.
- Van der vossen HAM (2005). A critical analysis of the agronomic and economic sustainability of organic coffee production. *Experimental Agriculture* 41:449-473.
- Vega FE, Infante F, Johnson AJ (2015). The genus *Hypothenemus*, with emphasis on *H. hampei*, the coffee berry borer. In *Bark Beetles, Biology and Ecology of Native and Invasive Species*, 1st ed.; Vega, F.E., Hofstetter, R.W., Eds.; Elsevier: London, UK pp. 427-494.
- Wegbe K, Cilas C, Alauzet C, Decazy B (2007). Impact of environmental factors on bark beetle populations (*Hypothenemus hampei* Ferrari) (Coleoptera: Scolytidae). *Proceedings of the 21st International Scientific Colloquium on Coffee*, Association Scientifique Internationale du Café (ASIC), Montpellier, France pp. 1349-1353.
- Wexler M (2003). The Coffee Connection. *National Wildlife Magazine*. National Wildlife Federation, Wildlife Center VA 41:1.
- Wright SJ, Muller-Landau HC, Condit R, Hubbell SP (2003). Gap-dependent recruitment, realized vital rates and size distributions of tropical trees. *Ecology* 84(12):3174-3185.

Review

The use of Information Communication and Technology in advancement of African agriculture

Dionysious Kiambi

School of Humanities and Social Sciences, Pan Africa Christian University, P. O. Box 56875-00200,
Nairobi, Kenya.

Received 4 June, 2018; Accepted 21 August, 2018

Food security in Africa continues to be a big a challenge and one of the key constraints is lack of information on many facets of agricultural research and development to the key sector stakeholders. However, in recent years a wide range of Information Communication and Technology (ICT) platforms and mechanisms have been used across Africa in enhancement of exchange of agricultural related information for increased productivity and improvement of marketing of crops and livestock products. The purpose of the review paper was therefore to assess the nature, diversity and impacts of ICTs used in African agriculture and also highlight the key challenges hindering more widespread use of the technologies. A Kenyan case study has been used to typify the integrated nature of ICTs use in agriculture. The paper reveals that there is a very wide range of ICTs being used and these include web portals, mass media and different types of mobile telephone based services. Of all the ICTs, the radio service is the most effective in reaching a wide cross-section of agricultural research and development fraternity. It is evident that ICTs are making impact in increasing productivity and marketing of products but there are still several constraints including unconducive policy environment, insufficient communication infrastructure and inadequate farmer level capacities to use available ICTs. Public policy should therefore address these challenges and constraints within the sphere of rural development in general and agricultural productivity in particular. The review concludes that when mobile phones are combined with other ICT platforms such as mass media, the impact on agriculture is likely to be very high.

Key words: Information Communication and Technology (ICTs), African agriculture, agricultural research and development, mass media, mobile telephones.

INTRODUCTION

Information and Communication Technologies (ICTs) is a convergence of telecommunication and computing technologies for acquisition, retrieval and dissemination of information. It generally refers to the growing assembly

of technologies currently being applied in facilitated communication and handling of information in different economic sectors. These technologies include computer software and hardware, CD-ROMs, radio, telephone,

E-mail: dionysious.kiambi@pacuniversity.ac.ke.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

email, internet, television, videos and digital cameras as well as processing, storage, transmission and presentation of information in different formats such as texts, images, voice and data (Asenso-Okyere and Mekonnen, 2012; Aina, 2004). These platforms allow for the acquisition, processing, storage, sharing as well as information dissemination among humans and computers, locally and globally. The various ICTs enable the agricultural sector to benefit from increased flow of information to its stakeholders in a cost-effective manner. In the last two decades, the increased use of mobile telephones, the internet as well as personal computers has provided a diversity of choices in collection, storage, processing, transmission and presentation of information in various formats in response to different needs and user requirements (Asenso-Okyere and Mekonnen, 2012).

The agricultural sector is the source of livelihood for a great majority of the 75% of the people living in rural areas in Africa (OECD, 2016). Africa's agricultural sector has witnessed a notable decline over the past 40 years yet food security is critical for the survival of individuals, households and ultimately nations. According to World Bank (2010), 73% of the African people live in rural areas surviving on less than a dollar a day and poor farmers have largely remain poor. Just like in other sectors, African agriculture is faced with a number of challenges and constraints which include insufficient investment in rural areas, inadequate advanced appropriate technologies and inputs including improved varieties as well as inadequate access to markets and unbalanced market conditions, among other things. Agriculture in Africa is predominantly rainfed and is characterized by low yields and productivity, poor market facilitation as well as lack of access to financial intermediation services and other related critical information (World Bank, 2010).

Potentially, ICT can play a significant role in addressing some of these challenges since there is now an increased availability and use of such personal ICT devices as computers, mobile phones and tablets. The mainstreaming of ICT in agricultural stakeholder systems could spur economic development and growth by bridging critical knowledge gaps and increasing access to improved varieties and other technologies as well as the related information. One of the most widely used ICT is mobile technology, which is rapidly being adopted as the technology of choice in the delivery of agricultural related ICT services and solutions (Martiz, 2011). The main beneficiaries of the wider adoption of ICT in agriculture are five stakeholder groups which include agricultural businesses, farmers and farmers' associations, researchers, government ministries and citizens at large.

Over the years, the use of ICTs in African agriculture has increased considerably (May et al., 2007; Munyua, 2008). The application of ICT in agriculture, the largest economic sector in most African countries, provides great opportunities for poverty alleviation as well as the continent's economic growth (Christoplos and Kidd,

2000). In Africa, ICTs are complemented by social systems and/or networks which are instrumental in the sharing of knowledge. For example, a few available mobile phones can be used to spread a message quickly from an authentic source to different communities as well as members of a community including clans, solidarity association members and households. When combined with radio, mobile telephony enables transmission of messages to a large number of listeners. Some African communities have even tried the use of knowledge management web portals for the access of production and marketing information, albeit with some challenges. It is also evident that the technology is being used effectively for dissemination of information on weather forecasts, market prices, transport, storage facilities, livestock and crop diseases as well as general advice on agriculture (Gakuru et al., 2009). Studies conducted in several countries, have revealed that there is a positive correlation between investment in ICTs such as internet, fixed-line, mobile telephone or broadband penetration and Gross Domestic Product (Qiang and Rossotto, 2009; Verdier-Chouchane and Karagueuzian, 2016). The reported returns on ICTs investment include development of the private sector, increased trade competitiveness and innovation as well as job creation and poverty reduction (Adera et al., 2014; Chavula, 2014). Though some information on the use of ICTs in African agriculture is available, documentation is not comprehensive enough. The purpose of the review paper was therefore to assess the nature, diversity and impacts of ICTs used in African agriculture through document analysis, published and grey literature, case studies website information extracts. The paper also aims at highlighting the key challenges hindering more widespread use of the technology in the African continent.

METHODOLOGY

The overall philosophical approach was inductive and interpretive through literature review and document analysis. The literature review was conducted according to procedures established by Okoli and Schabram (2010). It was a stepwise process that started with defining the research topic and understanding the concept of 'broader' and 'narrower' terms. Narrowing the topic made it easier to limit the number of sources that needed to be read in order to get a good survey of the literature. This was followed by literature review, document analysis, collation and synthesis of information as well as report compilation. The methodological flowchart is provided in Figure 1.

The most relevant sources of the literature for the topic were identified and these included books, journals and institutional documents that contained useful and relevant information. This was supplemented with information from internet sites, institutional websites, web portals, project reports, theses and dissertations, conference papers, ePrints and government or industry reports. Ebsco Host, Emerald and Jstor journal databases were searched for relevant information using wildcards and logical brackets. Information sources were then grouped into themes and subthemes of the research topic. The literature review was supplemented with information retrieved through document analysis, which was used

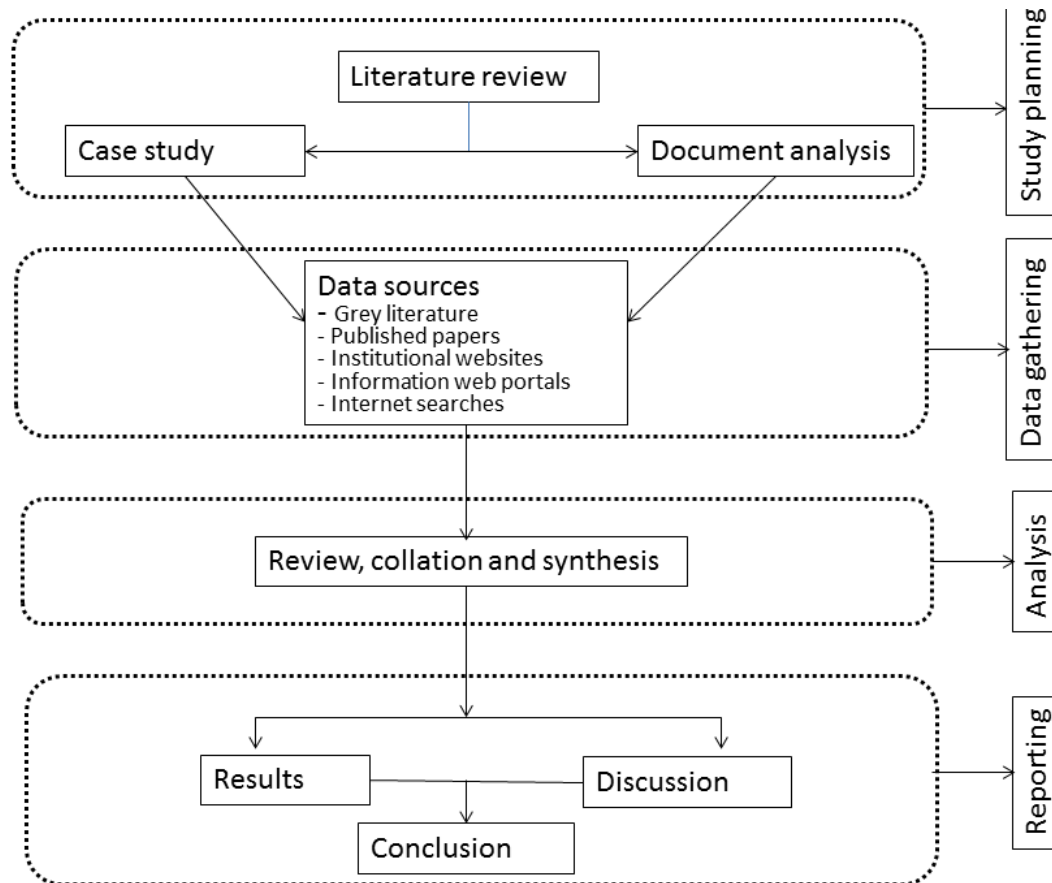


Figure 1. Research methodology flowchart.

as a form of qualitative research in which documents were interpreted to extract relevant information and data on the topic (Bowen, 2009). This involved analyzing documents from publicly available records and coding content into themes as guided by Bowen (2009) and O'Leary (2014). The information from literature review and document analysis was then collated, synthesized and analyzed to develop the results and discussion component of the review. In the analysis, several factors were considered and these included the subjectivity of the authors and also the personal biases they may have brought into the research; evaluation of the original purpose of the document, such as the target audience; latent content, which refers to the tone, style, agenda, facts or opinions that exist in the document and assessment of their completeness, particularly the selectivity or comprehensiveness of the data (Bowen, 2009).

RESULTS AND DISCUSSION

ICT platforms being used in African agriculture

The study revealed that there is a wide variety of ICT platforms that are currently being used to provide, exchange and disseminate different types of information and technologies to farmers and other agricultural research and development stakeholders in Africa. These include online PC based platforms, internet websites, mobile telephones, radios, TV's and GIS tools among

others (May et al., 2007)

There is a wide range of websites and online portals providing interaction platforms for agricultural research and development information. A good example is the Africa Trial Sites (<http://africats.org/>) which was established upon the recognition that the variability of African growing conditions hindered the widespread adoption of high yielding and stress resistant varieties. This variability also contributed to difficulties in selection of appropriate testing sites for improved varieties and matching them to appropriate growing environments throughout the continent. This portal makes it possible for both international and national research organizations to pool their information on trial sites electronically. It also provides a wide range of tools that are based on ICT advances in GIS, bioinformatics as well as data management in order to enable plant breeders, agronomists and farmers to acquire more useful data from field trials through the efficient field evaluation of improved varieties. The portal has a lot of the data from field trials and research conducted over many decades and for some time was held in the shelves of research institutions, making it difficult to assemble, analyze on a large scale and utilize. In addition, it allows users to browse the website for trial sites and other data on a

country basis, design trials for cultivar evaluation, access tools for trials management, trial data analysis, viewing of spatial analyses results, examination of data on an interactive google map and online reporting of results.

It is also possible for portal users to rank varieties and give comments on their performance at any given site. Through the website, climate data for any point in Africa can be analyzed and comparison of climate similarity between trial sites and other areas in Africa can be made. Finally, the site provides links to a variety of resources including websites of the participating institutions where users can request seed from gene bank curators and breeders. The combination of interactive data analysis tools and data from trial sites has made it possible for valuable information to be more widely available for use by stakeholders in agricultural research, development and extension. Although some results for improved varieties evaluated in Africa are available online, more data from researchers could significantly increase knowledge on the suitability of varieties to different environments, particularly those that are susceptible to diseases, pests or environmental stresses. The trial sites are now being used by international agricultural research centers in a climate adaptation research program that draws in national partners and using Africats.org for standardization of the information from trial sites (World Bank, 2011).

Mobile communications technology is another platform that is rapidly becoming one of the most widely used channels of transmitting voice, data and related services for use in a wide variety of economic sectors in Africa (Martiz, 2011). In light of this remarkable change, the potential for advancing development is significantly increased by mobile applications (m-apps) in general and mobile applications for agricultural and rural development (m-ARD apps) in particular. The focus of most of the m-ARD apps is to improve agricultural supply chain integration and they normally have a wide range of functions, including provision of market information, facilitation of market links and improving access to extension services. The users of these apps are diverse and they include buyers of farm produce, farmers, input suppliers, cooperatives, content providers and other stakeholders in the agricultural sector. A good example of the use of these apps is in Zambia, where "e-voucher" which is an electronic voucher system has been piloted by CARE, the United Nations World Food Program (WFP) and the local Conservation Farming Unit (CFU). Mobile Transactions, a company that specializes in low-cost payment and financial transaction services (<http://www.mtzi.net/>) supports the e-voucher system to empower smallholders in obtaining subsidized inputs from private firms. This, in turn, gives the firms an incentive to improve and expand their business. In addition, the e-voucher system provides support to private agribusinesses by allowing them to be the direct source for inputs and competition increases as more

private input dealers participate (World Bank, 2011). This system can also be used to access varieties and the related information as key inputs supplied by agro-dealers.

The use of ICT based agricultural products market platforms is slowly gaining pace in Africa. Since markets as well as market information are available, farmers have the opportunity to use the information to make informed choices about marketing and also improve their incomes by bargaining. They can also seize market opportunities by adjusting production plans and allocating production factors better. In this regard, ICT based market platforms are playing a crucial role by providing timely and relevant information in a manner that makes it easy to be absorbed and acted upon immediately. The services provided by these platforms are usually easy to understand, subscribe to and use. This makes them an excellent point of entry for more information services, such as general agricultural education and long-term extension services (May et al., 2007). For example in Ethiopia, ICT based market platform is enabling real time transmission of commodity price information to farmers by the novel Ethiopian Commodity Exchange (ECX). (World Bank, 2011) states that market data is transmitted to farmers through electronic display boards that are located in 31 centers across Ethiopia and also on the ECX's website. This data is also provided through text messages to interested mobile phone users. It is also provided in four local languages through automatic telephone messages. The service is in high demand and close to 20,000 calls by users seeking for price information are made daily through a toll free number World Bank (2011). Similarly, the Kenya Agricultural Commodity Exchange (KACE) and the Malawi Agricultural Commodity Exchange (MACE) also have ICT based commodity exchange services which include bids and offers that are displayed prominently on blackboard and also disseminated through text messages as well as internet. For instance, KACE gathers, updates, analyses and provides timely and reliable market information as well as intelligence on a wide range of crops commodities. The exchange platform targets actors in commodity value chains, mainly focusing on small scale agribusinesses and smallholder farmers (KACE, 2011). The exchange platform harnesses the advantages of modern ICTs and its power to collect, process and deliver market information using its effective Market Information and Linkage System (MILS). Moreover in Kenya, smallholder farmers also receive market information through text message and this enables them to have access to daily agricultural commodity prices. Text messages are also used to send extension related information and also in selling of commodities or bidding for their prices. Farmers are also connected with buyers in different urban centers through rural-based market information points that are linked to an electronic information system (KBDS, 2004; Muriithi et al., 2009;

Davis and Addom, 2010).

The agricultural marketing service (SIMA) in Mozambique uses a variety of ICTs including email, text messages, national and rural radios, internet as well as television and newspapers to collect and disseminate provincial and nation-wide data on product processing, availability and market prices. Available reports from CTA (2006) and Jenson et al. (2004) reveal that farmers usually obtain higher farm prices when they have access to market information. Similarly, the use of ICTs in Uganda has greatly enhanced exchange of agricultural related market information. For example, the Grameen Foundation has developed a comprehensive SMS-based system that enhances delivery of market information to farmers (Pyramid Research, 2010). Since 2008, the Foundation has also been using such programs as Application Laboratory to test new uses of the village phone infrastructure and then launched a series of mobile phone applications for dissemination of market information in 2009. This technology was developed in partnership with Google and MTN Uganda. It leverages MTN's network of village phones and a total of 35,000 public-phone operators in testing and delivery of mobile information services to rural communities. Moreover, the Grameen Foundation has trained and established a network of community knowledge workers (CKWs) which serve as "knowledge hubs" for smallholder farmers in Uganda. The hubs give the farmers online advice and information on diverse agricultural activities. All these services are based on text messaging and are designed for use with basic mobile telephones in order to reach the widest possible audience. The services can usually be accessed through existing village phone operators, who provide the service to farmers without mobile phones. The farmers send their queries and then receive the answers later (Pyramid Research, 2010). Similarly, in Kenya, a pilot project called Banana information line, has been using text-to-speech (TTS) telephone service in either English or Kiswahili to provide farmers with information on planting, growing and harvesting of bananas. Recently, this was superseded by the National Farmers Information Service (NAFIS) which covers a wide range of livestock and crops. Through the service, the country's farming community receives and exchanges timely information and news on weather patterns, agriculture and related issues through mobile telephones (Gakuru et al., 2009). Radio services are also a widely used communication technology in dissemination of agricultural information. A good example is the Farmer Voice Radio (FVR) which is a radio extension service that targets smallholder farmers in Ghana, Kenya, Malawi, Mali, Tanzania and Zambia. The FVR extension agents provide on-site extension support on regular basis to a small group of pre-selected farmers. The information and experiences are then documented and broadcast via radio (Payne et al., 2010a). In Tanzania, community radio stations are now incorporating mobile technology into

programming for use in advisory services in agriculture. The approach is building on the utility of mobile telephones as recording tools and listening devices (Gakuru et al., 2009). The acquired information is then used or shared in many ways. For instance, the farmers living near the radio station can obtain information directly by walking in to enquire, ask questions or report issues related to agriculture and farming. Farmers also have the option of listening to information and agricultural related news over the radio. The radio stations have also developed an SMS messaging system for sending and receiving information on a wide range of agricultural issues.

In west Africa, there are several examples of use of ICT in agricultural research, development and marketing. For instance, Manobi in Senegal collects price data on various crops from different markets across the country and provides this information to a wide variety of users. Mobile phones are used to send the price data to the Manobi database via wireless application protocol (WAP) and farmers then query the database using their mobile phones (ITU, 2010b). These mechanisms can potentially be used for a wide range of services including varietal availability and related information. Similarly, the Market Information Systems and Traders' Organizations of west Africa (MISTOWA) has partnered with the private sector to develop a platform (www.tradenet.biz) that enhances real time exchange of market information on-line or through mobile phones. The system uses text messages for relaying information on market prices, sales and purchase offers as well as trader contact information for ease of business links. The system also provides producers and trader organizations with online space to create websites for dissemination of their business related information (Davis and Addom, 2010).

In Nigeria, the Integrated Cassava Project disseminates market information to cassava growers through the internet, mobile phone and online market place platform called Trade Net Africa. The platform disseminates market information through the Agri-Business Information Points (market information centers) as well as trade agents. The services provided include market information such as prices, demand volumes and offers. They also include assistance in trade and market trends, training, SMS alerts and technical messages on different aspects of agricultural products marketing (Pyramid Research, 2010). In Ghana, a local company called Esoko has developed ICT based services that include placement of purchasing and selling orders by both farmers and traders. The service is supported and complemented by a network of agents who collect information on prices of about 20 agricultural commodities from 30 in-country markets. The company has a system of providing information on commodity prices to farmers and other stakeholders on a subscription basis (Martiz, 2011). Further experiences from Ghana demonstrate the power of mobile phones in

obtaining and providing production and marketing information to cocoa farmers. For instance, the Ghana Cocoa Board has launched a pilot program called Cocolink. This is public-private partnership between the World Cocoa Foundation and Orange which provides cocoa farmers with useful information on prevention of crop diseases, post-harvest production, marketing of crop products, farm safety and improvement of farming practices. Through the program, specific answers to questions and agricultural related information are sent to farmers by both voice and text messages in English or in their local languages free of charge (Martiz, 2011). This program enlisted 3,700 users in Ghana by the end of 2013 (United Nations, 2014) and aims to access 100,000 cocoa farmers in Côte d'Ivoire, since it is known that there are over one million Ivoirians engaged in cocoa production in the country (Grow Africa Secretariat, 2014).

There are other forms of ICTs such as GIS, Remote Sensing (RS) and satellite imagery which are useful in land selection by facilitating the process of land registration and allocation as well as enhancing tenure security for farmers to leverage their assets (WEF et al., 2015). These ICTs are increasingly being used to ensure more efficient land use and water management. In some countries such as Cameroon, for instance, GIS systems are being used to register land before implementing redistribution mechanisms (WEF et al., 2015). In addition, GIS in combination with RS has been used in supporting the assessment of soil conditions, land capability, flood and drought risk, crop condition and yields, pest infestation and groundwater contamination (Wilson, 2005). Egypt for instance has developed a soil and terrain database for the Sinai Peninsula as well as other regions (WEF et al., 2015). In Ethiopia and Mozambique, satellite imagery data and GIS have also been used in crop inventories and facilitating land registration (Deloitte, 2012).

Use of ICT in agriculture: Kenyan case study

Agriculture is an important sector in Kenya's economy and its growth is critical to the country's social as well as economic development. The direct contribution of this sector is about 26% of Gross Domestic Product (GDP) while it contributes another 27% through linkages with distribution, manufacturing and service related sectors (GOK, 2010). Close to one-third of the country's agricultural produce is exported, accounting for 65% of the total exports. The agricultural sector employs about 80% of the country's labour force and it generates 60% of foreign exchange earnings. It controls 40% of the government earnings and provides 75% of industrial raw materials (GOK, 2007, 2010). However, the agricultural sector is characterized by low crop productivity, limited marketing opportunities and inadequate access to appropriate technologies by farmers, particularly seeds

and related inputs (GOK, 2003). Just like other sectors of the economy, agricultural development depends on access to information as an important prerequisite for crop production, processing and marketing (Jones, 1997).

In Kenya, the framework for sharing agricultural information through implementation systems is provided by the E-government Strategy, the National ICT Policy, Vision 2030 and the Strategy for Revitalising Agriculture (SRA) (GoK, 2007, 2010, 2016). Recently, E-Agriculture has emerged as a new field that focuses on enhancing rural and agricultural development through improved information and communication processes. In particular, e-Agriculture comprises conceptualizing, designing, developing, evaluating and applying innovative approaches of using ICT in the rural settings, primarily focusing on agriculture. ICT is being used in diverse ways to enhance agricultural research and development in Kenya. There are various ICT strategies and platforms being used to receive and provide information to the agricultural community as next outlined.

Mass media

Studies conducted by Rogers and Nichoff (2002) and Nabutola (2014) revealed that mass media is an important channel for communicating and conveying agricultural information. The studies also revealed that the radio is the best medium of spreading agricultural information, provided chain agents maintain close follow-up to assure farmers of the integrity of the information disseminated to them. In Kenya, the mass media programs being used include:

Mali Shambani: This is a one hour long weekly radio program produced by the Kenya Broadcasting Corporation radio station (www.kbc.co.ke). The program features agricultural related news and responds to various issues such as farming methods, market prices and trends, weather patterns and seasonal issues, agricultural inputs, financial opportunities, land use and quality standards. The weekly program comprises an interactive call-in service that allows farmers to send agricultural questions to a panel of experts by text messages or phone. An impact assessment on this service by Nabutola (2014) found out that it was very effective in reaching farmers across the country.

Shamba shape up: This is a weekly TV and radio program that provides a wide range of information on agricultural technologies including seed varieties and their sources. The program has recently included iShamba which is a subscription based sms service that farmers can use to get agricultural related information from agronomists and other agricultural experts. The information that is provided includes weather alerts,

seeds and seed sources, pests and diseases as well as market price information. The advice is tailored to the crops of interest, agro-ecology and in line with the region's crop cycle (www.shambashapeup.com).

Seeds of Gold: This is a weekly pullout in the Daily Nation, the country's most widely read newspaper published by Nation Media Group (NMG) (www.nationmedia.com). The pullout aims at enhancing farmers' knowledge in best practices for farming as well as transference of new innovations and technologies from different diverse sources to farmers. The information is wide ranging and includes crop varieties that have been recently released.

Soko Hewani: This is a radio service where bids and offers are announced on the Soko Hewani program mainly targeting farmers and agricultural small and medium size enterprises (SMEs). During the radio program, the listeners who are mostly smallholder farmers and agricultural SMEs, call in or send IVR, e-mails and text messages to bid on the offers or give offers on bids. The Soko Hewani radio broadcast staff on standby then use mobile phone calls and text messages to match the offers and bids. They may also reference back to the specific person who submitted the offer or bid in order to negotiate further and conclude the deal (www.sokohewani.com).

Mobile telephone platforms

Mobile telephones are increasingly being used because of their wide reach and usage in rural areas where farmers are domiciled. They provide a fast mechanism of creating "contact" with farmers and extension workers. Extension workers answer questions from farmers on telephone on the spot. Mobile phone technology has been used to provide a wide range of services in the agriculture sector. This includes information and analysis of commodity and stock market price, collection and dissemination of meteorological data, agricultural extension advisory services, information on prices and sources of inputs (seeds, chemicals and fertilizers), financial services, early warning systems for disaster prevention and control, gathering of agricultural statistical data and traceability of agricultural products. The mobile telephone platforms include the following:

Phone-based voice messages: The service is provided by the National Farmers' Information Service through the Local Language Speech Technology Initiative. Through this initiative, farmers living in remote rural areas receive information on crops and inputs, livestock production, market prices, disease outbreaks and weather reports. They also receive information on crop suitability for specific areas and this is very helpful as most of the farmers are illiterate and don't have access to the internet

or extension services. Through the service, text-based information is converted to audio messages, in either English or Swahili. It is then transmitted and provided to farmers over a landline telephone or cell phone. The staff of the service respond to farmers' queries by reading the relevant information back to them (Tucker and Gakuru, 2009).

iKilimo: This is a mobile information reference tool for farmers developed as an easy way to acquire and understand farming information. The service provided includes information on plant production (including information on seed varieties and various sources), high value crops as well as marketing (www.ikilimo.org).

KenCall farmers helpline: This is a profit oriented call center that provides real time agricultural advice, information and support to smallholder farmers by phone using voice and voice call-back to farmers (Payne et. al., 2010a). The service is provided by agricultural experts and primarily targets individual farmers in Kenya but will soon be accessible to agriculture extension workers in order to complement existing efforts of supporting and engaging the SHFs with varied but detailed information on how to improve agricultural production (growing, harvesting and rearing), planning (agricultural inputs and planting), negotiating and selling. Kencall has recently established a mobile telephone based helpline for farmers as an integrated online system of information collection, handling and dissemination. Farmers are provided with information on improved agricultural planning, production, inputs including seeds, processing, value addition, climate and marketing. For the usage of this service, farmers call the helpline with specific questions which are addressed by agricultural experts and subject matter specialists. This service primarily targets the smallholder farmers but also supplements the extension services with the relevant information (www.kencall.com).

Kilimo salama: This is an innovative mobile phone based scheme which allows farmers to insure seeds and inputs against climate change risks. The scheme operates through appointed dealers who sell seeds, fertilizers and chemicals to farmers with a small insurance premium. The farmer gets an insurance confirmation that is registered through a mobile phone SMS. The SMS contains the insurance details and the policy number. At the end of the season the farmer gets an SMS with information on whether there is a payout. In case of payout, the compensation is transferred to the farmer's mobile phone number via M-PESA, a popular and widely used money transfer system. The system is linked to weather stations that provide data on climatic conditions and the payouts are made when there are severe droughts and floods and there are high likelihoods that the farmers may have lost their seeds, chemicals and fertilizers (<https://kilimosalama.wordpress.com>)

M-Farm: This mobile platform provides an SMS service which allows farmers to buy agricultural inputs such as seeds, fertilizers and chemicals collectively or sell farm products directly to the market. Through the platform, groups of farmers can agree on a price and collectively sell directly to a buyer instead of selling through middlemen. This is done by farmers joining other farmers in their community through SMS subscription to the platform. In order to sell their produce, farmers send text messages giving information on the product, its weight and the asking price. M-Farm then matches local buyers and sellers on the basis of the prices they have submitted to the platform. The platform enables the 6,000 subscribed farmers to retain higher sales margins by circumventing value chain middle-men. M-Farm is a for-profit organization based in Kenya. The company started in 2010 and has grown to 7,000 users (<http://mfarm.co.ke>). The system features includes, market prices for 42 crops, group selling tool and SMS advertising, group buying tool for fertilizers and seeds and information dissemination, for example on international regulations.

National Farmers Information Service (NAFIS): This is a voice service which provides farmers with agricultural extension information accessed through mobile phones. NAFIS is updated through the Web, and a Text-to-Speech engine in both Kiswahili and English is used to create IVR automatically (www.nafis.go.ke).

Mkulima Farmer Information Service: This is a helpline and farmer information resource provided through mobile phones and the Web. It is a mobile IVR (Interactive Voice Response), service using USSD (Unstructured Supplementary Services Data) to guide farmers through a set of options when they are seeking information on a particular agricultural issue. This includes information on market prices for farm products, prices and sources of seeds and weather related information.

DrumNet: The basis of Drum Net's service is provision of an IT platform that targets agricultural suppliers in Kenya. The platform is compatible with mobile telephone networks, the internet as well as other wireless devices. This platform also enables Drum Net to provide such unique products as text messages, scouting, mapping of data and tailor made reporting. The incomes of Kenyan farmers who use the DrumNet app has risen by a third because of the service's comprehensive system of contracting, price negotiation and other value chain support. The service also enables rural residents and farmers to access extension services including inputs such as seeds and fertilizers, advice on agricultural production and information on marketing, technology, food security and nutrition (www.drumnet.net).

Variety information text messaging service: Through

this service provided by the Kenya Plant Health Inspection Services (KEPHIS), farmers are provided with information on planting and growing recommended crop varieties in their regions. This sms service provides farmers with information on recommended varieties of various crops that are suitable for their regions and ecological zones. The farmers send text messages specifying the name of the crop and the region and then get a reply with a recommendation on the right variety for their region (www.kephis.org).

The impacts of ICT-based agricultural advisory and extension services

Although the number of ICT-based initiatives providing agricultural extension and advisory services in Africa is growing, there is hardly any rigorous evidence-based impact assessment of use of ICTs in agriculture. According to the available literature, most of the studies have only assessed impact on prices and markets but even then the results are mixed. There are hardly any reports on the impact of ICT initiatives on cropping patterns, changes in crop production practices, availability and adoption of technology as well as productivity. Aker (2008) assessed the impact use of cell phones on grain trade in Niger. The author used a meta-dataset that combined subsets of data on transport costs, prices, rainfall and grain production. The study revealed that across markets, mobile telephones reduced grain price dispersion by a minimum of 6.5% and reduced the variation of intra-annual prices by 10%. The study also revealed that cell phones mainly affected market-level outcomes through a reduction in search costs since grain traders who used cell phones could cover a greater number of markets and sell in more markets. The results also suggested that cell phones led to increased consumer welfare during Niger's severe food crisis of 2005 and this may have averted a worse outcome. Likewise, Muto and Yamano (2009) found that in Uganda, the number of the farmers selling bananas increased in communities more than 20 miles away from district centers after the expansion of the mobile telephone coverage. This was based on data collected from 856 Ugandan households in 94 communities. The results imply that mobile phone coverage enhances the market participation of farmers who produce perishable crops and are located in remote areas.

In their studies, Verdier-Chouchane and Karagueuzian (2016) revealed that technologies with low infrastructure requirements and low costs such as the radio are the most used ICTs in the African continent compared to other traditional mass media such as newspaper, television and broadband fixed lines. For example, studies conducted in several sub-Saharan African countries (Ghana, Malawi, Mali, Mozambique, South Africa and Tanzania) revealed that rural radios that had innovative programs such as dramas and radio fora tailor

Table 1. Successful new ICT-based services in the agriculture sector in Africa.

Stage	ICT oriented activities	Status of application
Crop production stage	Enhancement of land tenure security for farmers by leverage GIS, Remote Sensing (RS) and satellite imagery technologies to (land registration, crop inventories)	Cameroon, Egypt, Ethiopia
	Payment tool for crop insurance and credit in the agriculture sector using mobile phones	Mozambique
	Build a virtual common information system platform (through mobile phone) linking all stakeholders in the agriculture sector, comprising a database containing farmers' information	Kenya (Kilimo salama, using M-PESA), Kenya (M-Kilimo), Kenya (NAFIS)
	Provision of information through mobile phones and mass media (radio, TV, newspapers) on crop cultivation, best agriculture management practices and market prices to enhance agriculture production and productivity in a sustainable way and increase farmers' income	Kenya, Mali, Tanzania, Ghana, Côte d'Ivoire (Agri VAS) Kenya, Malawi, Ghana, Tanzania, Zimbabwe, Mali (FVR) Kenya (KenCall, Mali Shambani, Shamba shape up, Seeds of Gold, iKilimo, Kilimo salama, Drum net)
	Use of mobile phones and internet based platforms in commodity exchange in dissemination of information on market prices and knowledge data on products as well as coordination and contract enforcement between buyers and sellers	Ghana (E-Soko) Ethiopia (Ethiopia Commodity Exchange) Kenya (Kenya Agricultural Commodity Exchange) Malawi (Malawi Agricultural Commodity Exchange) Ghana and Cote d'Ivoire (Cocoalink) Senegal (Manobi)
Post-harvest stage	Provide quality and traceability information on products through mobile phones to improve integration into global agriculture value chains	Nigeria (Trade Net Africa) Mozambique (SIMA) Uganda (Application Laboratory)

made for local communities were effective communication channels of agricultural messages (FRI, 2008a). Moreover, in Malawi, these studies found that farm radio messages led to farmer behavioral changes. These changes included reduction of overdependence on maize through crop diversification; engagement in soil improvement, on-farm tree planting, use of compost manure, crop rotation, small-scale irrigation, micro-enterprises, environmental conservation, home economics and nutrition (FRI, 2008a). The study also suggested that the use of farm radio is even more effective when complemented with new information and communication technologies (ICTs).

Another success story is "Talking Book" which is an ICT designed to provide information on agricultural technologies in local language to illiterate farmers using audio computer. A pilot study conducted in a rural village in Ghana in 2009 revealed that households using Talking Books on an intermittent basis grew 48% more food than other households (World Bank et al., 2011). A summary of successful ICT applications in agriculture is provided in

Table 1.

Factors influencing the use of ICTs in African agriculture

The application of ICTs in African agriculture is growing, especially the expansion of mobile telephones usage, though they have mainly been used to provide marketing information. However, this information alone may not necessarily lead to innovations and the desired increased productivity of smallholder agriculture if ICTs are not supported with such extension services as advice on improved agricultural practices, availability of agricultural technologies including seeds and other inputs as well as farmer education. The use of ICTs has several constraints compared to human-based extension service, which requires deployment of a large number of extension workers. These constraints can be summarized into three broad categories viz the rural setting; the policy environment; infrastructure and capacity constraints and

the nature of local communities including their inability to use the technology to access information for various agricultural activities.

The policy environment

The African continent as a whole continues to lag behind the rest of the world although the telecommunications sectors of some of the countries such as Ghana, Kenya, Nigeria and Senegal, are quite dynamic. This is primarily due to the high cost of services as revealed by a study that was conducted by Calandro et al. (2010) in 17 sub-Saharan African countries. This study argues that the achievement of affordable and universal access to the full range of ICTs has been undermined by poor policies which constrain market entry and the competitive allocation of available resources; weak institutional arrangements characterized by low technical capacities and competencies; and in some cases, regressive taxes on usage of ICTs. Furthermore, Gillwald (2010) argues that effective regulation is needed in order to enhance competition and open access regimes. Regulation of other factors such as spectrum, interconnection and tariffs are also required for stimulation of market growth, improvement of access to ICTs and lowering of their prices. This is exemplified in Cote d'Ivoire where many competitive markets with several players have experienced spectrum allocation problems as well as high cost of services due to retrogressive taxes on mobile communications despite having an open market with several operators as the case of Uganda. In some cases, the situation is made worse by expensive leased lines that are only provided by incumbent operators who are usually unregulated. This contributes to the high cost of conducting business and inhibits opportunities for ICT growth and development (Gillwald, 2010).

The rural setting, infrastructure and capacity constraints

Most of the rural areas are sparsely populated, making provision of such services as electricity, water, modern ICTs, infrastructure and public utilities difficult to deploy. Private firms are the primary ICT service providers and they invest their resources where they are likely to get good returns. They are therefore unlikely to invest in rural areas where returns on investments are minimal due to lack of essential services and infrastructure. For example, electricity which is an important requirement for provision of ICT services is quite limited in most of the rural areas in Africa and many countries still lack good GSM networks (Torero, 2014). In addition, rural people's incomes are normally lower than in urban areas and most rural households cannot afford modern ICTs such as computer, internet and mobile phones. The combined effect of all these constraints is a digital divide between

the rural and urban areas (Asenso-Okyere and Mekonnen, 2012). Moreover, unless there are strong incentives, ICT operators are generally unwilling to cover the rural areas because of the high cost of start-up, operating and programming in addition to the low capacity of the rural people to pay for the services (Souter et al., 2005).

The nature of local communities and inability to access information using technology

The level of education, income, social and cultural constraints influences the likelihood of an individual to have the necessary e-skills to use different technologies (Gillwald and Stork, 2010; Hafkin and Odame, 2002; Hafkin and Taggart, 2001). A study by Muto and Yamano (2009) in Uganda found that possession of mobile phones was directly related to the total value of assets and the level of education of household members. A scoping study conducted by Munyua (2008) on small-scale agriculture and ICTs in Africa found low usage patterns and anecdotal adoptions. The study also revealed that ICT initiatives were uncoordinated and scattered. It summarized the main challenges and factors that influence the use of ICTs as high cost of technologies, low ICT skills, inadequate infrastructure, poor and expensive connectivity, language barriers, inappropriate ICT policies, low bandwidth, inadequate and/or inappropriate credit facilities and systems. The study also identified other constraints including poor involvement of women and other disadvantaged groups, inadequate collaboration and awareness of existing ICT facilities and resources, inappropriate local content, weak institutions, a poor information sharing culture and low awareness of the role of ICTs in development at all levels.

A survey that was based on household and individual access and usage conducted across 17 African countries (Gillwald and Stork, 2010) revealed that the diffusion of ICTs such as mobile telephones, radio, internet and television was highly uneven. The diffusion concentrated in urban areas and left many rural areas almost untouched. The study also found out that income is a major constraint to the access and usage of these technologies. However, as the technologies become more complex, literacy and education increasingly become the main constraints. Further disaggregation of the data by gender revealed that women were more disadvantaged than men in the access and use of even the more prevalent forms of ICTs. The study also reported that such factors as education, income and social position played an important role in explaining and expanding ICT access and usage. It was also noted that the differences in access to ICTs and their usage were much less when men and women had similar academic and socio-economic backgrounds. However, women generally have less access to ICTs because of unequal

access to opportunities such as income and education, which seem to enhance ICT access and usage. This inequality increases as the services as well as technologies become more expensive and sophisticated, with their access and operation requiring higher income and education levels. Moreover, a study by GSMA (2010) revealed that women in low and or middle income countries are 21% less likely to own a mobile phone than men. This knowledge is unsettling for agricultural development in Africa where food production is primarily in women's domain and they need ICT related technology and market information in order to increase farming productivity and profitability. In their studies on agriculture, gender and ICTs in Africa, Hafkin and Odame (2002); Hafkin and Taggart (2001) identified several factors that hinder the use of telecenters and communication facilities by women. These include multiple roles and heavy workloads, which limit the time available for women to use telecenters; men's attitudes towards women's use of technology and to women visiting mixed-sex public facilities; opening of public facilities during evenings which exposes women to dangers; the lower levels of educational of women in comparison to men's and lack of disposable income to pay for services rendered in the centers, among others.

Conclusion

There is no doubt that the development of ICTs has facilitated the dissemination of knowledge and information and it is revolutionizing the use of technology in agricultural research, development and marketing. The wide range of ICT platforms have a great potential for increased use in dissemination of information on seeds, varieties and their sources as well as information on other agricultural inputs. However, there is need for better integration of information between the ICT service provides, agricultural research and development sector and private sector, especially private seed companies and agro-dealers.

It is also evident that rural incomes have increased with the use of ICTs in accessing knowledge and information. However, there are still challenges in accessing of ICTs and related platforms by a large number of the rural population who are engaged in agriculture. These challenges and constraints need to be addressed through public policy within the context of rural development in general and agricultural productivity in particular. It is worth noting that in Africa, the acquisition and usage of mobile phone has increased tremendously and when they are used in combination with other ICT platforms such as mass media, the impact on agriculture is likely to be very high. The expansion of access to these platforms could be increased through the reduction of costs of the devices and connectivity charges. A key strategy in the reduction of costs would be greater cooperation among African countries in rolling out ICT platforms, particularly

equipment and content.

CONFLICT OF INTERESTS

The authors has not declared any conflict of interests.

REFERENCES

- Adera EO, Waema TM, May J, Mscarenhas O, Diga K (2014). *ICT Pathways to Poverty Reduction: Empirical Evidence from East and Southern Africa*, Rugby, UK: Practical Action Publishing.
- Aina LO (2004). *Library and information science text for Africa*. Third World Information Services Limited. Ibadan, Nigeria.
- Aker JC (2008). *Does Digital Divide or Provide? The Impact of Cell Phones on Grain Markets in Niger*, University of California, Berkeley
- Asenso-Okyere K, Mekonnen AD (2012). *The Importance of ICTs in the Provision of Information for Improving Agricultural Productivity and Rural Incomes in Africa*. Working Paper. United Nations Development Program.
- Bowen GA (2009). *Document Analysis as a Qualitative Research Method*. *Qualitative Research Journal* 9(2):27-40.
- Calandro E, Gillwald A, Moyo M, Stork C (2010). *African Telecommunication Sector performance Review 2009/2010. Towards Evidence-Based ICT Policy and Regulation*, Vol. 2. Policy Paper no. 5
- Chavula HK (2014). *The Role of ICTs in Agricultural Production in Africa*. *Journal of Development and Agricultural Economics* 6:7.
- Christoplos I, Kidd A (2000). *Guide for Monitoring, Evaluation and Joint Analyses of Pluralistic Extension*. Support. Neuchatel Group.
- CTA (2006). *Technical Centre for Agricultural and Rural Cooperation ACP-EU Annual Report 2006*. D. H. Neun. Wageningen, The Netherlands, CTA. <https://cgspace.cgiar.org/handle/10568/42211>
- Davis KE, Addom BK (2010). *Sub-Saharan Africa*. In R. Saravanan, Ed. *ICTs for agricultural extension: Global experiments, innovations and experiences*. New Delhi: New India Publishing Agency.
- Deloitte (2012). *Transform Africa: Agriculture Sector Study: Sector Assessment and Opportunities for ICT*. Available at <http://siteresources.worldbank.org>
- FRI (2008a). *Communicating with Radio: What Do We Know? Findings from selected rural radio effectiveness evaluations*. African Farm Radio Research Initiative (AFRRI). Farm Radio International Ottawa, Canada. <https://publications.farmradio.org/wp-content/uploads/2017/07/communicating-with-radio.pdf>
- Gakuru M, Winters K, Stepman F (2009). *Inventory of Innovative Farmer Advisory Services using ICTs*. The Forum for Agricultural Research in Africa (FARA).
- Gillwald A (2010). *ICT regulation in Africa - The Good, The Bad and the Ugly*. *Communication Technologies Handbook*. BMI-TechKnowledge
- Gillwald A, Stork C (2010). *Towards Evidence-based ICT Policy and Regulation: ICT access and usage in Africa*. *Research ICT Africa*. Policy Paper 1:2.
- Government of Kenya (GOK) (2003). *Economic Strategy for the Revitalization of Agriculture*. Government Printers.
- Government of Kenya (GOK) (2007). *Vision 2030*. Ministry of planning and economic development. Government of Kenya.
- Government of Kenya (GOK) (2010). *Agricultural Sector Development Strategy 2010 – 2017*. Government of Kenya.
- Government of Kenya (GOK) (2016). *The national ICT Policy*. Ministry of Information and Communications Technology. Government of Kenya.
- Grow Africa Secretariat (2014). *Agricultural Partnerships Take Root across Africa*. 2nd annual report on private-sector investment in support of country-led transformations in African agriculture.
- GSMA (2010). *Women & Mobile: A Global Opportunity-A Study on the mobile phone gender gap in low and middle-income countries*, http://www.gsmworld.com/documents/women_mobile.pdf.
- Hafkin N, Taggart N (2001). *Gender, Information Technology and Developing Countries*. Washington, D.C: Academy for Educational

- Development, 2001. http://ict.aed.org/infocenter/pdfs/Gender_Book_Photos.pdf.
- Hafkin NJ, Odame HH (2002). Gender, ICTs and Agriculture. A Situation Analysis for the 5th Consultative Expert Meeting of CTA's ICT Observatory meeting on Gender and Agriculture in the Information Society.
- ITU (2010b). World Telecommunication/ICT Development Report 2010. Monitoring The WSIS Targets - A mid-term review. International Telecommunication Union (ITU), Geneva, Switzerland
- Jenson M, Myers M, Southwood R (2004). The Impact of ICT in Africa. Paper Prepared for the Commission for Africa.
- Jones GE (1997). The history, development and the future of agricultural extension. In: B.E. Swanson, R.P. Bentz and A.J. Sofranko (1997). Improving agricultural extension – a reference manual. FAO, Rome.
- Kenya Agricultural Commodity Exchange (KACE) (2011). Kenya Agricultural Commodity Exchange. KACE Services: The KACE Market Information and Linkage System. <http://www.kacekenya.co.ke/section.asp?ID=64>
- Kenyan Business Development Service (KBDS) (2004). Kenyan Business Development Service Program Monthly Newsletter, November 2004.
- Martiz J (2011). How mobile phones are transforming African Agriculture. Agri4Africa. <http://www.howwemadeitinafrica.com/how-mobile-phones-are-transforming-african-agriculture/8704/>.
- May J, Karugia J, Ndokweni M (2007). Information and communication technologies and agricultural development in sub-Saharan Africa: transformation and employment generation. Framework paper prepared for the African Economic Research Consortium (AERC).
- Munyua H (2008). ICTs and small-scale agriculture in Africa: a scoping study. International Development Research Centre (IDRC)
- Muriithi AG, Bett E, Ogaleh SA (2009). Information Technology for Agriculture and Rural Development in Africa: Experiences from Kenya. A paper presented at Conference on International Research on Food Security, Natural Resource Management and Rural Development, University of Hamburg, October 6-8.
- Muto M, Yamano T (2009). The Impact of Mobile Phone Coverage Expansion on Market Participation: Panel Data Evidence from Uganda, *World Development* 37(12):1887-1896
- Nabutola T (2014). The impact of radio agricultural programmes on small scale farmers: the case of "Mali Shambani" program on KBC Radio Taifa. Masters Thesis, Nairobi University.
- O'Leary Z (2014). *The Essential Guide to Doing Your Research Project* (2nd ed.). Thousand Oaks, CA: SAGE Publications, Inc.
- OECD (2016). *OECD-FAO Agricultural Outlook 2016-2025*. Organisation for Economic Co-operation and Development, Paris, France. <http://www.fao.org/3/a-i5778e.pdf>
- Okoli C, Schabram K (2010). A Guide to Conducting a Systematic Literature Review of Information Systems Research. *Sprouts: Working Papers on Information Systems* 10(26). <http://sprouts.aisnet.org/10-26>
- Payne J, Woodard J, IRIS (2010a). ICT to Enhance Farm Extension Services in Africa. Briefing Paper. USAID. November https://pdf.usaid.gov/pdf_docs/PA00J7P8.pdf
- Pyramid Research (2010). The Impact of Mobile Services in Nigeria: How Mobile Technologies Are Transforming Economic and Social Activities. <http://www.pyramidresearch.com/documents/IMPACTofMobileServicesInNIGERIA.pdf>.
- Rogers L, Nichol G (2002). The communication of agricultural research to farmers in Africa. Proceedings of the 2nd General Conference on Making Agriculture More Meaningful to Farmers. Dakar, Senegal, March 24-28.
- Souter D, Scott N, Garforth C, Jain R, Mascarenhas O, McKemey K (2005). The economic impact of telecommunications on rural livelihoods and poverty reduction. A study of rural communities in India (Gujarat), Mozambique and Tanzania. Report of DFID KaR Project 8347 http://www.telafrica.org/R8347/files/pdfs/Final_Report.pdf.
- Torero M (2014). The Impact of Rural Electrification. Challenges and Ways Forward. International Food Policy Research Institute. Paper prepared for the 11th Conference AFD Proparco/EUDN: Energy for Development.
- Tucker RC, Gakuru M (2009). Experience with developing and deploying an agricultural information system using spoken language technology in Kenya. In IEEE: Proceedings of Spoken Language Technology Workshop, 2008. SLT 2008. IEEE.
- United Nations (2014). L'Afrique à l'assaut de l'agriculture. Edition spéciale agriculture. AfriqueRenouveau. Information Department, New York. https://www.un.org/africarenewal/sites/www.un.org.africarenewal/files/Africa_Renewal_Special_Edition_2014_fr_0.pdf
- Verdier-Chouchane S, Karagueuzian C (2016). Moving Towards a Green Productive Agriculture in Africa: The Role of ICTs. African Development Bank Group. AEB 7:7.
- Wilson JP (2005). Local, National and Global Applications of Global Information Systems in Agriculture. In *Geographical Information Systems: Principles, Techniques, Management and Applications*, 2nd edition, Longley, P.A., M.F. Goodchild, D. J. Maguire and D.W. Rhind, eds. New York: Wiley. https://www.researchgate.net/publication/284664222_Local_national_and_global_applications_of_GIS_in_agriculture
- World Bank (2010). *World Development Report 2010: Development and Climate Change*. World Bank. Washington DC, USA. <https://siteresources.worldbank.org/INTWDR2010/Resources/5287678-1226014527953/WDR10-Full-Text.pdf>
- World Bank (2011). *ICT in agriculture: Connecting Smallholders to Knowledge, Networks and Institutions*. Report Number 64605. The International Bank for Reconstruction and Development / The World Bank. Washington DC, USA. <http://documents.worldbank.org/curated/en/455701468340165132/pdf/646050ESW0P11801tore0e0Sourcebook12.pdf>
- World Economic Forum (WEF), African Development Bank, and the World Bank (2015). *Africa Competitiveness Report 2015*. Geneva: World Economic Forum. http://www3.weforum.org/docs/WEF_ACR_2015/Africa_Competitiveness_Report_2015.pdf

Full Length Research Paper

Use of renewable energy resources in agriculture the case of Turkey

Bekir Yelmen

Wastewater Treatment Department, Water and Sewage Authority, Adana Metropolitan Municipality, 01120 Turkey.

Received 24 July, 2018; Accepted 3 September, 2018

The rapid growth in the world economy has led to significant increases in energy demand. However, due to the limited formation of fossil fuel reserves such as petroleum, coal and natural gas, and the damage they cause to the environment, it has brought the trend towards renewable energy sources. The main renewable energy sources that can be effectively utilized in agriculture sector are; solar, biomass, geothermal and wind energies. The type of energy that can be used in agricultural production depends on the design of the renewable energy source and the agricultural structure and processes. The main energy consuming processes during production are irrigation, drying of products, heating and cooling of greenhouse gases and animal shelters. Fossil fuels are used during these operations. New technological applications in agriculture, further increases energy consumption. However, due to the increase in the cost of fossil fuels and environmental pollution; the use of renewable energy resources, which have a great potential in the agriculture sector, can be eliminated from this problem. This study examines examples of renewable energy sources that can be effectively utilized in the agricultural sector, Turkey. Proposals have been made for energy efficiency through the use of renewable energy source technologies that can be utilized in energy agriculture and agricultural production operations.

Key words: Renewable energy sources, fossil fuels, agriculture, environmental impact.

INTRODUCTION

Energy as a sign of economic and social development is an indispensable requirement of mankind. Sustainability of energy resources has been one of the most important issues and problems in the world. Energy is also important for technological production and development as well as for increasing quality of life. In recent years; energy use, greenhouse gas emissions, and their potential impacts on global climate change are among the most debated topics. One of the most effective ways to reduce energy use in industry, transport, commerce,

housing and agriculture is to increase energy efficiency. In today's industrial world, the use of energy resources has reached a significant level. Therefore, the origin of natural resources has begun to decrease and the damage given to the natural environment has continued to increase. In this direction, the diversity of domestic renewable energy sources has also been increasing. The term of renewable energy is used for energy resources such as water, sun, wind, geothermal and biofuels that are present in nature and sustain in their existence. Also,

E-mail: bekiryelmen@gmail.com. Tel: +90-322-428-8350.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

It should be noted that fossil fuels will be consumed (Kadioğlu and Telloğlu, 1996). When fossil fuels are burned, carbon dioxide, sulfur dioxide, nitrogen oxides, dust and other emissions spread to the atmosphere and pollute the environment with leading to deaths. Besides, carbon dioxide and similar greenhouse gases lead to global climate change and threaten life in all the countries of the world (Uyar, 2001). Unless measures are taken to protect the environment and human health from the use of fossil fuels, it will be inevitable that the future cost of living will reach a very large size (MNE, 2012). The energy requirement in the world has been increasing by about 4-5% each year. However, the search for renewable energy sources has accelerated because of the limited worldwide fossil fuel reserves and the fact that they will be consumed in the near future (Bayram, 2001). In addition, the use of fossil fuels has increased the world average temperature and has resulted in a noticeable increase in natural disasters such as floods and storms, which cause intense air pollution as well as billions of dollars in damages. Therefore, mankind must turn to renewable energy sources without waiting for fossil fuel reserves to be exhausted (Görez and Alken, 2005).

The importance of strategies, plans and policies for the adequate utilization of renewable energy sources are significantly increasing (Öztürel et al., 2001). Biomass and biofuels have an important potential in renewable energy sources. These are composed of oil seeds, carbohydrates, fiber plants, and all kinds of materials of animal origin. The energy generated from these sources is defined as biomass or biofuel energy. The use of animal and vegetable food wastes as clean energy is important for the prevention of environmental pollution and the development of energy resources. This energy is produced by converting organic wastes into methane gas in an oxygen-free environment, while the remaining part is used as an enriched fertilizer source. Increasing energy efficiency is important for assessing the environmental impact of energy resources. System efficiency needs to be increased to use less energy and to minimize damage to the environment.

Energy consumption requires careful planning of energy consumption against side effects that result from the scarcity of energy resources and careless use (Öztürk, 2004a). Like other sectors, energy dependency is increasing in the agricultural sector. This increase is increasing all over the world due to the use of technology (Gowdy et al., 1987). In addition, energy input is an important factor in the agricultural production function (Pachauri, 1998). Some studies have shown that the energy factor in agricultural productivity and efficiency are dominant (Felloni et al. 1999). Energy has also an important role in social and economic development. However, the policies developed for energy use in rural areas are insufficient. This may be due to the low pre-fertilization of agriculture due to the industrialization of emerging countries, and the low level of education and

organizational skills in rural areas (Karkacığer and Göktolga, 2004). The detailed studies have been carried out in regional and national production systems and product-based, and total energy use of Turkey agricultural sector (Barut and Öztürk, 2004). Agricultural production has played an important role in the level of welfare achieved by developed country economies. When the economic development process is examined, it is seen that the income obtained from agriculture first goes to the industrial sector after the commercial and this capital provides resources for industrialization. Turkey in terms of its geographical structure, ecological conditions, product variety and quantity has a great potential in agricultural production. With this rational, effective and planned use of this potential, it will grow in line with the discourses of sustainable development that are frequently discussed in the international public.

In today's industrial world, the use of energy and other resources has reached a significant level. For this reason, the damages of natural resources such as environmental pollution are increasingly increasing on one side as the natural resources of the other side are decreasing. However, energy conversion can not be achieved efficiently. There are many factors such as population growth, economic productivity, consumer habits and technological developments that need to be considered in order to determine future energy production and consumption levels in developed and developing countries. Effective management of the energy sector will play an important role in future energy production and consumption levels and distribution. Thus, efficient design methods will be developed by reducing inefficiencies in existing energy systems. One of the most fundamental elements of the economic and social development of countries is energy (Pamir, 2003). The demand for energy will continue to increase in the future. In 2030, energy consumption is foreseen to increase by 60% in the world and higher than 100% in Turkey (Satman, 2007). It is known that fossil fuels will meet the needs of today's energy needs in the coming years (Kumbur et al., 2005).

Renewable energy sources, on the other hand, are inexhaustible and they do not pose a significant threat to the environment and human health, unlike fossil fuels. Globally, the contribution of these energy sources is still low, but it has risen by 10-30% in recent years (Martinot et al., 2002). Direct energy is used during the mechanization of agricultural production. However, sufficient use of renewable energy resources is required in the agricultural sector for the effective prevention of environmental problems caused by the use of fossil fuels (Öztürk, 2010). Thus sustainable development will be achieved by using energy resources in a sustainable way. Nowadays, it is understood that the theme of sustainable development is understood and increased in the efforts towards energy efficiency. Therefore, the development of energy efficiency, the prevention of

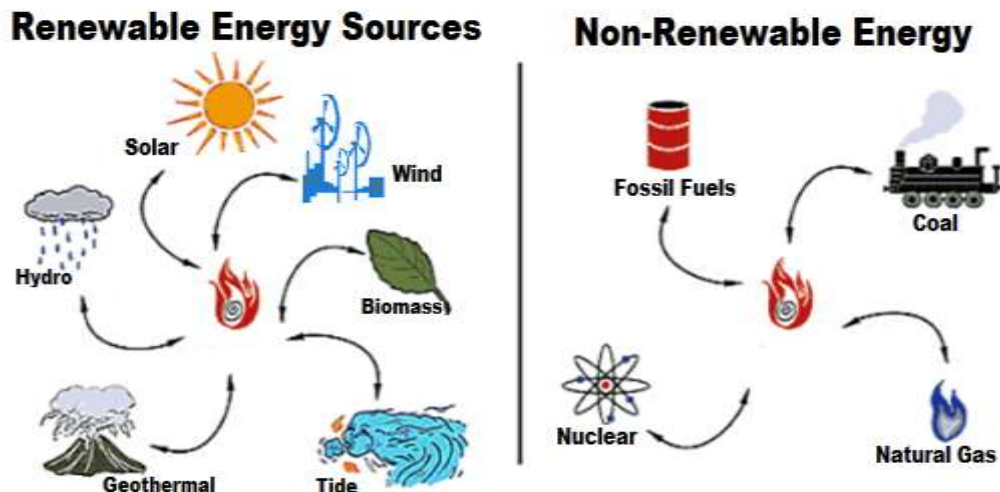


Figure 1. Renewable and non-renewable energy sources.

unconscious use and waste, and the reduction of energy intensity both at sectoral and macro level are priority and important components of national energy policies (Direk, 2017). While fossil fuels are energy resources that are burned and renewed, natural resources such as hydro (water), sun, wind, biomass and geothermal are not only renewable but also as a clean energy source. As of 2006, about 18% of the world's energy consumption is provided by renewable energy sources (Gönüllü, 2009). Renewable energy sources need to be utilized to effectively prevent environmental problems arising from the direct or indirect use of fossil fuels. However, the economic feasibility and implementation method of renewable energy sources in the agricultural sector varies depending on regional conditions. The main renewable energy sources that can be effectively utilized in agriculture sector are; solar, wind, geothermal and biomass energies. Renewable and non-renewable energy sources are given in Figure 1 (Anonymous, 2018).

In this study, the role of agriculture in renewable energy is examined and it is also aimed at establishing a relationship between agriculture and renewable energy sources and the current situation of environmentally sensitive renewable energy production, whether or not agriculture has an impact on renewable energy sources, and how effective agricultural products or other wastes are produced.

ENERGY USE IN AGRICULTURE

In the agricultural sector, vegetable and animal production processes require the use of specific amounts of energy. The use of energy in agriculture includes the energy used in irrigation-pump operations, the heat control processes in the greenhouse, the farms and vegetable productions, the transport of agricultural products, the agricultural machinery and tools used in the

processing and evaluation of agricultural products, and the production, packaging and transport of chemical fertilizers and agricultural chemicals (Özkan et al., 2003; Hatırlı, et al., 2004). In overall energy consumption in Turkey, the change in the amount of energy consumed in agriculture between 1990 and 2011 is given in Table 1 (TurkStat, 2011). While the amount of energy consumed in agriculture sector was 1956 Thousand TOEs in 1990, it increased to 2556 Thousand TOEs in 1995, 3073 Thousand TOEs in 2000, 3340 Thousand TOEs in 2005, and 5755 Thousand TOEs in 2011, respectively. While the amount of energy consumed in agriculture sector increases regularly, the share of agriculture sector in total energy consumption does not change regularly. The share of agriculture in total energy consumption was 3.69% in 1990, 4.01% in 1995, 3.82% in 2000 and 3.65% in 2005 and 6.62% in 2011, respectively. The share of agriculture in total energy consumption was 4.66% on average basis between 1990 and 2011. While the share of agriculture in total energy consumption declined in 2002-2005, it started to increase after 2005.

In the agricultural sector, the changes in energy consumption per agricultural area in years between 1990 and 2011 are given in Table 2 (TurkStat, 2011). The amount of energy used per hectare in the agricultural sector was 0.78 TOE in 1990, 0.104 TOE in 1995, 0.128 TOE in 2000, 0.140 TOE in 2005, and 0.280 TOE in 2011, respectively. As a result of mechanization and advanced technology applications in the agriculture sector, energy use is seen to increase gradually. Therefore, the use of renewable energy sources in the agriculture sector and the increase in energy use efficiency are necessary.

USE OF RENEWABLE ENERGY RESOURCES IN AGRICULTURE

Turkey's energy production and targets based on

Table 1. Turkey energy consumption in the agricultural sector.

Years	Energy consumption		Share of agriculture in total energy consumption (%)
	(Thousand TOE*)		
	Agriculture	Total consumption	
1990	1956	52.987	3,69
1995	2556	63.679	4,01
2000	3073	80.500	3,82
2001	2964	75.402	3,93
2002	3030	78.331	3,87
2003	3086	83.826	3,68
2004	3314	87.818	3,77
2005	3340	91.576	3,65
2006	3608	77.441	4,66
2007	3944	82.747	4,77
2008	5174	79.559	6,5
2009	5073	80.574	6,3
2010	5089	83.372	6,1
2011	5755	86.952	6,62
Average	3712	78.912	4,66

*TOE : Tons of oil equivalent .

Table 2. Energy consumption in the agricultural sector and per cultivated area in Turkey.

Years	Total energy consumption in agriculture (Thousand TOE)	Processed agriculture area (Thousand ha)	Planted field of agriculture (Thousand ha)	Total energy consumed in agriculture / working field (TOE/ha)	Total energy consumed in agriculture / fields farmed (TOE/ha)
1990	1.956	24.827	18.868	0.078	0.103
1995	2.556	24.373	18.464	0.104	0.138
2000	3.073	23.826	18.207	0.128	0.168
2001	2.964	23.800	18.087	0.124	0.163
2002	3.030	23.994	18.123	0.126	0.167
2003	3.086	23.372	17.563	0.132	0.175
2004	3.314	23.871	18.110	0.138	0.182
2005	3.340	23.830	18.148	0.140	0.184
2006	3.608	22.981	17.440	0.156	0.206
2007	3.944	21.979	16.945	0.179	0.232
2008	5.174	21.555	16.460	0.240	0.314
2009	5.073	21.351	16.217	0.237	0.312
2010	5.089	21.384	16.333	0.237	0.311
2011	5.755	20.539	15.712	0.280	0.366
Average	3.711,6	22.977,3	17.476,9	0,164	0,216

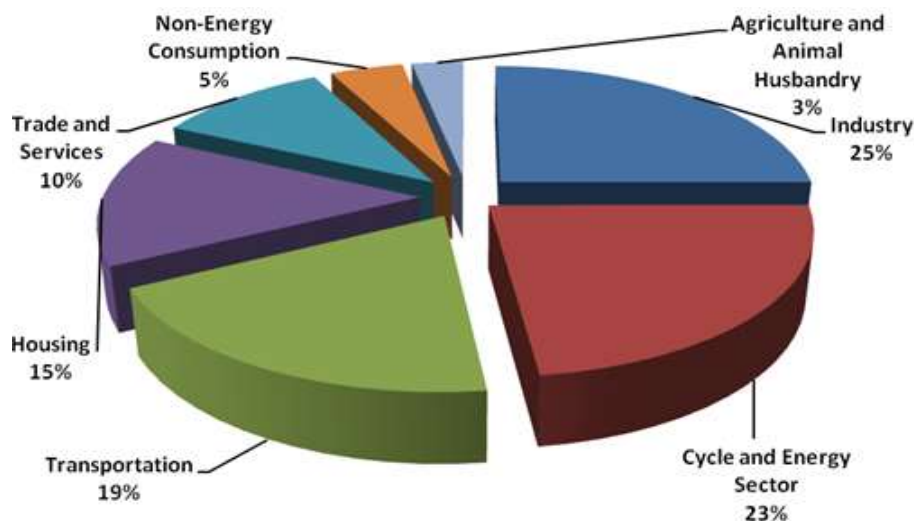
renewable energy sources are shown in Table 3 (Yılmaz, 2017). As of 2015, hydro-power and wind energy are the most used from renewable energy sources. Utilization of geothermal energy is in third place and its use is still limited. While the use of solar energy is at a low level, the use of wind energy and solar energy is steadily increasing

in 2017. At the target of 2023, it is planned to increase the wind energy to 20000 MW and the solar energy to 5000 MW.

In case of using renewable energy resources in agriculture; operating costs, the need for imported fossil energies, the excessive demand for electrical power and

Table 3. Turkey's energy production and targets based on renewable energy sources.

Years	Hydropower energy MW	Wind energy MW	Solar energy MW	Geothermal energy MW	Biomass energy MW
2015	25.526	5.660	300	412	377
2017	28.763	9.549	1.800	559	530
2019	32.000	13.308	3.000	706	683
2023	34.000	20.000	5.000	1.000	1.000

**Figure 2.** The distribution of primary energy consumption by sectors in Turkey.

environmental pollution are reduced. Economic development is achieved at this point. The choice of renewable energy technology that can be utilized in agricultural production operations and the type of energy required depends on the design of the renewable energy source and agricultural structures and processes. The main energy consuming processes among agricultural production processes are irrigation, crop drying, heating and cooling of greenhouses and animal shelters. During these operations, fuels such as diesel oil, natural gas, electricity, liquefied petroleum gas or propane are used. The distribution of primary energy consumption by sectors in Turkey is given in Figure 2 (MENR, 2018). As can be seen, the share of the agriculture and livestock sector in general energy consumption by 2015 is given as 3%. The distribution of installed power by sources in Turkey is given in Figure 3 (TEİAŞ, 2017). As can be seen, the total installed power by 2017 is given as 80.343,3 MW.

Renewable energy sources need to be utilized to effectively prevent environmental problems arising from the direct or indirect use of fossil fuels. The main renewable energy sources that can be effectively utilized in agriculture sector are solar, wind, geothermal, and

biomass energies. 55 countries in the world began to focus on renewable energy sources in 2005, while more than 100 countries have set targets for renewable energy and developed some policies since 2010 (REN21, 2010). Ten countries, including the US, Japan, Scotland and Denmark, target 100% of renewable energy in some sectors (REN21, 2011). Support for renewable energy by governments around the world reached \$41 billion in 2007, \$44 billion in 2008, and \$57 billion in 2009 (Deloitte, 2011). At the end of 2010, the Asian Development Bank provided \$21 million to the Bhutanese region in South Asia to achieve electricity and promote clean energy use for their rural population under the Rural Renewable Energy Development project (Öztürk, 2011). Under the scope of rural development, Ministry of Agriculture, TUBITAK, and State Planning Organization in Turkey and the European Union institutions devote significant resources to support the agricultural sector in recent years.

Use of solar energy in agriculture

Solar energy systems can be investigated under two

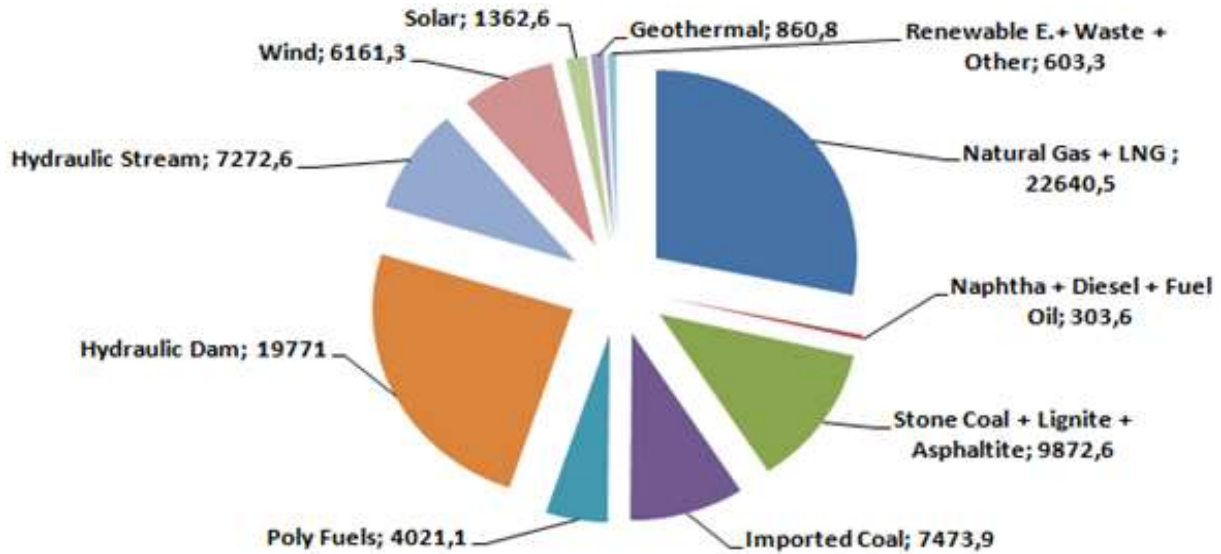


Figure 3. The distribution of installed power by sources in Turkey (MW).

Table 4. The distribution of Turkey's solar energy potential by months.

Months	Monthly total solar energy	Hours of Sunshine
	(kWh/m ² -month)	(hour/month)
January	51,75	103
February	63,27	115
March	96,65	165
April	122,23	197
May	153,86	273
June	168,75	325
July	175,38	365
August	158,4	343
September	123,28	280
October	89,9	214
November	60,82	157
December	46,87	103
Total	1.311	2.640
Average	3.6 kWh/m²-day	7.2 h/day

groups as heat systems and electrical systems (Ulanır, 1998a), although they are very diverse in terms of method, material and technological level. It can be said that Turkey, with a nominal position, is in good condition in terms of solar energy potential. According to data provided by the General Directorate of Electrical Power Resources Survey and Development Administration, the distribution of Turkey's solar energy potential by months is given in Table 4 (Taşkın and Korucu, 2014).

Turkey's annual total sunshine hours of 2.640 h (average daily sunbath time is 7.2 h) and the total radiation intensity of 1.311 kWh/m²-year (average daily

radiation intensity is 3,6 kWh/m²) have been identified. Turkey has a high solar energy potential, such as 110 days and the country can produce a total of 1.311 kWh of solar energy per square meter per year in case of necessary investments. Turkey's total annual solar energy potential by regions is given in Table 5 (Taşkın and Korucu, 2014). Looking at the region of the solar energy potential in Turkey, the most sunshine hours with 2.993 h/year is the Southeastern Anatolia region. Looking at the breakdown by region of the solar energy potential in Turkey, the most sunshine hours with 2.993 h/year is the Southeastern Anatolia region. On the other hand, the

Table 5. Turkey's total annual solar energy potential by region.

Regions	Total solar energy (kWh/m ² -year)	Hours of sunshine (hours/year)
Southeastern Anatolia	1.460	2.993
Mediterranean	1.390	2.956
Eastern Anatolia	1.365	2.664
Central Anatolia	1.314	2.628
Aegean	1.304	2.738
Marmara	1.168	2.409
Black Sea	1.120	1.971
Average	1.303	2.623

**Figure 4.** Turkey's solar energy potential.

least sunshine hours is the Black Sea region with 1.971 h/year. As can be seen from the table, it is determined that the solar energy potential can produce an average of 1.303 kWh of energy per unit per year while the annual average sunshine duration is 2.623 h (Figure 4) ((REGD, 2017a).

Drying agricultural products with solar energy

Most of the agricultural products, which are not consumed within a short period of time after they are produced, deteriorate and lose their nutritional value. Therefore, agricultural products need to be dried to extend their usable life. Drying is the process of evaporation of excess water in the agricultural products (Yağcıoğlu, 1996). After natural drying, the most economical method of drying is the process using solar energy (Kısakürek, 1980). Solar-powered dryers can be used to dry a lot of food because their operating costs are very low and they are hygienic (Ünalın, 2006). In combined type dryers, air is first heated in solar collectors, then dryer cabinet is dried under the sun

(Dalgıç, 2006). There are various renewable energy sources in the literature such as solar powered and electric dryer system (Boughali et al., 2009), the desiccant system that generates heat and electricity from solar energy (Aktaş et al., 2013), photovoltaic-thermal (PV/T) greenhouse type dryer system (Barnwal and Tiwari, 2008), geothermal energy dryer design for drying granular products in geothermal field in Kamojang (Indonesia) (Sumotarto, 2007), the cabin type biomass energetic dryer system (Mukaminega, 2008), and hot water and solar collector dryer system (Amer et al., 2010).

Greenhouse heating with solar energy

In recent years, many researches have been conducted to reduce energy consumption in undergrowth cultivation. In these studies, new and renewable natural energy sources with the aim of developing low cost and efficient heating systems have been used as an alternative to heating systems consuming fossil fuels. In Table 6 (Kendirli and Çakmak, 2010a), the distribution of the

Table 6. The distribution of the greenhouse areas by regions (ha).

Region	Glass material greenhouse	Plastic material greenhouse	High tunnel	Low tunnel	Total	%
Mediterranean	7.525,4	17.355,2	5.115,9	17.131,3	47.127,8	86,9
Aegean	691,4	2.695,5	602,9	484,3	4.474,1	8,2
Black Sea	1,7	659,7	430	465,5	1.556,9	2,9
Marmara	2,3	359,7	481,3	10,4	853,7	1,6
Central Anatolia	0,3	58,4	45,7	-	104,4	0,2
Eastern Anatolia	-	13,7	14,7	6,9	35,3	0,1
Southeastern Anatolia	4,2	25,8	5,5	28,1	63,6	0,1
Total	8.225,3	21.168,0	6.696,0	18.126,5	54.215,8	100,0

undergrowth (greenhouse) areas by regions (ha) is given. As can be seen in Table 6, 86.9% of the total uncovered areas of the greenhouses are located in the Mediterranean Region. At the end of the 1980s, greenhouse activities started in other areas and show an increasing tendency today (Kendirli and Çakmak, 2010a; Tüzel, et al., 2010). The share of heating in production expenditures has increased by up to 60% in controlled greenhouses. Reducing this share will increase the profitability of the greenhouse sector, which constitutes a significant potential in agriculture, and will contribute greatly to the economy of the country. The methods used to heat the greenhouses with solar energy can be examined in two groups as active and passive (Öztürk, 2008a). Passive systems used to heat the greenhouses are the most important ones to work in natural ways. There is no need for any mechanism and energy to operate the passive system, which is easy and cheap. The most significant drawback to active systems is the fact that there is virtually no controlled operating opportunities (Yağcıoğlu, 2005). In the case of solar active heating systems, heat collection and storage units designed separately from the greenhouses are used. The overcapacity of the heat collection units in these systems and the high initial investment and operating costs significantly limit the economic feasibility of these systems.

Greenhouse ventilation with solar energy

There is always a need for clean air in agricultural applications that must be done in closed areas. Ventilation is carried out by replacing the air in the greenhouse with outside air to control high temperatures during summer and to protect the relative humidity and carbon dioxide concentration during winter months at an acceptable level. The movement of air also helps to develop plant respiration (Boyacı et al., 2017). In literature, a fan operating with 3 direct currents was installed in a greenhouse in Thailand. Low-voltage fans can be used effectively with a solar panel with 50 W

installed power (Janjai et al., 2009).

Irrigation with solar energy

Solar water pumping systems are becoming increasingly common in irrigation systems for agriculture. Since solar panels transform the sunlight directly into direct current (DC), the efficiency and cost of the system decrease in case of direct current (DC) load of the receivers fed by solar energy. Therefore, in recent years, PV systems have been given considerable importance to electricity generation and significant progress has been made in this regard as a result of intensive research (Dursun and Saygun, 2005). Solar cell (PV) systems are designed specifically for water supply and agricultural irrigation where electricity can not be delivered. One of the applications of PV systems is to use them as a power source for the pumping of the water required to water a particular crop. Water pumping applications are the main application area of independent PV systems. In water pumping applications, water is pumped for the duration of sunlight or stored for later use. Power can be stored in the battery for use during periods when there is no sunlight. Electronic control units are required to control the system if a battery charging system is used. In the design of PV systems, the climate of the region, the characteristics of the water consumption of the plant, the characteristics of the irrigation system and the characteristics of water resources should be considered. The electric motor to be used in the PV system should be selected depending on the power requirement and current type (Öztürk, 2009). There is a filter on the connection pipes between the pump and the irrigation system to separate foreign substances such as fertilizer and drug additive as well as fertilizer tank and sand gravel likely to mix with water (Atay et al., 2009).

Pest control with solar energy

Pest control can be achieved throughout the year without

damaging the environment with the solar energy harmful killer. Pesticide-free solar-powered pest killers are suitable for use on farms, fruit gardens and vineyards. Only harmful insects, which are active at night, are killed without affecting useful insects. With this method, night light traps were operated using power stored in the battery throughout the day, and killing of non-target insects could be prevented (Tianhua et al., 2014).

Drilling machine with solar energy

Agricultural warfare and herbal products are protected in economic measures from the effects of diseases, pests and weeds. In this regard, product losses are minimized and quality is increased. Along with the application of chemical-fighting drugs (herbicides, fungicides and insecticides), the selection and use of appropriate tools and equipment has greatly contributed to the reduction of product losses (Demir, 2005). With solar-powered back pumps, liquid formulations could be made and conversion to a free energy system instead of a fuel-based system could be achieved (Joshua et al., 2010).

Soil disinfection with solar energy (solarization)

Soil disinfection is the process of destroying pathogens so that plant species can develop before the planting and sowing of the root system from the risk of infection. Soil heating is used to control soil-borne pests in plant breeding in the greenhouses (Öztürk, 2008b). Steam disinfection and biofumigation applications and the use of high toxicity bases in soil fumigation cause not only the destruction of soil-borne pests but also the death of saprophytic bacteria and beneficial microflora (Gamliel et al., 2000). Soil solarization is a method of hydrothermal disinfection that can create physical, chemical, biological and thermal changes through mulching at a time appropriate to the soil that has been sufficiently humidified (Sesveren, 2007). In other words, soil solarization is the process of covering the soil with plastic for hot and warm days of the year for one or two months in order to heat and pasteurize the soil through solar energy. Solarization is an ideal method for soil disinfection in greenhouse production environments.

Fence system with solar energy

Solar-powered fence systems are emerging as one of the best ways to prevent the introduction of fertile agricultural land as well as especially wild and predatory animals into the meadows, beaks and beehives. With this method, animals can be kept together in large quantities, and predatory animals can be prevented which can damage production. Particularly with the use of bees, possible wildlife damages that may occur in hives are removed.

These systems are operated with a 3 milliampere current which is not harmful to wild animals and human health (Ambarlı, 2014).

Use of wind energy in agriculture

Wind energy is a clean, abundant and renewable energy source as well as an opportunity to exploit many areas where agricultural activities are. Wind turbines are a more economical source of energy due to the fact that operating costs other than labor are zero compared to fossil fuel power plants (Turan, 2006). Today, wind turbines in high wind fields are able to generate electricity for several cents per kilowatt-hour and compete with unit production costs of fossil-fueled power plants (Fischer et al., 2006). In agricultural areas, energy production costs are reduced considerably through wind roses to be installed in each farm or settlement, and such systems to be installed in remote areas to transmission lines are economically in every way (NREL, 2004). By evaluating the wind potential in rural areas in Turkey, it is seen that wind farms can be built in these regions with a capacity of 50 MW in 371 different rural areas with high wind power. The number of workers to be employed in these plants has shown that 40439 persons will be employed during the installation and 6307 persons will be employed annually in the process of operation, thus contributing to rural employment. The wind is the movement of the air whose mass is certain. The kinetic energy of a mass in motion is proportional to mass. Wind energy can be converted to mechanical energy. From this point of view, it is possible that the drum or propeller, which can rotate about one mile, with winds backwards. Today, the wind has been converted to mechanical energy by braking with a rotary turbine. This technology is called as wind turbine technology (Yerebakan, 2001). According to a report from the European Wind Energy Association, the price of wind turbines has shown three-fold reduction. The investment costs of wind turbines of \$ 1000/kW in 1997 decreased to \$ 600/kW in 2006 (Öztürk, 2008c). The power of grid-independent wind electrical systems varies from a few kW to 100 kW, but often does not exceed 30 kW. Such wind turbines consist of the following units: a three-blade impeller, transmission system, guiding tail and braking system. The turbine is placed on a mast type pylon. DC electricity from wind energy can be stored with the battery. Grid-free large powerful (10-100 kW) systems are run in parallel with diesel generators as a backup power source. In wind-diesel systems, the consumer is supplied with AC by using DC/AC inverter. Agricultural application areas of wind energy are as follows (Vardar, 2009): Electrical applications, greenhouse climate, irrigation-drainage applications, heat pump applications, cooling applications and wind mill installations (Vardar, 2009). Because the wind energy is an intermittent source, it is used together with the storage systems in order to meet the water need continuously. Practically, the

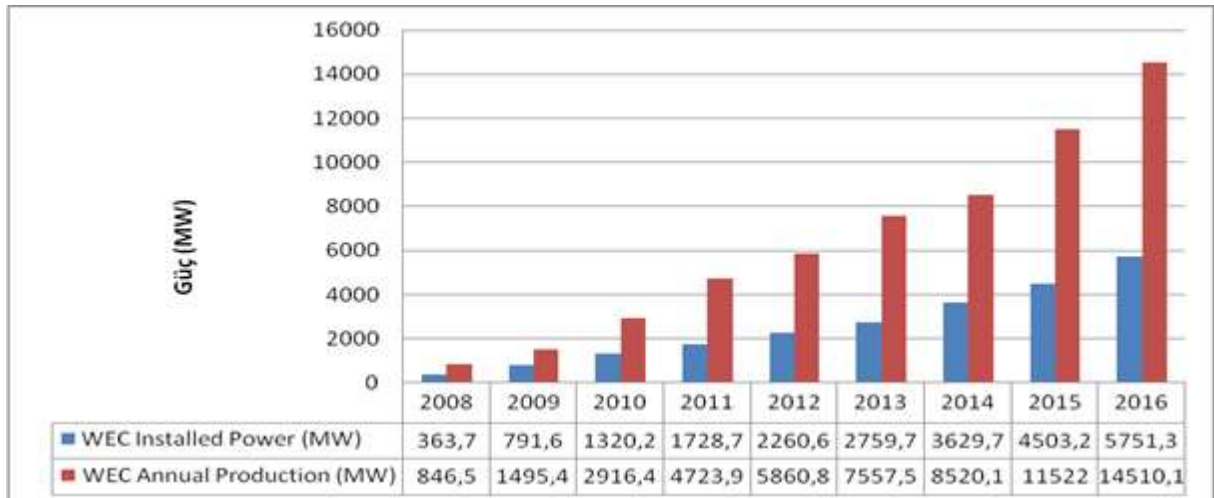


Figure 5. The development of wind energy in Turkey (installed power-production).

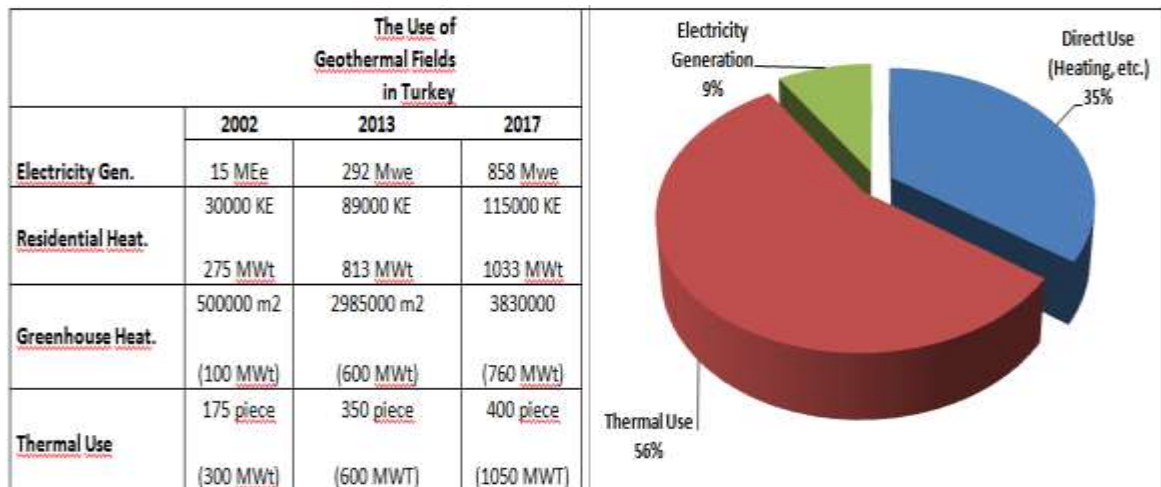


Figure 6. The use of geothermal fields in Turkey.

average water pumping time is estimated to be 6-8 hours at wind speeds of 4 to 7 m/s (Ultanir, 1998b). The development of wind energy in Turkey (installed power-production) is shown in Figure 5 (TWEA, 2017).

Use of geothermal energy in agriculture

Among the agricultural practices in the world, geothermal energy is used for heating the greenhouse at the highest rate of 14%. The rate of utilization of geothermal energy in fisheries and other livestock enterprises is 12%. Geothermal energy is also used in industrial farming areas such as reducing food water volume (dehydration), grain drying and fungal culture. Geothermal heat pump systems are used in agricultural areas in many parts of Europe and Australia, and the number of systems heated

in the USA by in-ground grid system is estimated to be between 600.000 and 800.000 (Öztürk et al., 2010; Lund, 2005). According to data provided by the General Directorate of Electrical Power Resources Survey and Development Administration, a plurality of existing geothermal potential in Turkey is seen to be advantageous to heat the agricultural field. For example, by heating geothermal resources and 500,000 rural areas, it would mean saving an average of \$1 billion m³ natural gas imports a year and saving \$400 million in foreign exchange savings (Alptekin, 2014). It is the energy source that is available geothermal resources in place and limited the transport over long distances (to be up to about 100 km) (Özyurt, and Dönmez, 2005), which limits the field of energy use for these resources in Turkey. Figure 6 (Kaya, 2017) illustrates the use of geothermal fields in Turkey, while geothermal wells

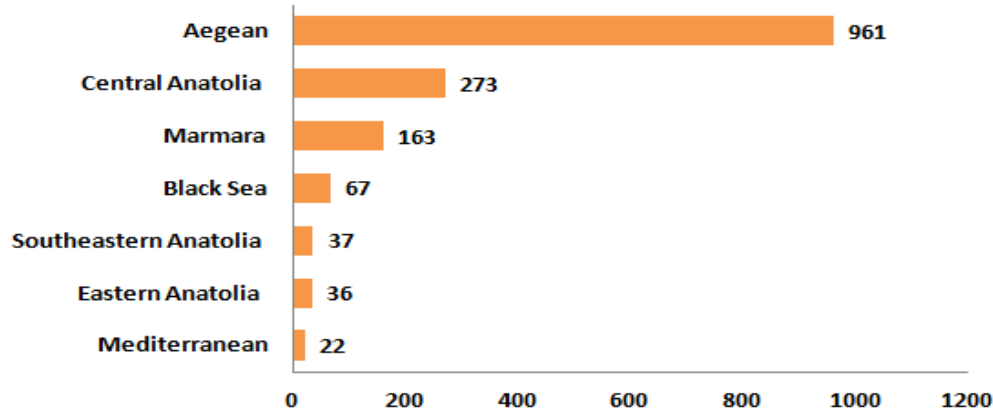


Figure 7. Geothermal well distribution by regions.

Table 7. Direct use of geothermal energy .

Chemical production	Heating applications	Industrial applications	Agricultural practices
Chemical production	Residential heating	Food drying	Greenhouse heating
Dry ice production	Soil heating	Sterilization	Animal shelters
	Street heating	Canning	Fish farms
	Fields heating	Logging	Soil heating
	Swimming pools	Wood coating industry	Product drying
	Thermal treatment centers	Paper industry	Mushroom production
	Touristic facilities	Weaving industry	Soil rehabilitation
		Paint industry	Irrigation
		Leather drying and processing	
		Brewing and distillation	
		Cooling plants	
		Concrete block drying	
		Drinking water	
		Laundries	

distribution by each region are shown in Figure 7 (Çerçioğlu and Şahin, 2016).

Direct use of geothermal energy

Heat exchanger systems can be in different designs depending on the field characteristics such as well heads and heat exchangers in the well. The efficiency of heating systems depends on their use in accordance with their continuity or success technology. Geothermal resources at low and medium temperatures can be used in many different areas. Direct use areas of geothermal energy can be summarized as in Table 7 (Öztürk, 2006). Direct use of geothermal energy can be examined under three main groups, residential and business, industrial applications and agriculture. A common aspect of all these applications is the fluid distribution system. Depending on the flow of the fluid, the distribution system

consisting of pipelines of different diameters and pump, valve, regulator and measurement-control device is insulated to reduce heat losses.

In geothermal applications, heat recovery from medium-temperature fluids with a temperature of 40-70°C can be achieved primarily with heat exchangers (Öztürk, 2008c). Geothermal energy is used as the greenhouse heating purpose at the highest rate of 12% among the agricultural applications in the world. The rate of utilization of geothermal energy in fisheries and other livestock enterprises is 10%. In agricultural applications, geothermal energy is used for drying products as low as 1%.

Use of geothermal energy for soil heating in open fields

Applications of geothermal energy and outdoor heating in

open areas can be economical, especially for early spring and late autumn production. As in the case of greenhouse heating, it is necessary to take into account factors such as the most suitable soil conditions in the open-area soil heating applications, the optimum depth and range of the heating pipes, pipe material, soil temperature and effect of soil temperature on plants to be grown.

Use of geothermal energy in animal shelters

Geothermal energy can be utilized in cattle and small animal shelters in the presence of suitable environmental conditions. The fresh air entering the system is heated and delivered from the distribution ducts to the blowing holes, and the returning water is collected in a reservoir (Tüzel et al., 1994a). Therefore, the use of renewable energy resources in the greenhouse has reduced costs and increased product quality, while eliminating the environmental costs of using fossil fuels.

Greenhouse heating with geothermal energy

Research shows that fossil-based heating covers 60-70% of total greenhouse waste (Toros and Başçetinçelik, 1990; Şahin and Taşlıgil, 2012). The inability to regularly heat due to high cost brings problems such as low yield, limitation of production type and necessity of using hormone (Kendirli and Çakmak, 2009b). 95% of geothermal resources in Turkey is at a temperature suitable for heating. There are 172 geothermal areas with a temperature above 30°C. Geothermal energy and greenhouse heating systems are considered as a collection of elements used to transport the geothermal fluid to areas where consumers are located. Geothermal energy heating systems can be examined depending on the heat transfer, the materials used and the location of the heat exchangers. In regions with potential geothermal energy, this source has been shown to be useful for greenhouse heating due to the fact that the heat loss in some places is very high especially at night and because fossil-fuel heating systems increase operating costs (Çanakçı and Acarer, 2009). There are different application examples in greenhouse heating systems. However, the selection of the system to be selected in the greenhouse as well as the economics of the system to be selected is of great importance (Chiasson, 2005). In some applications, heat exchangers are used to provide heat transfer to the normal flow (water) circulation in the greenhouse due to the chemical components that are present in the geothermal fluid and cause corrosion (Yıldız, 2010).

Use of geothermal energy in fish farming

In fish breeding, the application temperature may vary

depending on the species of fish, but may be utilized in fishing establishments from low temperature geothermal sources such as 21-27°C. However, fish species such as trout and salmon can be grown at low temperatures, not higher than 15°C (Öztürk, 2004b). When the water temperature falls below the desired values, the body metabolisms of the fish are negatively affected and the fish lose their nutritional ability. Providing a constant temperature value with geothermal water instead of only the sun that has the desired characteristics can be removed (Günerhan, 2010; Erden, 2005).

Use of geothermal energy in mushroom production

Since the increase in yield in fungal production depends on the environmental conditions, especially temperature, humidity, and ventilation, geothermal energy can be utilized in the production rooms and in pasteurization rooms. In the production of beech fungus which grows differently from culture cork, wheat stalks are taken to pasteurization after wheat stalks are wetted and rinsed with geothermal water at the stage of compost preparation (Tüzel et al., 1994b).

Geothermal energy use in soil remediation

Soil rehabilitation is a precautionary action that removes the limiting factors that prevent or restrict the cultivation of cultivated plants in the soil. The treatment of sodium soils is carried out only through chemical remediation. Additives such as soluble calcium salts, which reduce the proportion of the bound sodium, are given to replace the sodium that is attached to the soil (Kara and Çiftçi, 1994).

Use of geothermal fluid in irrigation

Geothermal fluid is different from surface water in terms of its chemical properties. The amount of dissolved cations and anions is more than that. Beside the boron element, the cations important for irrigation are sodium, calcium and magnesium and the anions are chloride, sulphate, bicarbonate, carbonate. In order to use the geothermal fluid in the irrigation system, it is necessary to compare the chemical properties with the criteria of irrigation water. Although the boron boundaries of waters to be used for irrigation vary according to the plant species, it is suggested that water containing more than 1 ppm of boron should not be used in water (Kara and Çiftçi, 1994).

Use of geothermal energy in the drying of agricultural products

One of the technologies with the highest energy consumption in agriculture is the drying of cereals, vegetables, fruits and other products. The drying system

Table 8. Energy value by turkey biomass energy potential atlas.

Variable	TOE/year
Animal wastes	1.323.714,67
Vegetable wastes	15.941.321,26
Municipal organic wastes	2.186.228,09
Forest wastes	855.805
Total	20.307.069,02
	94.000 GWh/yıl
Elektricity generation assumed	
Annual production capacity	35.000 GWh/yıl
Power plant installed	12.000 MW

Table 9. Cycle techniques using biomass sources and fuels and application areas obtained using these techniques.

Biomass	Cycle method	Fuels	Application areas
Agricultural wastes	Pyrolysis	Ethanol	Heating, transport vehicles
Animal wastes	Fermentation, anaerobic digestion	Methane	Transport vehicles, heating
Vegetable and Animal oils	Esterification reaction	Diesel	Transportation vehicles, heating, greenhouse
Energy plants	Direct combustion	Hydrogen	Heating
Energy forests	Biophotolysis	Diesel	Product drying
Forest residues	Anaerobic digestion	Biogas	Electricity generation, heating
Algae	Hydrolysis	Synthetic oil	Rockets
Organic litters and wastes	Gasification	Methanol	Aircrafts

can be arranged together with the heating systems of other agricultural structures such as greenhouse to increase the utilization of geothermal resources.

Use of biomass energy in agriculture

Biomass refers to raw materials and waste that are agricultural, forestry and vegetable products and that are produced energy as whole or part. Today, biomass energy can be divided into two classes as classical and modern. While simple burning of wood and animal wastes is defined as classical biomass energy, various fuels such as biodiesel, ethanol and biogas derived from energy plants, energy forests, and refuse are regarded as modern biomass energy sources or biofuels (Karaca et al., 2004; ETO, 2009). The smell of animal fertilizers used in biogas production is lost during the process, and many elements that threaten human health are emerging (Kumba et al., 2005). The two main biofuels used today are bioethanol and biodiesel. Opinions that oil is not a sustainable resource, political instability, supply risk in large oil producing regions, and carbon emission results of fossil fuels have increased incentives for governments to use biofuels (Runge and Senauer, 2007; Hazell and

Pachauri, 2006). Energy value by Turkey biomass energy potential atlas is shown in Table 8 (REGD, 2017b).

The conversion techniques using biomass sources and the fuels and application areas obtained using these techniques are given in Table 9 (Anonymous 2011). With the rapid advancement of technology and the increasing mechanization of agricultural production activities in Turkey, the use of diesel has increased in production stages such as tillage, fertilization, spraying, harvesting, agricultural product transport (Dellal et al., 2007). Despite its contribution to the environment and the country's economy, the biofuels sector has had negative impacts on the food industry, causing serious contraction in food supply, causing increases in agricultural product prices, threatening food safety with regard to access to food and affordability of food (Taşkaya, 2011). According to 2008 data, the size of available unused agricultural land in Turkey was determined to be about 146 million hectares. With an effective legal base and coordination, it is assumed that our country will be able to generate significant income from the biofuels sector by activating these idle resources (TEAM, 2009). In the 2012 Global Renewable Energy Status Report, biomass, biofuels and biogas energy are employed around 2,480,000 people all over the world and this employment is a great opportunity

for rural areas.

Biogas production

Anaerobic fermentation is used to obtain gaseous fuel from biomass sources. Anaerobic fermentation is the conversion of biomass into other products and by-products in an environment free of oxygen and microorganisms. Biogas consists mainly of methane (CH₄) and carbon dioxide (CO₂) gases, which are released as a result of biological degradation of organic substances under anaerobic conditions (anaerobic fermentation). Anaerobic fermentation is the process of converting biomass into other products and by-products in an environment free of oxygen and microorganisms. With a colorless, odorless, light, bright blue flame; biogas is the result of decomposition of organic waste/residues in an oxygen-free environment. Biogas consists of a gas mixture containing 60-70% methane, 30-40% carbon dioxide, 0-3% hydrogen sulfide and very little nitrogen and hydrogen, depending on the content of organic matter (Öztürk et al., 2009). Cultivating agricultural products for energy production is partly a new approach. Methane yield is the highest value in maize varieties ranging from 7.500-10.200 m³/ha. The methane production of cereals ranges from 3.200 to 4.500 m³/ha. The yield of methane production from wheat is 143-343 m³/ton (Murphy and Power, 2008). Biogas is a high energy energy carrier. The energy value of biogas varies depending on the methane content. The energy value of 1 m³ biogas with methane content of 55 and 95% is 21 MJ and 35,9 MJ, respectively (Murphy et al. 2004). As a result of the anaerobic fermentation process, the produced gas has very similar properties to the natural gas. The main product that has been uncovered as a result of this process is methane. Methane is a fuel with superior properties for many uses. In practice, it can be used in many applications where natural gas is used. One of the most commonly used fields of natural gas for power generation is internal combustion engines. The electrical conversion efficiency can be up to 25% in small-scale (<200 kW) installations. This activity is 30-35% in large installations (Öztürk, 2008c). Biogas is a versatile energy source that can be used for direct heating and lighting purposes as well as by converting electricity and mechanical energy. In addition, by-products resulting from biogas production can be used for a variety of purposes. Biogas is mainly used in electricity generation, heating, cooling and drying applications.

Biofuel production in Turkey

Biofuels in parallel with global developments in Turkey have come to the agenda again at the beginning of the 2000s and studies in universities has increased rapidly.

In this direction, "Biodiesel Working Group" was established in the Ministry of Industry and Commerce in 2001. Legal arrangements have been made regarding the production and use of biofuels. Total fuel consumption in Turkey is 22 million tons and diesel and fuel-oil consumption is 16 million tons. In addition, 1.5 million tons of biodiesel and 160 thousand tons of bioethanol are available as installed capacity. Turkey is the second country in the world (after Germany) in terms of installed biodiesel capacity. Soybean, sunflower, date, cotton, canola and safflower are used for biodiesel production. However, canola and safflower are preferred due to higher quality in Turkey. The more preferred of these products in Turkey is the fact that they are not used as a food source. Another reason is that the effects of biodiesel can be observed in agriculture. The highest increase in Turkish agriculture production in the last three years is the result of the multiplier effect of biodiesel on oil seeds. Approximately 1.2 and 1.8 tonnes of bagasse are produced from 3 tons of canola used in the production of biodiesel. This process results in the addition of 1.2 kg of biodiesel and 120 kg of glycerin (soap base) with the addition of 120 kg of methanol. Albiyobir is established in order to monitor developments in the world in biodiesel alternative energy, to participate in activities in Turkey, to encourage the consumption and production of biodiesel and to promote alternative energy, to improve the country's agricultural potential of alternative products, and to assess the environmental problem of waste in Turkey. For the import of raw materials and oilseeds used in the production of biodiesel, \$985 million in 2004, \$1.1 billion in 2005 and \$1.4 billion in 2006 were spent (Akınerdem, 2007). With the use of domestic raw material, carbon dioxide will be absorbed in plant growth and internal migration will be prevented by creating employment opportunities in agriculture, industry and transportation sectors (Ar, 2007). The production of bioethanol from sugar molasses in Turkey is mainly supplied from the factory. As agreed in the TSE standards, 225.000 cubic meters of bioethanol per year is required when calculated on the basis of 5% mix. 2.5 kg of wheat is required for one liter of bioethanol with the current bioethanol production technology. The most suitable agricultural product for the production of bioethanol are corn and wheat and Turkey has the potential to increase these products. It is possible to increase corn production to 8 million tons and wheat production to 23 million tons in five years.

CONCLUSION AND RECOMMENDATIONS

One of the indispensable elements of human life is energy. A large part of the world's electricity needs are still provided by fossil fuels. This rate is up to about 86% in Turkey. These sources pose a great danger to human health and the environment. Hence, energy production

based on fossil fuels is not a sustainable production. In response to this situation, renewable energy production is becoming increasingly important. Studies show that there is a direct relationship between total energy production and renewable energy production. This relationship has led people to renewable energy when natural resources are inadequate for human needs and unconscious use. Considering the problems that can be associated with energy nowadays and the expectations for the future, the prospect of renewable energy sources is accepted by most of the social sectors. The economic viability and method of implementation of renewable energy sources in the agricultural sector varies depending on regional conditions. An effective mechanization plan to be made at the enterprise scale should provide a suitable mechanization infrastructure for the enterprise. Progress in renewable energy technologies should be followed worldwide, and work across the country should be encouraged and supported. As in Europe, an attractive market for investors should be established for the widespread use of renewable energy. Investors and even users should be encouraged by the state (tax deduction, credit, etc.). A system should be established in which sustainable energies are rewarded for their social and environmental benefits, and added to the prices of the social costs of polluting energies. Moreover, in investment decisions, priority should be given to the projects with the lowest social cost in the long run. Priority national targets and implementation plans, supports and investments should be identified in the agriculture sector, which will increase the share of renewable energy. Importance of energy use should also be emphasized in agricultural production processes. Technologies that have high energy efficiency should be utilized for the mechanization infrastructure of the enterprises. Agricultural support policies should be provided to reduce fossil-based energy consumption and use of renewable energy in the agricultural sector. In addition, precautions should be taken such as the use of inputs and production optimization and the support of technology transfer in agriculture.

Renewable energy sources need to be utilized to effectively prevent environmental problems arising from the direct or indirect use of fossil fuels. Therefore, the introduction of incentives in the form of planned use of green energy is a top priority in order to protect today's energy presence in agriculture sector and to prevent negative effects on environment. The widespread use of renewable energy resources in the agricultural sector will benefit both socio-economic development and sustainable agriculture. For effective use of renewable energy resources, the application of photovoltaic-irrigation systems and modern irrigation techniques (drip and sprinkler irrigation) combined with photovoltaic-pump applications in agricultural areas by evaluating the feasibility of solar heating and greenhouse heating systems in terms of region contributes to energy saving

as well as to solve important problems such as water waste, salivation and salting. With the electric energy obtained from the photovoltaic panels in summer, the energy needs such as lighting, ventilation and irrigation of the greenhouse can be met. Thus, regional development will be achieved with high added value products. Geothermal energy is one of the natural energy sources that can be utilized for the climate conditioning of agricultural structures in terms of technology level and economic feasibility. Development goals, rising levels of prosperity and increasing population bring energy demand growth. These factors increase the agricultural production and energy production is done from the energy plants. Bio-resources should be strengthened and brought to bioenergy production, which is the energy of the future in terms of environmental economy. Some of the energy should be supplied by making more production than the plants of agricultural origin. With an important and great potential, biofuels from renewable energy sources in order to ensure sustainable energy in Turkey meet a large part of the demand for energy imports.

Therefore, biofuels and the agricultural energy field that constitutes the basic raw materials should be considered as strategic areas and the national targets and programs should be determined in this respect. A "Biofuels Board" consisting of relevant ministries, official and scientific organizations and sector representatives should be established to coordinate the work in this area. The new premium system, which will be applied to the oil seeds used in biofuel production, has to be created in a way that will protect the producer and increase production. Selection and design of biomass power plants requires different optimization studies on the available amount of biomass in the area at a certain distance from the basin. The number of combined heat-power installations required depends on the presence of biomass in the region and the technical, economic and operational characteristics of the investment to be made. As a result, alternative energy resources (solar energy, geothermal energy, biomass energy and wind energy) will be used in agriculture to increase the level of income in the rural area. In this way, great contributions will be gained in the integration of agricultural production and agricultural industry and in the creation of alternative income sources in the rural area. A basic energy policy should be to present the energy to the consumers in sufficient, quality, sustained, low cost and sustainable. Domestic, new and renewable energy sources should be given importance in energy production. Energy planning should aim to protect national and public interests and increase social benefits, and enable citizens to access cheap, sustainable and reliable energy sources easily. Incentives for renewable energy production should be increased and production areas should be expanded. Fossil fuels, which are considered to be unsustainable in the world, are also restricted in the agricultural sector.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

- Akinerdem F (2007). "Energy Agriculture; Our Potential of Energy Plants" Energy Safety, Energy Agriculture, Biofuels in terms of Global Warming International Symposium, April 6, 2007, http://www.albiyobir.org.tr/files/img_etk/fikret_akinerdem.pdf
- Aktaş M, Şevik S, Doğan H, Öztürk M (2013). Drying Tomatoes in a Continuous Dryer with Photovoltaic and Thermal Solar Energy. *Journal of Agricultural Sciences*. (18):287-298.
- Alptekin Z (2014). Renewable Energy Sources and Turkey / Energy Potential and Opportunities A brief analysis on the terms of the issue in September 2014, Krefeld, Germany. pp.15. <https://yenilesme.files.wordpress.com/2015/08/tc3bcrkiye-ve-yenilenebilir-enerjiler1.pdf>
- Ambarlı H (2014). Application of suitable electric fence system for Beekeeping, Farm, Livestock and Fruit farming. Url address: <http://www.bozayi.blogspot.com.tr/p/elektro-soklu-cit-sistemi-briefing.html>
- Amer BMA, Hossain MA, Gottschalk K (2010). Design and Performance Evaluation of a New Hybrid Solar Dryer for Banana. *Energy Conversion and Management* 51(4):813-820.
- Anonymous (2011). Youth for Habitat Turkey, Sustainable Energy Education Books, Biomass Energy, <http://www.habitatingenclik.org.tr/dl/yayinlar/enerji/BioKutle.pdf> (01.04.2011).
- Anonymous (2018). Images of non renewable resources » Full HD MAPS Locations – Another World. <https://www.picemaps.com/images-of-non-renewable-resources/>
- Ar F (2007). "Liquid Biofuels: Current Situation in Turkey-World Applications", 4. New and Renewable Energy Resources Symposium, Chamber of Mechanical Engineers, Kayseri Branch, 23-24 November 2007, Kayseri, ss.81-91
- Atay Ü, İşiker Y, Yesilata B (2009). "General principles of photovoltaic power assisted micro irrigation system project", V. Renewable Energy Sources Symposium, Diyarbakır P. 6367.
- Barnwal P, Tiwari A (2008). Design, Construction and Testing of Hybrid Photovoltaic Integrated Greenhouse Dryer. *International Journal of Agricultural Research* 3(2):110-20.
- Barut ZB, Öztürk HH (2004). Evaluation of Energy Inputs in Maize Production in Çukurova Region of Turkey. *International Conference on Science and Research -Tools of Global Development Strategy*, Czech University of Agriculture, Prague, Czech Republic, 24 September.
- Bayram A (2001). Pirina as a Renewable Energy Source: Production, Properties. *Symposium on Renewable Energy Sources* pp. 106-112, İzmir.
- Boughali S, Benmoussa H, Bouchekima B, Mennouche D, Bouguettaia H, Bechki D (2009). Crop drying by indirect hybrid solar - Electrical dryer in the eastern Algerian Septentrional Sahara. *Solar Energy* 83:2223-2232.
- Boyacı S, Akyüz A, Üstün S, Baytorun A, Güğercin Ö (2017). The Methods Used to Decrease High Temperatures in Greenhouses. *Turk African Journal of Agricultural Research* 4(1):89-95.
- Çanakçı C, Acarer S (2009). "Design Principles of Geothermal Energy Greenhouse Heating Systems" (originally written in Turkish), 9th Turkish National Congress of HVAC & Sanitary Engineering (TESKON), İzmir, Turkey. 6-9 May 2009, pp.115-125. http://www.mmo.org.tr/resimler/dosya_ekler/0892ae68a06e27d_ek.p df
- Çerçioğlu M, Şahin H (2016). The use of geothermal energy in the heating of greenhouses in Simav. *The Journal of Academic Social Science Studies: International Journal of Social Science* 47(1):459-475.
- Chiasson A (2005). Greenhouse Heating With Geothermal Heat Pump Systems. *GHC Bulletin* 26(1):2-5.
- Dalgıç AC (2006). "Solar Energetic Dryers" <http://www1.gantep.edu.tr/~dalgic/gunes.htm>
- Dellal İ, Özat HE, Özüdoğru T (2007). Diesel Use and Diesel Support in Agriculture, Working Report, Ministry of Agriculture and Rural Affairs Research Institute, Release No. 163 Ankara. http://apbs.mersin.edu.tr/files/erkanaktas/Publications_011.pdf
- Deloitte (2011). Deloitte Turkey, "New Life for Renewable Energy Resources: Renewable Energy Policies and Expectations" 2011, in Istanbul on 15 November 2011. <http://dergipark.gov.tr/download/article-file/361219>
- Demir C (2005). A Research on Determination of Technical Specifications and Application Problems of Plant Protection Machines and Machines Used in Chemical Warfare in Tekirdağ Agricultural Farms. Master Thesis. Trakya University Institute of Science and Technology. Tekirdağ.
- Direk M (2017). Energy Use and Efficiency in Agriculture <http://www.tarimturk.com.tr/yazar-tarimda-enerji-kullanimi-and-verimliliği-19.html>
- Dursun M, Saygun A (2005). Analysis of an Arm Drive System Fed from Boost Converters in a Solar Energized Irrigation System, pp.19 - 21. 10.2005 (MERSİN) www.emo.org.tr/ekler/ae0a504e3af13e2_ek.pdf
- Erden O (2005). Geothermal Energy Use in aquaculture activities in Turkey. *National Water Days 2005, Trabzon* 30(1):179-184. <http://dergipark.gov.tr/ziraatuludag/issue/23971/255533>
- ETO (2009). Convention on Agricultural and Environmental Pollution Relevance, ETO Association, <http://www.eto.org.tr/?p=564>
- Felloni F, Thomas IW, Wandschneider P (1999). Evidence of the effect of infrastructure on agricultural production and productivity: implications for China. In: *Chinese Agriculture and the WTO. IMPACT Center, Washington State University, Pullman* December. *Australian Journal of Basic and Applied Sciences*, 5(9):1627-1632, 2011 ISSN 1991-8178. <http://ajbasweb.com/old/ajbas/2011/September-2011/1627-1632.pdf>
- Fischer JR, Finnell JA, Lavoie BD (2006). Renewable Energy in Agriculture: Choices 1st Quarter 21:1. <http://www.choicesmagazine.org/2006-1/biofuels/2006-1-05.htm>
- Gamliel A, Austerweil M, Kritzman G (2000). "Non-chemical Approach to Soilborne Pest Management Organic Amendments". *Crop Protection* 19:847-853.
- Gönüllü MT (2009). Positive Effects of Usage of Green Energy Sources. *Standard January 2009*. 560(48):31-35. <https://mtgonullu.wordpress.com/hakkimda/yayinlar/>
- Görez T, Alken A (2005). Turkey's Renewable Energy Resources and Hydropower Potential, yeksan 2005 May. III.yenilen Energy Sources Symposium 19-21 October 2005 Mersin pp.123-127.
- Gowdy JM, Miller JL, Kherbachi H (1987). Energy use in US agriculture. *Southern Journal of Agricultural Economics* 19(2):33-41.
- Günerhan H (2010). Utilization of Geothermal Energy in Aquaculture. <http://dergipark.gov.tr/ziraatuludag/issue/23971/255533>
- Hatırlı SA, Özkan B, Fert C (2004). An Econometric Analysis of Energy Input-Output in Turkish Agriculture. *Renewable and Sustainable Energy Reviews* 9(6):608-623.
- Hazell P, Pachauri RK (2006). Bioenergy and agriculture: Promises and Challenges, *Focus* 14, Brief 1 of 12, December.
- Janjai S, Lamler N, Intawee P, Mahayothee B, Bala BK, Nagle M, Müller J (2009). Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for peeled longan and bananas. *Solar Energy* 83(9):1550-1565.
- Joshua R, Vasu V, Vincent P (2010). Solar Sprayer - An Agriculture Implement. *International Journal of Sustainable Agriculture* 2(1):16-19.
- Kadioğlu S, Telliöğlü Z (1996). "Use of Energy Resources and Their Effects on the Environment". *TMMOB Turkey's Energy Symposium* pp. 55-67.
- Kara M, Çiftçi N (1994). "The Use of Thermal Waters in Soil Breeding" *Symposium Book of Geothermal Practices*: pp. 471-483, Denizli.
- Karaca C, Başçetinçelik A, Öztürk H (2004). Biomass Policies in Some European Union Countries, V. National Clean Energy Symposium Book, Volume 1, Su Foundation Publications, Istanbul. <http://dergipark.gov.tr/tarekoder/issue/25844/272448>
- Karkacığer O, Göktolga ZG (2004). Input-Output Analysis of Energy Use in Agriculture. *Energy Conversion and Management* 46 (9-10):1513-1521.
- Kaya T (2017). Turkey Energy Conservation Report, TMMOB Kocaeli

- Branch, March 2017 <https://docplayer.biz.tr/47903554-Turkiye-enerji-gorunumu-25-mart-2017-odtu-md-visnelik-tesisleri.html>
- Kendirli B, Çakmak B (2009). The Use of Renewable Energy Sources in Greenhouse Heating. Ankara University Journal of Environmental Sciences 2(1):95-103.
- Kendirli B, Çakmak B (2010a). Using of Renewable Energy Sources in Greenhouse Heating. 2(1):96 <http://dergiler.ankara.edu.tr/dergiler/47/1445/16237.pdf>
- Kisakürek B (1980). "Drying Models" Turkey. Heat Science and Technology 2:37-40.
- Kumba H, Self Z, Özsoy HD, Hunter ED (2005). Potential of Traditional and Renewable Energy Sources in Turkey and Comparison of Environmental Impact, yeksan 2005, III. Renewable Energy Sources Symposium and Exhibition, 19-21 October 2005, pp. 32-38, Mersin.
- Kumbur H, Ozer Z, Özsoy HD, Hunter ED (2005). A comparison of conventional and renewable energy resources potential and environmental impact in Turkey. III. National Renewable Energy Sources Symposium, Mersin. <http://www.dergipark.gov.tr/dpusbe/issue/31354/345354>.
- Lund JW (2005). The United States of America country update. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey. April pp. 24-29. http://journal.tarekoder.org/archive/2013/2013_01_01.pdf.
- Martinot E, Chaurey A, Lew D, Moreira JR, Wamukonia N (2002). Renewable energy markets in developing countries. Annual Review of Energy and the Environment 27(1):309-348.
- MNE (2012). Republic of Turkey Ministry of National Education. Renewable Energy Resources and Priority. <http://www.solar-academy.com/menus/Yenilenebilir-Enerji-Teknolojileri-Kaynaklari-Onemi.164622.pdf>
- MENR (2018). Republic of Turkey Ministry of Energy and Natural Resources. The distribution of primary energy consumption by sectors in Turkey 2018 Annual Budget Presentation report P. 22. <http://www.enerji.gov.tr/tr-TR/Butce-Konusmalari/Sn-Bakanin-Butce-Sunus-Konusmalari>
- Mukaminega D (2008). Hybrid Dryer (Solar and Biomass Furnace) To Address The Problem of Post Harvest Losses Of Tomatoes in Rwanda. Degree of Master. Applied Sciences. Larenstein University. Wageningen. <http://dergipark.gov.tr/ziraatuludag/issue/23971/255533>
- Murphy JD, McKeogh E, Kiely G (2004). "Technical / Economic / Environmental Analysis of Biogas Utilization" Applied Energy 77:407-427.
- Murphy JD, Power N (2008). Technical and economic analysis of biogas production in Ireland utilizing three different crop rotations. Applied Energy 86(1):25-36.
- National Renewable Energy Laboratory (NREL) (2004). National Renewable Energy Laboratory. Wind power: Today and tomorrow. <http://www.nrel.gov/docs/fy04osti/34915.pdf>.
- Özkan B, Akcaoz H, Karadeniz F (2003). Energy Requirement and Economic Analysis of Citrus Production in Turkey. Energy Conversion and Management 45(11-12):1821-1830.
- Öztürel N, Zila R, Ecevit A (2001). Turkey's Renewable Energy Sources to be Monitored Strategy, Planning Policies and Their Social and Political Effects. Renewable Energy Sources Symposium pp. 28-32, Izmir.
- Öztürk E (2011). The Situation of Animal Husbandry in Samsun, The Possibilities of Improving Profitability and Productivity, Samsun Symposium, 13-16 October 2011, <http://dergipark.gov.tr/tarekoder/issue/25844/272448>.
- Öztürk HH (2004a). Turkey Energy and Exergy use in the Agricultural Sector. Agricultural Mechanization 22nd National Congress, Aydın, 08-10 September.
- Öztürk HH (2004b). "Geothermal Energy Use in Fish Farming" V. National Clean Energy Symposium 26-28 May 2004 Istanbul I:379-388.
- Öztürk HH (2006). "Geothermal Energy Use in Greenhouse" Turkey Union of Chambers of Agriculture Publication No: 259, S (394), ISBN: 975-8629-46-8.
- Öztürk HH (2008a) Greenhouse Climate Technique. Istanbul, Turkey: Hasad Publishing. <http://dergipark.gov.tr/akdenizfderg/issue/25316/267416>.
- Öztürk HH (2008b). "Solar Energy and Applications" Birsen Yayınevi, Cağaloğlu / Istanbul, ISBN 978-975-511-502-3.
- Öztürk HH (2008c). "Renewable Energy Sources and Usage", Technical Publishing House, Ankara, ISBN 978-975-523-042-9.
- Öztürk HH (2009). "Determination of Design Criteria for Agricultural Irrigation Systems Working with Solar Pilot" 4th Solar Energy System Symposium and Exhibition, 6-7 November 2009, Mersin, Abstract Book: 58-73.
- Öztürk HH (2010). Determination of Design Variables for Storing Solar Energy as Sensory Heat in Greenhouse Heating in Antalya Climatic Conditions. [Url Address: http://www1.mmo.org.tr/resimler/dosya_ekler/a1dfc4176d3ee05_ek.pdf](http://www1.mmo.org.tr/resimler/dosya_ekler/a1dfc4176d3ee05_ek.pdf)
- Öztürk HH, Kaya D, Ekinci K, Ertekin C, Yıldız O, Başçetinçelik A (2009). "Energy and Environmental Impact Assessment for Biogas Combined Heat and Power Generation" V. New and Renewable Energy, Energy Resources Symposium, 16-17 October 2009, Kayseri, Reports Book: 154-161, MMO Publication No: E /2009/512, ISBN: 978-9944-89-798-3.
- Öztürk HH, Yaşar B, Eren Ö (2010). Energy Use in Agriculture and Renewable Energy Sources. Chamber of Agriculture Engineers Chamber Turkey Agricultural Engineering VII. Technical Congress Report Book: 909-932, 11-15 January 2010, Ankara.
- Özyurt M, Dönmez G (2005). Evaluation of the Environmental Impacts of Alternative Energy Sources, Yeksem 2005 III. Renewable Energy Resources Symposium, 19-21 October 2005. Mersin
- Pachauri S (1998). Assessment Studies in India. Inputs to a Consultant report, ETS, New Delhi submitted to the Water Supply and Sanitation Program of UNDP and the World Bank, July 1998.
- Pamir AN (2003). Energy in the world and in Turkey, Turkey's Energy Resources and Energy Policy. [Url Address: https://metalurji.org.tr/dergi/dergi134/d134_73100.pdf](https://metalurji.org.tr/dergi/dergi134/d134_73100.pdf)
- REGD (2017a). The Republic of Turkey's Ministry Of Energy And Natural Resources, Renewable Energy Directorate General. <http://www.yegm.gov.tr/MyCalculator/>
- REN21 (2010). Renewables 2010 Global Status Report, Revised edition as of September 2010, Paris: REN21 Secretariat.
- REN21 (2011). Renewables 2011 Global Status Report, Revised edition as of September 2011, Paris: REN21 Secretariat http://www.ren21.net/Portals/0/documents/Resources/GSR2011_FIN_AL.pdf
- Runge C, Senauer B (2007). How Biofuels Could Starve the Poor, Foreign Affairs 86(3):41-53.
- Şahin G, Taşlıgil N (2012). Underground Cultivation in the Marmara Region in Terms of Agricultural Geography, ADYÜ Journal of Social Sciences Institute. <http://dergipark.gov.tr/marusad/issue/396/2774>
- Satman A (2007). "Turkey's Geothermal Energy Potential", the Geothermal Energy Electricity Generation Seminar, TESKON2007, VIII. National Installation Engineering Congress, 25-28 October 2007, Izmir. http://www1.mmo.org.tr/resimler/dosya_ekler/8188c7e9965c217_ek.pdf.
- Sesveren S (2007). "Traditional and Organic Agriculture in Seralard" Cukurova University Yumurtalık Vocational School. Soil Solarization 9:223-248.
- Sumarto U (2007). Design of A Geothermal Energy Dryer For Beans And Grains Drying In Kamojang Geothermal Field, Indonesia. GHC Bulletin. https://oregontechsfcdn.azureedge.net/oregontech/docs/default-source/geoheat-center-documents/quarterly-bulletin/vol-28/art57c7cee4362a663989f6ff0000ea57bb.pdf?sfvrsn=e1da8d60_4
- Şahin G, Taşlıgil N (2012). Underground Cultivation in the Marmara Region in Terms of Agricultural Geography, ADYÜ Journal of Social Sciences Institute. <http://dergipark.gov.tr/marusad/issue/396/2774>
- Taşkaya B (2011). Biodiesel, Institute for Agricultural Economics and Policy Development, Ankara. <https://docplayer.biz.tr/13410587-Tepge-bakis-temmuz-2012-issn-1303-8346-sayi-14-nusha-2.html>
- Taşkın O, Korucu T (2014). Solar Energy Potential and Facilities of Use in Kahramanmaraş Province. KSU J. Nat. Sci. 17(4):13. <http://dergipark.gov.tr/download/article-file/212063>
- TEAM (2009). Agriculture in Turkey with economic indicators, 2008 Agricultural Economics Research Institute, Ankara. <https://arastirma.tarim.gov.tr/tepge>.
- TEİAŞ (2017). Role of Renewable Sources of Electric Energy

- Production in Turkey. . Url Address: <http://ekolojist.net/turkiyede-elektrik-enerjisi-uretiminde-yenilenebilir-kaynaklarin-rolu/>
- Tianhua L, Zhengkun P, Sha Y (2014). Research on the design and installation of solar LED pest control light. *Journal of Chemical and Pharmaceutical Research* 6 (7):1366-1369.
- Toros H, Başçetinçelik A (1990). Possibilities of Benefiting from Solar Energy Stored in Plastic Covered Greenhouse in Çukurova Region. Tarsus Research Institute Directorate Publications. General Publication No. 165. Tarsus. <http://dergipark.gov.tr/marusad/issue/396/2774>.
- Turan S (2006). Renewable Energy Sources, Research Reports, Konya Chamber of Commerce Publications, Konya. <https://docplayer.biz.tr/15252533-Arastirma-raporu-konya-ticaret-odasi-etud-arastirma-servisi-tarih-27-01-2006-sayi-2006-42-39-konu-turkiye-de-enerji-sektoru.html>.
- TurkStat (2011). Turkish Statistical Institute (TURKSTAT) Official Web Site. Url Address: http://istmat.info/files/uploads/47802/turkeys_statistical_yearbook_2011.pdf.
- Tüzel Y, Gül A, Daşgan, HY, Öztekin GB, Boyacı HF, Ersoy A, Tepe A, Uğur A (2010). Development of Uncovering Cultivation. Chamber of Agriculture Engineers Chamber Turkey Agricultural Engineering VII. Technical Congress Report Book pp. 559-576, 11-15 January 2010, Ankara.
- Tüzel Y, Gül A, Dura S (1994a). "Possibilities of Use of Geothermal Energies in Agriculture" Symposium Book of Geothermal Applications: P 485. Denizli. <https://vdocuments.net/tarimda-enerji-kullanimi-ve-yenilenebilir-enerji-kaynaklari.html>.
- Tüzel Y, Gül A, Dura S (1994b). "Possibilities of Use of Geothermal Energies in Agriculture" Symposium Book of Geothermal Applications: pp. 487-490. Denizli. <https://vdocuments.net/tarimda-enerji-kullanimi-ve-yenilenebilir-enerji-kaynaklari.html>.
- TWEA (2017). Turkish Wind Energy Association. Turkish Wind Energy Statistics Report January 2017. https://www.tureb.com.tr/files/tureb_sayfa/duyurular/2017_duyurular/subat/turkiye_ruzgar_enerjisi_istatistik_raporu_ocak_2017.pdf
- Ultanır BC (1998a). "Evaluation of the onset of the 21st Century Turkey's Energy Strategy" Publication No: TUSIAD-T / 98-12 / 239, ISBN: 975-7249-59-9, publish Lebibe Yalkin
- Ultanır BC (1998b). "Evaluation of the onset of the 21st Century Turkey's Energy Strategy" Publication No: TUSIAD-T / 98-102 / 239, ISBN: 975-7249-59-9, Publications and Printing Works Lebibe I Yalkin Inc., Istanbul.
- Ünalın S (2006). "Alternative Energy Sources lecture notes. https://birimler.dpu.edu.tr/app/views/panel/ckfinder/userfiles/48/files/alt_ener_kay_ders_notlari.pdf.
- Uyar TS (2001). What is Energy Problem?, Is Alternative Energy a Solution?, NEU-CEE 2001, Electrical, Electronic & Computer Engineering Symposium, NEU-CEE Proceedings, ISBN: 975-8359-11-8 pp.23-26, TRNC, Nicosia May,23-25 2001
- Vardar A, Okursoy R (2006). Possibility of Use of Some Irrigation Submersible Pumps with Wind Turbines.Agricultural Mechanization Congress Proceedings, Çanakkale pp. 39-45.
- Vardar A (2009). "Wind Energy Use in Agriculture" Seminar Notes, Çanakkale. <http://www.alivardar.com/yayinlar.htm>.
- Yağcıoğlu A (1996). "Product Processing Techniques" Ege University, Faculty of Agriculture Publications No: 517, Bornova-İzmir, ISBN 975-483-303-6.
- Yağcıoğlu A (2005). Greenhouse Mechanism. Ege University, Faculty of Agriculture Publications No: 562, İzmir. <http://dergipark.gov.tr/download/article-file/521202>.
- YEK (2014). General Directorate of Electrical Power Resources Survey and Development Administration. 2014. Wind Energy Water Pumping Systems Project. Url Address: http://www.eie.gov.tr/eie-web/turkce/YEK/ruzgar/ruzgar_supompa.html
- Yerebakan M (2001). "Wind Energy" Istanbul Chamber of Commerce Publication No: 2001-33, Istanbul, ISBN-975-512-582-5. <https://vdocuments.net/tarimda-enerji-kullanimi-ve-yenilenebilir-enerji-kaynaklari.html>.
- Yıldız M (2010). A Research on Utilization of Geothermal Energy Sources for Greenhouse Heating in Aydın Province Çukurova University Institute Of Natural And Applied Sciences Department of Agricultural Machinery, Adana, 2010. Url Address: <http://library.cu.edu.tr/tezler/8133.pdf>.
- Yılmaz ÖB (2017). Large increase in installed power. <http://www.ekonomist.com.tr/dosya/kurulu-gucte-buyuk-artis.html>

Full Length Research Paper

Agronomic effectiveness of water hyacinth-based composts

Dennis Beesigamukama^{1,2*}, Alice Amoding-Katusabe², John Baptist Tumuhairwe², John Muoma³, John M. Maingi⁴, Omwoyo Ombori⁴, Josephine Nakanwagi² and Dative Mukaminega⁵

¹Department of Crop Production and Management, Faculty of Agriculture and Animal Sciences, Busitema University, P. O. Box 203, Soroti, Uganda.

²Department of Agricultural Production, College of Agricultural and Environmental Sciences, Makerere University, P. O. Box 7062, Kampala, Uganda.

³Department of Biological Sciences, Masinde Muliro University of Science and Technology (MMUST), Kakamega, Kenya.

⁴Department of Plant and Microbial Sciences, Kenyatta University, Nairobi, Kenya.

⁵Faculty of Applied Sciences, Kigali Institute of Science and Technology (KIST), Kigali, Rwanda.

Received 6 August, 2018; Accepted 5 September, 2018

Because water hyacinth-based compost contains substantial amounts of nitrogen (N), phosphorus (P) and potassium (K) its application can boost crop production. We evaluated the agronomic performance of water hyacinth - based composts using field experiments and five treatments which were; water hyacinth compost made using cattle manure (WH+CM), poultry manure (WH+PM), molasses (WH+MO), water hyacinth alone (WH alone) and the control. The composts were applied at two rates of 3 and 6 t ha⁻¹ using maize (LONGE 4) as a test crop. Grain yields of 6.8 t ha⁻¹ harvested in WH+CM applied at 6 t ha⁻¹ and 6.5 t ha⁻¹ harvested in WH+PM applied at 3 t ha⁻¹ were statistically similar, and were the highest in the experiment. The highest harvest index and agronomic nitrogen efficiency were obtained at 3 t ha⁻¹ from WH+PM (4.57) and WH+MO (42.6 kg kg⁻¹) respectively. Compost formulation WH+PM applied at 3 t ha⁻¹ was the most effective as measured in terms of grain yield and is recommended for application by farmers for good yields of maize crop.

Key words: Nitrogen, phosphorus and potassium, water hyacinth-based composts, effective application rate, maize grain yield.

INTRODUCTION

Crop production in sub-Saharan Africa is greatly hindered by low soil fertility (Tully et al., 2015). A study by Nkonya et al. (2008) revealed that nutrient levels for most soils in

Uganda are below the critical levels for most crops grown in the country. Most soils in Central Uganda are Ferralsols that are highly weathered and leached, with

*Corresponding author. E-mail: dbesiga@gmail.com. Tel: +256779911268.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

low cation exchange capacity, low pH and low organic matter (Aniku, 2001). The soils also have high contents of sesquioxides and a problem of phosphorus fixation and aluminium toxicity. Very high nutrient losses occur due to poor farming practices in most farming communities. Soil erosion alone was found to contribute up to 24, 59 and 33% of total N, P and K losses respectively from the soils in the Lake Victoria crescent region of Uganda (Nkonya et al., 2008). This implies that farming practices used by farmers are not sustainable and calls for use of feasible soil fertility management practices to boost crop production. As a result, most fields have negative nutrient balances due to leaching, denitrification and soil erosion (Ebanyat, 2009).

Use of inorganic fertilizers would be the quickest entry point for elevating agricultural productivity and production (Sanchez et al., 2009). However, mineral fertilizer use in Sub Saharan Africa where Uganda lies is still low at 10 kg ha⁻¹ (FAO, 2017). Furthermore, studies show that on farms where mineral fertilizers are used, there are low nutrient use efficiencies (Ebanyat, 2009) and this has been partly attributed to low organic matter content (Vanlauwe et al., 2015). Organic matter increases fertilizer use efficiency by supplying the secondary and micronutrients required in the uptake and utilization of macronutrients supplied from mineral fertilizers. Musinguzi et al. (2016) established a range of 1.9-2.2% carbon as the critical concentration for crop response to mineral fertilizer inputs. However, most soils in Uganda have carbon levels below this range (Nkonya et al., 2008). Addition of organic matter would help to improve soil organic carbon stocks but there are limited sources of manure especially in regions where animals are not part of the farming system. Organic resources in most African farming systems have competing uses on the farm (Rufino et al., 2011). Bekunda (1999) revealed that crop residues from maize and beans are mainly put in banana plantations and a result cause soil mining in annual cropping fields. Moreover, the natural means of managing soil fertility like use of fallows have broken down due to land scarcity as a result of increased population pressure on land (Ebanyat, 2009). As a result, most farmers who have continued to get low crop yields due to continued soil nutrient depletion without affordable means of replenishing the lost nutrients to maintain the soil fertility. Therefore, any strategy for improving crop yields should consider building organic matter to levels that can improve the soils' response to fertilizer inputs. This can be achieved by sole or combined application of organic matter with mineral fertilizers and providing farmers with readily available organic matter sources. In this study, we focus on the use of water hyacinth as a potential source of manure for crop production.

The water hyacinth is an aquatic weed present on Lake Victoria and other water bodies in Uganda and spreads rapidly due to its high productivity rate (Amoding et al., 1999). It is considered a menace on aquatic resources

but, it accumulates nutrients like nitrogen (N), phosphorus (P), potassium (K) and micronutrients which may be recovered for use to boost agricultural productivity. Amoding et al. (1999) reported that water hyacinth absorbs about 99 kg N ha⁻¹, 8 kg P ha⁻¹ and 182 kg K ha⁻¹ within a week. However, the study did not go ahead to produce water hyacinth compost and determine the effect of such compost on crop production. In this study, the water hyacinth was co-composted with locally available materials like poultry manure, cattle dung and molasses to fortify its nutrient levels. We assessed the comparative performance of water hyacinth-based compost on crop production using field experiments to determine the most effective water hyacinth-based compost formulation and application rate for crop production.

MATERIALS AND METHODS

Preparing the composts

In order to hasten compost maturity, the water hyacinth was composted using the above ground pile method in boxes of 1.5 m length x 1.5 width x 1.5 m height as described in Beesigamukama et al. (2018). The experiment had four treatments: (i) Water hyacinth co - composted with cattle manure (WH+CM), (ii) Water hyacinth co - composted with poultry manure (WH+PM), (iii) Water hyacinth composted with molasses (WH+MO) and (iv) the control where the water hyacinth was composted alone (WH alone). Table 1 shows selected characteristics of water hyacinth and other materials used in composting. Molasses had a total sugar content of 54.6%, which was determined phenol sulphuric acid method (AOAC International, 2003). The experiment was managed using standard composting procedures (Epstein, 1997) and compost from all treatments was mature in six weeks. The mature compost was harvested and used in the field experiment. Table 2 presents the chemical characteristics of the composts that were used in the experiment. Fortification of water hyacinth with poultry manure produced compost with highest concentration of N, P and K while the unfortified compost had least nitrogen and potassium.

Field experiment

Field experiments were set up on four sites in Wakiso district, Central Uganda. The sites were: MUARIK (E 32° 36'42.0"N 0° 27' 03.0"), Bugiri 1 (E 32° 34' 256"), Bugiri 2 (E 32° 34'106" N 0° 06' 184"), Bugiri 3 (E 32° 33' 668" N 0° 06' 604"). Farmers near Lake Victoria that have access to the water hyacinth were involved in the study. Table 3 shows selected soil characteristics of the sites. The soils are acidic in nature with low nitrogen, phosphorus, organic matter and calcium levels, moderate potassium, and sufficient magnesium. Earlier classification categorized the soils in the area as Ferralsols formed from pre- Cambrian acid rocks and belonging to the Buganda catena (Aniku, 2001). The experiments were set out in RCBD with three replicates and nine treatments which were: four water hyacinth- based composts: WH+PM, WH+CM, WH+MO and WH alone applied at two rates of 3 and 6 t ha⁻¹ and the control where no compost was applied. LONGE 4 maize variety which is high yielding, early maturing (95-115 days) and drought tolerant was used as test crop and planted at a spacing of 75 x 30 cm (one plant per hill). Plots of 3 x 3 m were used and spacing of one and two metres was left between the plots and blocks respectively.

Table 1. Characteristics of raw materials used in composting.

Material	Moisture content	TOC (%)	TON	Total P (mg kg ⁻¹)	Total cations (mg kg ⁻¹)			C/N ratio
					K	Ca	Mg	
Water hyacinth	92.3	34.5	1.8	3.1	39	19	6.7	19.2
Poultry manure	40.0	27.5	1.7	22.3	25	30	4.2	16.2
Cattle manure	67.7	19.9	1.4	5.6	13	5	1.7	14.2

TOC= Total organic carbon, TON= Total organic nitrogen.

Table 2. Characteristics of the water hyacinth compost formulations used in experiment.

Compost formulation	Moisture content (%)			pH(1:2.5 water)	Total cations (%)			C/N ratio
	TON	TOC	Total P		K	Ca	Mg	
WH+PM	2.21	16.1	1.36	8.3	1.5	0.84	0.18	7.3
WH+CM	1.94	14.5	0.46	8.2	0.8	0.46	0.17	7.5
WH+MO	1.62	8.6	0.36	7.9	1.1	0.47	0.15	5.3
WH alone	1.36	10.4	0.38	7.6	1.1	0.55	0.18	7.6

Key: WH+PM = compost from water hyacinth and poultry manure, WH+CM = compost from water hyacinth and cattle manure, WH+MO = compost from water hyacinth and molasses, WH alone = compost from water hyacinth alone, TON=Total organic nitrogen, TOC= Total organic carbon.

Table 3. Selected soil physical and chemical characteristics of the sites.

Sites	pH (1:2.5 water)	TON (%)		SOM (mg/kg)	Av. P K	Ex. cations (cmol/kg)		Textural class
						Ca	Mg	
MUARIK	5.6	0.16	2.7	3.6	0.57	2.6	1.24	Sandy clay
Bugiri 1	5.4	0.11	1.7	9.2	0.45	2.0	0.85	Sandy loam
Bugiri 2	4.7	0.14	2.1	3.2	0.20	1.3	0.99	Sandy clay
Bugiri 3	5.3	0.13	2.5	10	0.21	1.7	1.01	Sandy clay
Critical values	5.5†	0.25†	3†	15†	0.22†	4†	0.25†	

† Okalebo et al. (2002)

TON= Total organic nitrogen, SOM= soil organic matter, Av. P= available phosphorus, Ex. cations = Exchangeable cations.

Data collection

Data were collected on plant height, number of leaves and leaf area. Plant heights were determined by measuring the height of the selected plants from the ground level up to the base of the fully opened youngest leaf. Number of leaves was determined by counting while leaf area was calculated as a product of leaf length and width that were measured using a tape measure. Leaf area, number of leaves and a correction factor of 0.71 were used to calculate leaf area index (LAI) using the formula by Edje et al. (1987) below.

$$LAI = \frac{\text{Number of leaves} \times \text{leaf area}}{\text{Land area}} \quad (1)$$

Grain and stover yield data were collected at harvesting from a net plot area of 2.25 m². Grain samples were collected from each plot, taken to the laboratory and oven dried at 70°C for 72 h to determine total dry matter by correcting to a moisture content of 12%. The grain yield was then expressed on a hectare basis. Grain and

stover yields obtained were used to calculate harvest index as a ratio of grain yield to biological yield. The grain yield from each treatment was used to determine the additional amount of economic yield per unit N supplied from each treatment by calculating agronomic efficiency (AE) according to (Baligar et al., 2001).

$$AE \text{ (kg kg}^{-1}\text{)} = \frac{(\text{Yield}_F - \text{Yield}_C) \text{ kg}}{(\text{Quantity of nutrient applied, kg})} \quad (2)$$

Data analysis

Data were analyzed using GenStat discovery 10th edition for windows. Analysis of variance test was done to generate means for leaf area index, plant height, yield and agronomic nitrogen efficiencies. Correlation analysis was run to establish the relationship between maize growth parameters and grain yield. Significant means were separated using Fishers protected LSD at 5% significance.

Table 4. Effect of water hyacinth-based composts on maize leaf area index.

Compost type	Rates (t ha ⁻¹)	Leaf area index at different growth periods		
		6 weeks	8 weeks	10 weeks
Control	0	2.01	2.80	2.81
WH+MO	3	2.33	3.88	3.14
WH+CM	3	2.12	3.23	2.85
WH+PM	3	2.13	3.54	3.05
WH alone	3	2.26	3.43	2.99
WH+MO	6	2.31	3.64	2.17
WH+CM	6	2.30	3.59	3.05
WH+PM	6	2.28	3.66	3.10
WH alone	6	2.19	3.57	3.35
LSD_(0.05)		0.36	0.43	0.43
CV (%)		22.3	16.9	19.4

Key: WH+PM = compost from water hyacinth and poultry manure, WH+CM = compost from water hyacinth and cattle manure, WH+MO = compost from water hyacinth and molasses, WH alone = compost from water hyacinth alone; 3 and 6 t ha⁻¹ are compost application rates.

Table 5. Maize height at six weeks and increases in height at 8 and 10 weeks after application of water hyacinth-based composts.

Compost type	Rates (t ha ⁻¹)	Plant height at 6 weeks	Increase from 6 th to 8 th week	Increase from 8 th to 10 th week
		(cm)		
Control	0	32.1	49.7	75.2
WH+MO	3	45.7	70.2	70.1
WH+CM	3	41.1	61.4	76.4
WH+PM	3	41.0	62.6	69.6
WH alone	3	41.0	60.6	69.1
WH+MO	6	44.4	64.3	70.0
WH+CM	6	43.1	60.5	76.3
WH+PM	6	45.4	67.0	69.9
WH alone	6	43.6	61.7	73.1
LSD_(0.05)		6.9	7.5	16.2
CV (%)		22.5	41.6	37.9

Key: WH+PM = compost from water hyacinth and poultry manure, WH+CM = compost from water hyacinth and cattle manure, WH+MO = compost from water hyacinth and molasses, WH alone = compost from water hyacinth alone; 3 and 6 t ha⁻¹ are compost application rates.

RESULTS

Maize leaf area index (LAI)

Compost treatments had significant ($p < 0.05$) effect on leaf area index at eight and ten weeks after planting (Table 4). Leaf area index for all treatments increased up to eight weeks and started reducing beyond eight weeks. Compost formulations applied at 6 t/ha produced higher LAI than those applied at 3 t ha⁻¹ but the differences were statistically similar. However, the largest LAI of 3.88 was recorded from (WH+MO) applied at 3 t ha⁻¹, and this was significantly higher than that of control. At 10 weeks, LAI for (WH alone) at 6 t ha⁻¹ was significantly ($p < 0.05$)

higher than that of control by 19%.

Maize plant height

All compost treatments irrespective of the rates produced significantly higher plant heights ($p < 0.05$) than the control at six weeks (Table 5). Similar trends of events were observed in the eighth and tenth week. Similarly, increases in plant height after compost application were significantly ($p < 0.05$) higher than those of the control from the sixth to eighth week irrespective of the rates. At the tenth week, increases in plant height were not significantly different ($p \geq 0.05$), indicating slowdown in

Table 6. Effect of water hyacinth-based composts on maize yield.

Compost formulations	Rates (t ha ⁻¹)	Grain yield (t ha ⁻¹)	Harvest index	N _{AE} (kg kg ⁻¹)
Control	0	4.4	0.45	
WH+PM	3	6.5	0.47	25.3
WH+MO	3	6.5	0.42	42.6
WH+CM	3	6.3	0.43	29.8
WH alone	3	6.0	0.39	41.5
WH+CM	6	6.8	0.45	19.7
WH+MO	6	6.6	0.42	19.0
WH alone	6	6.1	0.42	20.8
WH+PM	6	5.8	0.41	11.0
LSD		1.1		19.4
CV (%)		25.7		77.1

Key: N_{AE} = agronomic nitrogen efficiency; WH+PM = compost from water hyacinth and poultry manure, WH+CM = compost from water hyacinth and cattle manure, WH+MO = compost from water hyacinth and molasses, WH alone = compost from water hyacinth alone; 3 and 6 t ha⁻¹ are compost application rates.

vertical growth. The highest increases in maize plant heights from the sixth to eighth week were recorded from (WH+MO) at 3 t ha⁻¹ while (WH+CM) at both rates recorded the highest increase from eight to ten weeks. The least increases in plant height were observed in the control treatment (no input) at both sampling weeks (Table 5).

Maize yield and agronomic nitrogen efficiency

All compost treatments irrespective of the rates produced significantly ($p < 0.05$) larger maize grain yields than the control (Table 6). With the exception of (WH+PM), all compost treatments applied at 6 t ha⁻¹ produced higher grain yields than at 3 t ha⁻¹ but the differences were statistically similar. Treatments (WH+PM) and (WH+CM) produced the highest grain yields at 3 and 6 t ha⁻¹ respectively and were higher than that of the control by 32 and 35%, respectively. However, the highest harvest index and agronomic nitrogen efficiencies were recorded at the lower rate of 3 t ha⁻¹, and the control treatment performed better than WH alone in terms of harvest index at the same rate. With the exception of WH+CM, increasing compost application rate to 6 t ha⁻¹ reduced agronomic nitrogen efficiencies by more than 50%.

Correlation between growth parameters and maize grain yield

There was generally strong positive correlation between plant heights at all growth periods and grain yield (Figure 1). The strongest relationship of all was obtained at six weeks ($r = 0.8$) while weakest was obtained at eight weeks. Of all the three stages, plant height affected yield

significantly only at 10 weeks ($p < 0.05$). The correlation between maize grain yield and leaf area index (LAI) varied greatly but strongest at eight weeks ($r = 0.8$) and weakest at 10 weeks ($r = 0.49$) (Figure 2). However, LAI did not significantly affect grain yield for all the three growth periods ($p \geq 0.05$).

DISCUSSION

Effect of water hyacinth composts on maize growth

It was noted that all compost treatments produced significantly ($p < 0.05$) higher plant heights than the control, and that compost treatments applied at 6 t ha⁻¹ produced higher plant heights than those applied at 3 t ha⁻¹ (Table 5). The higher mean plant heights associated with 6 t ha⁻¹ compared to the 3 t ha⁻¹ rate can be attributed to the supply of enough nutrients (N, P and K) that are essential for maize growth. The tallest plants height observed throughout the experiment for (WH+PM) applied at 6 t ha⁻¹ were because (WH+PM) had higher nitrogen and phosphorus concentrations (Table 2). Phosphorus is important in root growth and development and therefore nutrient uptake; while nitrogen is important in photosynthesis and protein formation hence fast growth in terms of height and leaf expansion (Hawkesford et al., 2012).

The higher increases in maize plant height associated with treatment (WH+MO) applied at 3 t ha⁻¹ at six, eight and ten weeks (Table 5) are because this treatment was able to supply just enough nutrients required for plant growth without excesses. The same trend was observed on leaf area index (Table 4). There, were therefore, little or no cases of antagonism or toxicity due to excess nutrient supply that could have affected plant growth. The

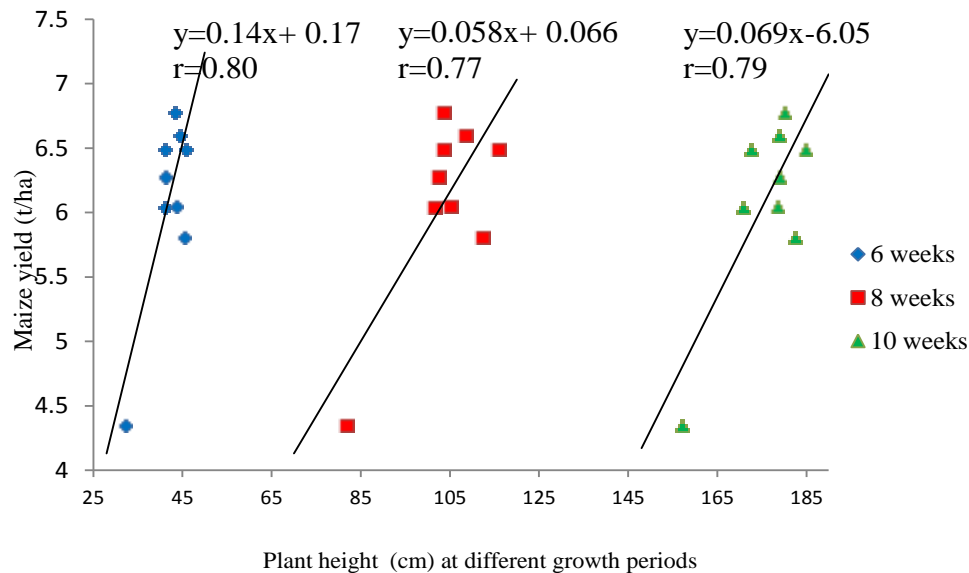


Figure 1. Relationship between maize grain yield and plant height after application of water hyacinth-based composts.

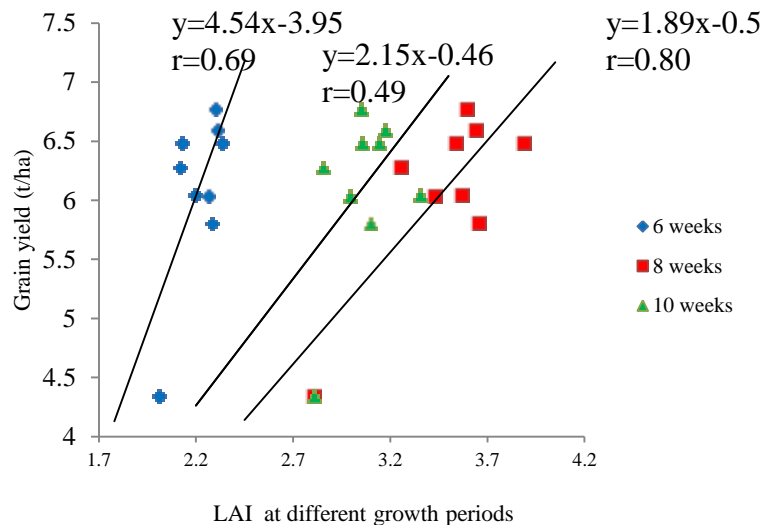


Figure 2. Relationship between maize grain yield and LAI after application of water hyacinth-based composts.

non-significant difference ($p \geq 0.05$) in maize height between 3 and 6 t ha⁻¹ implies that the plant had absorbed enough of the nutrients it required at 3 t ha⁻¹. Therefore, most nutrients that were absorbed beyond 3 t ha⁻¹ were not utilized in the plant growth and development processes hence no significant difference ($p \geq 0.05$) in growth parameters like height between the two rates even though 6 t ha⁻¹ produced higher means. High plant and leaf area index are important in positioning the plant to trap photosynthetically active radiation to make enough assimilates important for grain formation. This is confirmed by the strong correlation of

growth parameters with grain yield (Figures 1 and 2).

Effect of water hyacinth compost on maize grain yield

The control treatment (no input) realized the least grain yield yet there was no significant ($p \geq 0.05$) difference between grain yield at 3 and 6 t ha⁻¹ (Table 5). The significant difference ($p < 0.05$) in grain yield observed between different water hyacinth compost formulations and the control has been reported in other studies

(Evanylo et al., 2008; Rutonesha, 2009; Osoro et al., 2013). The significantly ($p < 0.05$) higher grain yields of compost formulations compared to the control could be because of the higher nutrient contents of the compost formulations applied. The site characteristics (Table 3) indicated low soil fertility and therefore, there was response to added compost and the rate of 3 t ha^{-1} could have been sufficient. Ming-Mang et al. (2008) reported similar corn uptake of N, P and K in compost but significantly higher ($p < 0.05$) than those in the control treatment, hence giving higher grain yield than the control. This study did not determine nutrient content in maize tissue but other studies. Renck and Lehmann (2004) reported highest yield and tissue concentrations of K and P where compost consisting chicken manure was applied. Therefore the higher grain yield observed at 3 t ha^{-1} than 6 t ha^{-1} for WH+PM could be because the lower rate was able to satisfy maize nutrient requirements.

The slightly higher but non-significant grain yield at 6 t ha^{-1} , higher harvest indices and agronomic nitrogen efficiencies obtained using lower application rate of 3 t ha^{-1} indicate the role of fortified composting in compost quality improvement. With a nutrient rich compost, a small amount is required to satisfy crop nutrient demands. The two fold reduction in agronomic efficiency at 6 t ha^{-1} means that the plant had taken up enough nutrients 3 t ha^{-1} and there was luxury consumption beyond this rate. The higher harvest indices recorded at 3 t ha^{-1} mean that enough nutrients were taken up and converted into economic yield.

Conclusion

This study has demonstrated that the compost derived from water hyacinth is a good soil conditioner to enhance maize grain yields in soils of Uganda, with acidic pH. Application of water hyacinth-based compost at higher rate of 6 t ha^{-1} produced higher maize grain yield, leaf area index and plant height than the rate of 3 t ha^{-1} but highest agronomic nitrogen efficiencies and harvest index were obtained at lower rate of 3 t ha^{-1} . The most effective dose of water hyacinth-based compost in enhancing grain yields is 3 t ha^{-1} and the compost should be made using poultry manure. Future studies should determine the effect of water hyacinth-based composts on soil physical, chemical and biological properties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

This research was funded by ViCReS and the researchers are grateful for the funding.

REFERENCES

- Amoding A, Muzira R, Bekunda MA, Woomer PL (1999). Bio-productivity and decomposition of Water hyacinth in Uganda. *African Crop Science Journal* 7(4):433-439
- Aniku JRF (2001). Soil classification and pedology: Soils classification and pedology, In: Mukiibi JK (Ed.). *Agriculture in Uganda* (vol. 1). General information. Fountain publishers limited Kampala, Uganda. Chapter 4:66-103.
- AOAC International (2003). Official methods of analysis of AOAC International. 17th edition, 2nd revision. Gaithersburg, MD, USA, Association of Analytical Communities. www.worldcat.org/title/official-methods-of-analysis-of-aoac-international/oclc/476032693. Accessed: 25th August 2016
- Baligar VC, Fageria NK, He ZL (2001). Nutrient Use Efficiency in Plants. *Communications in Soil Science and Plant Analysis* 32(7-8):921-950.
- Beesigamukama D, Tumuhairwe JB, Muoma J, Maingi JM, Ombori O, Mukaminega D, Nakanwagi J, Amoding A (2018). Improving Water Hyacinth-Based Compost for Crop Production. *Journal of Agricultural Science and Food Technology* 4:3.
- Ebanyat P (2009). A road to food? Efficacy of nutrient management options targeted to heterogeneous soils in the Teso farming system, Uganda. PhD thesis. Wageningen university, Netherlands. 230 p.
- Epstein E (1997). *The science of composting*. CRC press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431 USA. ISBN 1-56676-478-5: P 487.
- Evanylo G, Sherony C, Spargo J, Starnier D, Brosius M, Haerin K (2008). Soil and water environmental effects of fertilizer, manure and compost-based fertility practices in an organic vegetable cropping system. *Agriculture, Ecosystems and Environment* 127:50-58.
- Food and Agriculture organisation (FAO) (2017). *The state of food and agriculture. Food and Agriculture organisation of the united nations. Rome*. ISBN 978-92-5-109873-8. P. 181.
- Hawkesford M, Horst W, Kichey T, Lambers H, Schjoerring J, Skrumsager IM, White P (2012). In: Marschner P (Ed.) (2012): *Marschner's mineral nutrition in higher plants*. Third edition. Chapter 6:135-189.
- Ming-Mang X, Dong-Chu L, Jumei L, Dao-Zhu Q, Yagi K, Hosen Y (2008). Effects of organic manure application with chemical fertilizers on nutrient absorption and yield of rice in Hunan of Southern China. *Agricultural Sciences in China* 7(10):1245-1252.
- Musinguzi P, Ebanyat P, Tenywa JS, Basamba TA, Tenywa MM, Mubiru DN (2016). Critical soil organic carbon range for optimal crop response to mineral fertiliser. *Experimental Agriculture* 52(4):635-653.
- Nkonya E, Pender J, Kaizzi CK, Kato E, Mugarura S, Ssali H, Muwonge J (2008). Linkages between land management, land degradation, and poverty in Sub-Saharan Africa: The case of Uganda. *IFPRI Research Report* P 159.
- Okalebo JR, Gathua W, Woomer L (2002). *Laboratory methods of soil and plant analysis. A working manual*. The second edition. Nairobi Kenya.
- Osoro N, Muoma JO, Amoding A, Mukaminega D, Muthini M, Ombori O, Maingi JM (2013). Effects of Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) compost on Growth and Yield Parameters of Maize (*Zea mays*). *British Journal of Applied Science and Technology* 4(4):617-633.
- Renck A, Lehmann J (2004). Rapid water flow and transport of inorganic and organic nitrogen in a highly aggregated tropical soil. *Soil Science* 169:330-341.
- Rufino MC, Dury J, Tittone P, van Wijk MT, Herrero M, Zingore S, Mapfumo P, Giller KE (2011). Competing use of organic resources, village-level interactions between farm types and climate variability in a communal area of NE Zimbabwe. *Agricultural Systems* 104(2):175-190.
- Rutonesha FG (2009). Effects of manure from Water hyacinth on soil fertility and maize performance under controlled conditions in Rwanda. *Master thesis* 56:82.
- Sanchez PA, Denning GL, Nziguheba G (2009). The African green revolution moves forward. *Food Security* 1:37-44.
- Tully K, Sullivan C, Weil R, Sanchez P (2015). *The State of Soil*

Segradation in Sub-Saharan Africa: Baselines, Trajectories, and Solutions. Sustainability 7:6523-6552.
Vanlauwe B, Descheemaeker K, Giller KE, Huising J, Merckx R, Nziguheba G, Wendt J (2015). Integrated soil fertility management in sub-Saharan Africa : unravelling local adaptation. Soil Journal 1:491-508.

Full Length Research Paper

Bioactivity and phenolic composition of extracts of noni (*Morinda citrifolia* L., Rubiaceae) in tomato moth (*Tuta absoluta* Meyrick, 1917) (Lepidoptera: Gelechiidae)

Rubens Pessoa de Barros^{1*}, Ligia Sampaio Reis², João Gomes da Costa³, Amanda Cunha Lima⁴, Isabelle Cristina Santos Magalhães⁴, Claudio Galdino da Silva⁴, Aldenir Feitosa dos Santos^{5,9}, Jhonatan David Santos das Neves⁶, Adriana Guimarães Duarte⁷, Gabriela Souto Vieira de Mello⁸, Jhonnatan Duarte de Freitas⁸, Jonas dos Santos Sousa⁸ and Simone Paes Bastos Franco⁸

¹Department of Biological Sciences, State University of Alagoas, Campus I, Brazil.

²Plant Protection at the Agricultural Sciences, Federal University of Alagoas, Maceió, Brazil.

³Embrapa Coastal Tracks, Rio Largo-AL, Brazil.

⁴Biological Sciences and Chemistry, State University of Alagoas, Arapiraca-AL, Brazil.

⁵Department of Chemistry, Universidade Estadual de Alagoas, Brazil.

⁶Institute of Land and Agrarian Reform of Alagoas, Brazil.

⁷Plant Protection, Agrarian Sciences Center, CECA/UFAL, Brazil.

⁸Federal Institute of Alagoas, IFAL, Brazil.

⁹Department of Chemistry, Centro de Estudos Superiores de Maceió Brazil.

Received 8 August, 2018; Accepted 5 September, 2018

We evaluated the bioactivity of *Morinda citrifolia* L., Rubiaceae on *Tuta absoluta* (Lepidoptera: Gelechiidae) and quantified the phenolic components. Ethanolic extracts of leaves and fruits were used in five concentrations (0.01, 0.02, 0.03, 0.04 and 0.05 mg / L). The leaves of the plants were immersed in the solution (10 s) and placed in contact with five caterpillars of the same instar in Petri dishes. The caterpillars were kept under controlled conditions, temperature of 25 ± 1 ° C, and relative humidity of $65 \pm 10\%$, photophase of 12 h. The experimental design was completely randomized with five concentrations, five replicates with two different extracts, the control being distilled water. The phenolic composition of the extracts was determined by high-performance liquid chromatography (HPLC) based on the retention times using the standard external method. Leaf extracts and fruits of *M. citrifolia* had bioinsecticidal activity against caterpillars (leaves at 0.02 mg / L gave 100% mortality and fruits at 0.03 mg / L gave 46.08% mortality). The greater efficiency of leaves can be attributed to their high percentage of phenolic compounds and flavonoids. Eleven phenolic compounds were identified and quantified in extracts of leaves and fruits that showed significant bioactivity.

Key words: Plant bioinsecticides, secondary metabolism, plant protection, damages, olericulture.

INTRODUCTION

The tomato (*Solanum Lycopersicum* L., Solanaceae) adapts well to subtropical and temperate climate. Tomato

crop is infested by various pests that can substantially alter their productivity and quality. Of all the insect pests, the tomato moth *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) has been infesting the tomato crop in Brazil since 1980 (Carvalho and Borgoni, 2006; Araújo et al., 2013).

Farmers have attempted to control this insect pest with insecticides. Though these are effective management options, but insecticides carry the risk of environmental degradation. In addition, as use of these chemicals became routine, their efficacy against *T. absoluta* decreased (Silvério et al., 2009; Lebdi-Grissa et al., 2010). Several researchers have reported alternatives to the use of conventional pesticides, including plant extracts as bioinsecticides or mass capture with sexual pheromones that attract males to traps where they are killed (Hassan and Alzaidi, 2009; Moreno et al., 2011, Tomé et al., 2013; Cocco et al., 2013). The bioinsecticidal botanical families include Asteraceae, Meliaceae, Rutaceae, Annonaceae, Lamiaceae and Canellaceae (Zabel et al., 2002, Pereira et al., 2002, Tamm, 2004). *Morinda citrifolia* L., from the Rubiaceae family, popularly known as noni, has been used since antiquity for the treatment and prevention of various diseases in humans and animals. This species is well adapted to the various regions of cultivation in Brazil (Navarro-Silva et al., 2009). Among the chemicals found in *M. citrifolia* fruits, phenolic compounds such as anthraquinones (Deng et al., 2007) are found in trace quantities (Lin et al., 2007). Reyes et al. (2011) reported that ethanolic and aqueous extracts of the fruit contained free quinones, steroids and flavonoids. Studies have tested the bioactivity of extracts of *M. citrifolia* against Diptera such as *Drosophila sechellia* (Tsacas and Baechli, 1981) (Diptera: Drosophilidae). The plant's fruit contains secondary defense compounds, primarily octanoic acid that are lethal to most other flies of the same genus (Morales et al.; 2010; Kovedan et al., 2012; Silva et al., 2015; López et al., 2017). The bioactivity of noni extracts (*M. citrifolia*) has chemical similarities with other natural products in terms of bioinsecticidal activity. The hypothesis raised is that the phenolic compounds of this plant have bioinsecticidal properties. Therefore, the objective of this work was to evaluate the leaf and fruit ethanolic extracts in the control of the tomato moth, in addition to identifying and quantifying its phenolic compounds, to assist in the integrated pest management.

MATERIALS AND METHODS

Study location

The experiment was carried out in the Research Laboratory of the

State University of Alagoas, Campus I in Arapiraca-AL. Tomato plants were cultivated in a greenhouse from February to June 2016. The insect pest *T. absoluta* was raised in a Styrofoam cage in a Laboratory of the State University of Alagoas. The production of ethanolic extracts from *M. citrifolia* and the bioassay with the tomato moth caterpillars were carried out in subsequent phases.

Tomato cultivation

For maintenance of the caterpillars, we transplanted tomato seedlings in five-liter pots with organic management soil and placed them in a greenhouse where they were monitored weekly. The first and second instar caterpillars of *T. absoluta* were collected from tomato varieties in crops in the rural region of Alagoas.

Raising the insects in cages

The immature stages 1 and 2 moth were placed in Styrofoam cages of 50 cm long × 40 wide × 30 cm high and maintained until adulthood. After population stabilization, the next generation was used in the bioassays. The caterpillars were kept under controlled conditions, with a temperature 25±1°C, relative humidity of 65 ± 10%, and photophase 12 h. In each cage, the plant leaves were conditioned for oviposition by *T. absoluta*.

Obtaining plant ethanolic extracts

In order to obtain the extracts, the leaves and fruits of *M. citrifolia* were dried in an air circulation oven at 60°C for 72 h and were ground in a knife mill. Then, leaf extract was macerated in ethanol: 2,500 g of vegetable powder (leaves or fruit) was placed in 3,500 mL of absolute ethyl alcohol for seventy-two hours, with filtration and alcohol replacement done every 24 h. The dry ethanolic extracts of leaves and fruit of *M. citrifolia* were obtained by rotational evaporation of the extracting liquid.

Bioassay for evaluation of insecticidal activity

Five concentrations of vegetable ethanol extracts such as 0.01, 0.02, 0.03, 0.04, 0.05 mg/L were used. Tomato leaves were previously immersed in the extract for 10 s and dried under laboratory conditions; five caterpillars of the same instar were placed on each leaf and in five petri dishes. The experimental design was completely randomized with five concentrations, five replicates with two different extracts and distilled water as the control. The Petri dishes were kept on benches in the laboratory at room temperature of 24-28°C. Mortality index (MI) was evaluated every 24, 48 and 72 h, and dead insects were counted in the Petri plates using the hair of a watercolor brush, as described by Sun-Shepard and Schneider-Orelli (1947) adapted by Puntener (1981) and used by Silva et al. (2015) in a similar study. The results were analyzed by the Dunnett test at 5% probability using an alternative bilateral hypothesis. Dunnett (1955) pioneered the concept that when a control is present, comparisons of preliminary interest may be comparisons of each new treatment with control through the GENES Program (Cruz, 2006).

*Corresponding author. E-mail: pessoa.rubens@gmail.com.

Quantification of total phenols

The method for the determination of total phenols consisted of the reaction of the constituent acids of the Folin-Ciocalteu reagent and phenolic or non-phenolic compounds. The Folin-Ciocalteu reagent is composed of phosphomolybdic and phosphotungstic acids, in this solution, molybdenum is in the oxidation state +6 with a yellowish coloration; in the presence of phenolic compounds, it undergoes a reduction reaction and passes to a +5 oxidation state (Rezende, 2010). With the reduction reaction there is the formation of blue-colored molybdenum-tungsten complexes. This reaction occurs in alkaline medium, specifically in the presence of Na₂CO₃ (Rezende, 2010). The total phenol content was quantified by the method described by Freitas et al. (2014) with some adaptations. To create the gallic acid calibration curve, 0.04 g of gallic acid was weighed into 8 mL of MeOH (stock solution). Dilutions (Gallic acid test solutions) were then prepared at concentrations of 0.15, 0.1, 0.05, 0.025, 0.01 and 0.005 mg/mL.

The following procedures were performed from the dilutions of gallic acid (in triplicate for each concentration): into an amber glass we added 100 µL of gallic acid test solution, 500 µL of Folin-Ciocalteu reagent and 1 µL of distilled H₂O and then vortexed for one minute. Subsequently, 2 mL of 15% sodium carbonate was added and stirred for another 30 s in the vortex. Subsequently, the solution was filled into a 10 mL volumetric flask. The solution was incubated in the dark for two hours. Absorbance readings were obtained using a UV-VIS spectrophotometer with a wavelength of 750 nm. To obtain the test solution of the vegetable sample, 0.005 g of each vegetable ethanolic extract was diluted in 5 mL of MeOH. Then, a 0.075 mL aliquot of this solution was added to 0.425 mL MeOH. To perform the test, the same procedure was performed as for gallic acid, replacing the test solution of gallic acid with the test solution of the vegetable ethanolic extract. To obtain the blank control solution, a solution of 100 µL of MeOH, 500 µL of the Folin-Ciocalteu reagent and 1 mL of distilled H₂O was prepared. The procedure described for gallic acid was repeated, replacing the gallic acid test solution with the blank control solution. The absorbances were read in a UV-VIS spectrophotometer with a wavelength of 750 nm. Before any reading, the blank was used to reset the spectrophotometer.

Quantification of flavonoids

The method for the quantification of flavonoids consisted of preparing the calibration curve of quercetin, where 1 mg of quercetin was weighed and diluted in 1 mL of MeOH. Dilutions were then carried out at concentrations of 0.03, 0.025, 0.020, 0.015, 0.01, 0.005, 0.0025 and 0.00125 mg/mL. Subsequently, solutions were made of the extract, where 1 mg of the extract was weighed and diluted in 1 mL of MeOH. After preparation of the test solution, the solutions (in wells in triplicate) were prepared for reading with 200 µL of the test solution of the plant sample and 100 µL of 2% aluminum chloride methanolic solution. The solution was prepared for the blank (in triplicate) with 200 µL of MeOH and 100 µL of 2% methanolic chloride of aluminum chloride. Thereafter, the well plate was placed in the dark for 30 min. Then, the reading was performed in UV-VIS spectrophotometer at 420 nm. The flavonoid content was determined by interpolating the mean absorbance of the samples against the quercetin calibration curve and expressed in mg QE (quercetin equivalent) per gram of ethanolic extract.

Separation, identification and quantification of phenolic compounds

The determination of the phenolic compounds was performed using high-performance liquid chromatography (HPLC). The equipment

Table 1. Mobile phase gradient.

Time (min.)	A%	B%
0	93	7
10	84	16
30	75	25
38	50	50
50	30	70
54	25	75
58	15	85
66	93	7

used was a Shimadzu HPLC, equipped with four high pressure pumps, model LC-20AT, degasser model DGU-20A 5R, interface model CBM-20A, automatic injector model SIL-20A HT and detector model SPD-20A. The chromatographic column employed in both analyses was an Agilent-Zorbax Eclipse XDB-C18 column (4.6 × 250 mm, 5 µm).

The standards used for chromatographic analysis of the phenolic compounds were gallic acid, catechol, vanillic acid, salicylic acid, vanillin, syringaldehyde, coumaric acid, chlorogenic acid, coumarin, rutin, quercetin, kaempferol and caffeic acid. All standards were purchased from Sigma-Aldrich or AcrosOrganics. All solvents used for chromatography were of analytical grade; methane was from Panreac, formic acid was from Dynamic and ultrapure water was obtained from a Milli-Q system. For the standards, stock solutions with a concentration of 40 mg/L in water/alcohol at 30%/70% were prepared. The method used for quantification was that of external standardization. For the construction of analytical curves, dilutions of an intermediate solution were carried out containing a mixture of all the standards. This was obtained by diluting the stock solutions previously prepared. In this intermediate solution, all standards were at a concentration of 10 mg/L. The 1% formic acid solution in milli-Q water (Solvent A) and methanol (Solvent B) were used as the mobile phases for the elution of the tested compounds.

Plant samples and standards were eluted according to the gradient (Table 1) with a total run of 66 min. The wavelength used was 290 nm at 33°C, flow rate of 0.6 mL/min and injection volume of 20 µL. Samples and standards were filtered on 0.45 µm polyethylene membranes (Milipore) and were injected directly into the chromatographic system. Each injection was performed three times in the HPLC system, in order to obtain the mean concentrations and retention times. Thus, the identity of the analytes was confirmed by the retention time, and the profile of the peaks of the sample was compared to the patterns.

RESULTS AND DISCUSSION

Bioassay for evaluation of insecticidal activity

The data in Tables 2 and 3 refer to the average obtained by the Dunnett test at 5% probability, as an alternative bilateral hypothesis shown to be effective in relation to the control. The hypothesis was that both the ethanolic extract of the leaf and the fruit in the concentrations 0.01 to 0.05 mg/L would provoke a mortality effect in *T. absoluta* in a similar way. There was a higher mortality of *T. absoluta* with the leaf extracts at the concentration of 0.02 mg/L than in the control, with 88.04% mortality

Table 2. Insecticidal activity of the ethanol extract of *M. citrifolia* leaf.

	Mortality (%)	Mortality difference with control (%)
Control (H ₂ O)	11.46	-
**MC 0.01 mg/L	79.96	68.05*
MC 0.02 mg/L	100.00	88.04*
MC 0.03 mg/L	86.64	75.18*
MC 0.04 mg/L	86.64	75.18*
MC 0.05 mg/L	79.96	68.05*
C.V. (%)		23.96

*The Dunnett test was applied at a 5% probability level (bilateral). **MC – *M. citrifolia*.

Table 3. Insecticidal activity of the ethanol extract of *M. citrifolia* fruit.

	Mortality (%)	Mortality difference with control (%)
Control (H ₂ O)	11.46	-
**MC 0.01 mg/L	35.12	23.66*
MC 0.02 mg/L	33.50	22.04*
MC 0.03 mg/L	46.08	34.62*
MC 0.04 mg/L	36.62	25.16*
MC 0.05 mg/L	35.92	24.46*
C.V. (%)		9.00

*The Dunnett test was applied at a 5% probability level (bilateral). **MC – *M. citrifolia*

(Table 2). In the fruit extracts, the highest mortality was observed at the concentration of 0.03 mg/L, and the difference from the control was 34.62% (Table 3). To the best of our knowledge, this study was the first to show *M. citrifolia* bioinsecticidal activity against insects of agricultural interest, microlepidoptera such as *T. absoluta*. To date, there have been no reports on the bioactivity of this plant in relation to caterpillars of this order of insects. In the difference of the means of the treatments with the control, we observed that the results were better than the control, both for the leaf extracts and for the fruit extracts in terms of insect mortality.

Dunnett (1955) pioneered the concept that when a control is present, comparisons of preliminary interest may be the comparisons of each new treatment with the control. In this study, the control group was water (H₂O). When multiple comparisons are performed with a control, the primary interest parameters are the differences between each new mean treatment and the mean of the control, that is, the hypotheses are tested. In this test, a level of 5% significance is considered, thus, the hypothesis of equality between the mean concentrations of the bioactivity of the extracts of *M. citrifolia* on the mortality of *T. absoluta*.

The bioactivity of *M. citrifolia* has been demonstrated in Diptera such as *Drosophila sechellia* (Tsacas and Baechli, 1981) (Diptera: Drosophilidae), a species of fruit fly. Unlike other species of this genus that are generalists, *D.*

sechellia evolved to be specialist for the host plant *M. citrifolia*. This is interesting because the plant's fruit contains secondary defense compounds, especially octanoic acid that is lethal to most other flies of the same genus (López et al., 2017). Morales et al. (2010) tested several plant extracts on larvae of the dengue mosquito *Aedes aegypti* (Diptera: Culicidae). They obtained significant results using the *M. citrifolia* L. ethanolic extract at 300 mg/L, with a mortality of 98% of the larvae. The neurotoxic action was attributed to octanoic acid, the main ingredient of noni oil, also known as caprylic acid, a potential larvicide.

According to Silva et al. (2015), aqueous extracts of *M. citrifolia* applied to newly hatched larvae of fruit flies *Ceratitis capitata* (Wiedmann, 1824) (Diptera: Tephritidae), presented control efficiency (E%) of 10.8% and larval mortality of 18%. Kovendan et al. (2012) also confirmed the insecticidal activity of *M. citrifolia*, reporting that there were significant results with leaf extracts of this plant with the promotion of mortality of mosquito larvae of the order Diptera and family Culicidae: *Anopheles stephensi* (Liston, 1901), *Culex quinquefasciatus* (Say 1823), and *Aedes aegypti* (Linnaeus, 1762).

Quantification of total phenols and flavonoids

In the determination of the total phenols, the method was

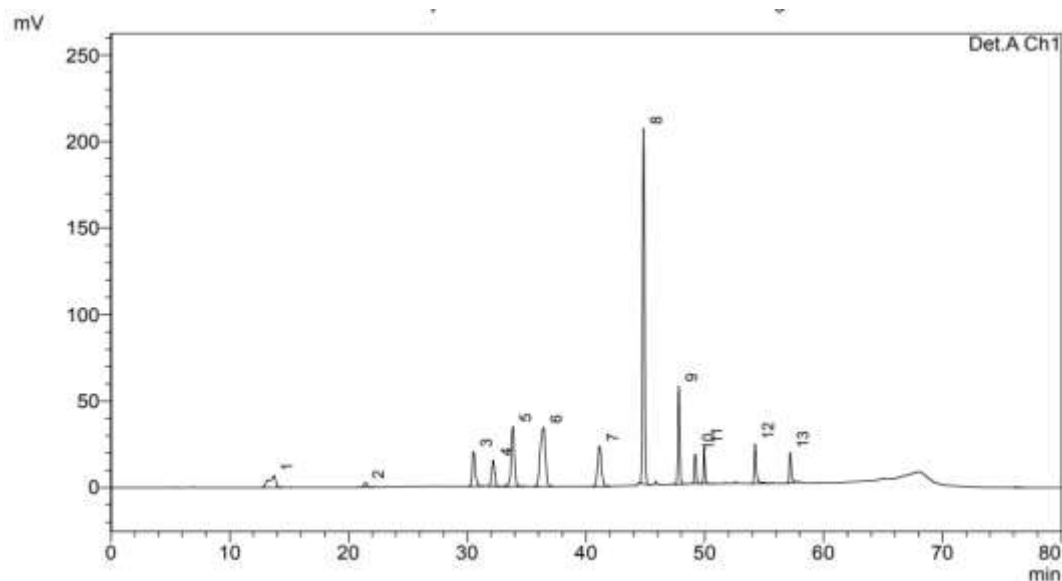


Figure 1. Chromatogram of the polyphenols solution with spectrophotometric detection of 290 nm. Identification of peaks: 1 = Gallic acid; 2 = Catechol, 3 = Chlorogenic acid, 4 = Vanillic acid, 5 = Caffeic acid, 6 = Vanillin, 7 = Seringaldehyde, 8 = Coumaric acid, 9 = Coumarin, 10 = Salicylic acid, 11 = Rutin, 12 = Quercetin; 13 = Kaempferol.

followed by determination of the calibration curve of synthetic standard Gallic acid ($y=7.701x + 0.0131$ and $R^2=0.9785$). We quantified the total phenols in all the extracts. The leaf of *M. citrifolia* had the highest phenol content with 1.094 g of GAE/g of crude extract compared to the extract of the fruit that had a ratio of 0.497 g GAE/g of the crude extract, compatible with its particular antioxidant potential. For the quantification of flavonoids, the method of determining the calibration curve of the quercetin standard was followed ($y=32.262x + 0.595$ and $R^2 = 0.9157$), allowing the quantification of the flavonoids of the ethanol extract of *M. citrifolia*. The leaf had the highest concentration of flavonoids (60.23 mg EQ/g of the crude extract) and the fruit had 12.20 mg EQ/g of the crude extract. The mean absorbance of the phenols and flavonoids in the fruit and leaf were different. We observed that the leaves of *M. citrifolia* had a higher percentage of phenolic compounds and of flavonoids, chemical constituents often mentioned in the literature for their bioactivity. These chemical characteristics may be related to higher bioactivity for *T. absoluta* mortality presented by the leaves of *M. citrifolia*.

According to Chan-Blanco et al. (2006), the most abundant bioactive compounds in *M. citrifolia* were phenolics, including damnacanthal, scopoletin, morindone and rubiadin, with rutin and scopoletin as major components and damanacantal with demonstrated anti-carcinogenic properties. In reports of phenolic compounds with insecticidal bioactivity of *M. citrifolia* on dipterans, nanoparticles synthesized from root extracts were used, with significant results against *Aedes aegypti* larvae (Suman et al., 2015). Many phenolic compounds

have antioxidant, anticarcinogenic, antimutagenic and anti-inflammatory activities. However, most interest is focused on antioxidant activity, and the attributed physiological and pharmacological functions originate in this activity (Thani et al., 2010).

Zin et al. (2002) demonstrated high levels of antioxidant activity in *M. citrifolia* extracts when using methanolic extracts of roots, fruits and leaves. Faria et al. (2014) measured the presence of various phytochemical compounds, including tannins, flavonoids, conjugated anthraquinones, saponins, coumarins and alkaloids and suggested pharmacological and functional functions. Studies demonstrate current interest in the study of phenolic compounds, primarily due to the antioxidant potential of these substances in terms of sequestering free radicals that are harmful to human health (Alves et al., 2007; Neves et al., 2008).

Costa et al. (2013) carried out studies with *M. citrifolia* using the seed, peel and pulp, and demonstrated the antioxidant capabilities of this plant. The bioactive compounds found in plants are phenolic substances with diverse functions including plant growth, sensory properties, seed germination processes, and defense against pests and oxidative damage (Liu, 2007).

Phenolic compounds identified and quantified

In this study, 11 phenolic compounds were detected in the fruit and leaf extracts of *M. citrifolia*. Figure 1 shows the chromatogram with spectrophotometric detection at 290 nm. The phenolic profile of the plant samples is very

Table 4. Concentrations of phenolic compounds in leaves and fruits of *M. citrifolia*.

Compound	Retention time (min.)	Concentration (mg / L)	
		Leaf extract	Fruit extract
Gallic acid	-	-	-
Catechol	20.915	31.853	8.370
Chlorogenic acid	29.951	14.690	-
Vanillic acid	31.540	16.250	22.921
Caffeic acid,	33.010	3.561	3.901
Vanillin	35.887	2.263	-
Seringaldehyde	-	-	-
Coumaric acid	44.259	12.611	24.508
Coumarin,	47.595	3.573	1.898
Salicylic acid	48.826	24.282	1.431
Rutin	49.708	89.1063	21.1252
Quercetin	53.858	24.767	16.515
Kaempferol	56.699	8.595	1.539

similar except for the detection of chlorogenic acid and vanillin patterns found only in the extract of the fruits of *M. citrifolia*. The other compounds were detected in both the fruit and leaf extracts. The concentrations of the identified products were calculated from standard curves generated with commercial products chromatographed under identical conditions (Table 4). The bioactivity of *M. citrifolia* on the mortality of caterpillars can be attributed to phenolic compounds that were found in greater quantity in leaf extracts than in fruit extracts. Some of these phenolic compounds are distinguished terms of insect control in bioassays.

Bendassolli et al. (2010) reported mortality of ants of the genus *Atta*, with extracts of Anacardiaceae. The results obtained with methyl gallate and quercetin were significant, with quercetin resulting in mortality of 50% and Gallic acid resulting in 50% mortality only at the end of the experiment. In the present study was this effect was found at concentrations 24.767 mg/L in the leaf and in the fruit 16.515 mg/L. Rutin had a bioinsecticidal effect on caterpillars (*Anticarsia gemmatalis*) that was potentiated when the caterpillars fed on mixed diets with rutin. In that study, the rutin was present in the leaf at 89.1063 mg/L and in the fruit at 21.1252 mg/L (Wang et al., 2002; Céspedes et al., 2004; Scott et al. 2010). Villaño et al. (2006) found that phenolic acids (syringic acid, vanillic acid and p-coumaric acid) protected plants against insects. Saponins have been shown to be substances in plant secondary metabolism that protect from insects as well. Peyser et al. (2017) suggested that octanoic acid and hexanoic acid were the toxins that mediated the effects of *M. citrifolia*, and that octanoic acid was a neurotoxin as well.

Conclusion

The bioinsecticidal action of *M. citrifolia* was efficient

against the tomato moth (*T. absoluta*), especially the ethanolic extract of its leaves. The effect of *M. citrifolia* leaves in terms of bioinsecticidal activity may be related to their chemical composition, evidenced here by the quantification of phenolic compounds and flavonoids. The mortality data from the tomato moth resulting from the bioactivity of *M. citrifolia* extracts and their chemical compositions suggest that they can be used to control the tomato moth.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Alves CQ, Brandão HN, David JM, David JP, Lima LS (2007). Avaliação da atividade antioxidante de flavonóides. Diálogos e ciência - Revista da rede ensino FTC 5(12):7-8.
- Araújo L, Silva KJP, Milagres CC, Cardoso DSCP, Alves LC, Pereira PRG (2013). Tomate cereja cultivado em diferentes concentrações de solução nutritiva no sistema hidropônico capilar. Unimontes Científica, Montes Claros 15:1.
- Bendassolli RHV, Sarria ALF, Fernandes JB, Bueno OB, Barbosa AO, Vieira PC, Silva MFG (2010). Atividade Inseticida de Substâncias isoladas de *Myracrodruon urundeuva* (Anacardiaceae), para o controle de formigas cortadeiras (*Atta sexdens rubropilosa*). Sociedade Brasileira de Química (SBQ). In. 34a Reunião Anual da Sociedade Brasileira de Química pp. 34-35.
- Carvalho GS, Bogorni PC (2006). Biologia de *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) em diferentes cultivares *Lycopersicon esculentum* Mill. Bioikos. Campinas 20(2):49-61.
- Céspedes CL, Torres P, Marín JC, Arciniegas A, Vivar AR, Pérez-Castorena AL, Aranda E (2004). Insect growth inhibition by tocotrienols and hydroquinones from *Roldana barbajohannis*. Phytochemistry 65(1):1963-1975.
- Chan-Blanco Y, Vaillant F, Pérez AM, Reynes M, Brillouet JM, Brat P (2006). The noni fruit (*Morinda citrifolia* L.): A review of agricultural research, nutritional and therapeutic properties. Journal of Food Composition and Analysis 19:645-654.
- Cocco A, Deliperi S, Delrio G (2013). Control of *Tuta absoluta* (Meyrick)

- (Lepidoptera: Gelechiidae) in greenhouse tomato crops using the mating disruption technique. *Journal of Applied Entomology* 137:16-28.
- Costa AB, Oliveira AMC, Silva AMO, Mancini-Filho J, Lima A (2013). Atividade antioxidante da polpa, casca e sementes do noni (*Morinda citrifolia* Linn). *Revista Brasileira de Fruticultura Jaboticabal - SP*. 35(2):345-354.
- Cruz CD (2006). Aplicativo Computacional em Genética e Estatística. Programa Genes: Biometria. Viçosa: UFV 382 p.
- Deng S, Palu AK, West BJ, Su CX, Zhou BN, Jensen JC (2007). Lipoxygenase inhibitory constituents of the fruits of noni (*Morinda citrifolia*) collected in Tahiti. *Journal of Natural Products* 70:859-862.
- Dunnet CW (1955). A Multiple Comparison Procedure for Comparing Several Treatments with a Control. *Journal of the American Statistical Association* 50:272.
- Faria WCS, Bett SC, Santos CGB, Silva-Brasil A, Gauto RF, Selhorst AM, Beserra S, Oliveira AP (2014). Physicochemical characterization and preliminary phytochemical analysis of the noni fruit (*Morinda Citrifolia* L.) produced in Cuiabá city – MT. *Revista Brasileira de Tecnologia Agroindustrial* 08(01):1208-1215.
- Freitas CR, Azevedo SRR, Souza OIL, Rocha MJT, Santos FA (2014). Avaliação da atividade antimicrobiana e antioxidante das espécies *Plectranthus amboinicus* (Lour.) e *Mentha x villosa* (Huds.). *Revista de Ciências Farmacêuticas Básica e Aplicada* 35:113-118.
- Hassan MN, Alzaidi SH (2009). *Tuta absoluta* – a serious pest advancing in the Mediterranean region. Role of pheromones in management strategies. *International Journal of Pest Management* 51:85-87.
- Kovendan K, Murugan K, Shanthakumar SP, Vincent S, Hwang JS (2012). Larvicidal activity of *Morinda citrifolia* L. (Noni) (Family: Rubiaceae) leaf extract against *Anopheles stephensi*, *Culex quinquefasciatus*, and *Aedes aegypti*. *Parasitology Research* 111:1481.
- Lebdi-Grissa K, Skander M, Mhafdi M, Belhadj R (2010). Lutte intégrée contre la mineuse de la tomate, *Tuta absoluta* Meyrick (Lepidoptera : Gelechiidae) en Tunisie. *Entomologie faunistique - Faunistic Entomology* 63:125-132.
- Lin CF, Ni CL, Huang YL, Sheu SJ, Chen CC (2007). Lignans and anthraquinones from the fruits of *Morinda citrifolia*. *Natural Product Research* 21:1199-1204.
- Liu RH (2007). Whole grain phytochemicals and health. *Journal of Cereal Science, Manhattan* 46:207-219.
- López JMA, Lanno SM, Auerbach JM, Moskowitz EC, Sligar LAPJ, Wittkopp PJ, Coolon JD (2017). Genetic basis of octanoic acid resistance in *Drosophila sechellia*: functional analysis of a fine-mapped region. *Molecular Ecology* 26:4.
- Morales J, Castillo J, Luna I (2010). Aceite esencial del fruto del noni (*Morinda Citrifolia*: Rubiaceae) como larvicida del mosquito *Aedes Aegypti* (Diptera: Culicidae). *Tecnociencia* 12:1.
- Moreno SC, Carvalho GA, Picanço MC, Morais EGF, Pereira RM (2011). Bioactivity of compounds from *Acmella oleracea* against *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) and selectivity to two non-target species. *Pest Management Science* 68:386-393.
- Navarro-Silva MA, Marques FA, Duque JEL (2009). Review of semiochemicals that mediate the oviposition of mosquitoes: a possible sustainable tool for the control and monitoring of Culicidae. *Revista Brasileira de Entomologia Curitiba* 53(1):1-6.
- Neves LC, Alencar SM, Carpes ST (2008). Determinação da atividade antioxidante e do teor de compostos fenólicos e flavonóides totais em amostras de pólen apícola de *Apis mellifera*. *Brazilian Journal of Food Technology* 2:15.
- Pereira LGB, Petacci F, Fernandes JB, Corrêa AG, Vieira PC, Silva MFGF, Malaspina O (2002). Biological activity of astilbin from *Dimorphandra mollis* (Benth.) against *Anticarsia gemmatalis* Hubner and *Spodoptera frugiperda* (Smith). *Pest Management Science* 58(5):503-507.
- Peyser RD, Lanno SM, Shimshak SJ, Coolon JD (2017). Analysis of cytochrome P450 contribution to evolved plant toxin resistance in *Drosophila sechellia*. *Insect Molecular Biology* 26(6):715-720
- Reyes M, Rocha K, Alarcón L, Siegwart M, Sauphanor B (2011). Metabolic mechanisms involved in the resistance of field populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) to spinosad. *Pesticide Biochemistry and Physiology* 102:45-50.
- Rezende LC (2010). Avaliação da atividade antioxidante e composição química de seis frutas tropicais consumidas na Bahia. Tese de doutorado, Programa de Pós-graduação em Química, Universidade Federal da Bahia, Salvador-BA.
- Scott IM, Thaler JS, Scott JG. (2010). Response of a Generalist Herbivore *Trichoplusia ni* to Jasmonate-Mediated Induced Defense in Tomato. *Journal of Chemical Ecology* 36:490-499.
- Silva HD, Souza MDC, Giustolin TA, Alvarenga CD, Fonseca ED, Damasceno AS (2015). Bioatividade dos extratos aquosos de plantas às larvas da mosca-das-frutas, *Ceratitis capitata* (Wied.) Arquivos do Instituto Biológico São Paulo 82:1-4.
- Silvério FO, Alvarenga ES, Moreno SC, Picanço MC (2009). Synthesis and insecticidal activity of new pyrethroids. *Pest Management Science* 65:900-905.
- Suman TY, Ravindranath RRS, Elumalai D, Kaleena PKD, Ramkumar R, Perumal P, Aranganathan LP, Chitrarasu PS (2015). *Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus* and its other effect on non-target fish. *Asian Pacific Journal of Tropical Medicine* 5(3):224-230.
- Tamm L (2004). Organic fruit production in humid climates of Europe: bottlenecks and new approaches in disease and pest control. *Acta Horticulturae* 638(1):333-339.
- Thani W, Vallisuta O, Siripon P (2010). Anti-proliferative and antioxidative activities of thai noni/yon (*Morinda citrifolia* linn.) leaf extract. *Southeast Asian J Trop Med Public Health* 41(2):482-489.
- Tomé HVV, Martins JC, Corrêa AS, Galdino TVS, Picanço MC, Guedes RNC (2013). Azadirachtin avoidance by larvae and adult females of the tomato leafminer *Tuta absoluta*. *Crop Protection* 46:63-69.
- Villaño D, Fernandez-Pchón MS, Troncoso AM, Garcia-Parrilla MC. (2006). Influence of enological practices on the antioxidant activity of wines. *Food Chemistry, Oxford* 95:394-404.
- Wang MY, West B, Jensen CJ, Nowicki D, Su C, Palu AK, Anderson G (2002). *Morinda citrifolia* (Noni): A literature review and recent advances in Noni research. *Acta Pharmacologica Sinica, Shanghai* 23(12):1127-1141.
- Zabel A, Manojlovic B, Rajkovic S, Stankovic S, Kostic M (2002). Effect of neem extract on *Lymantria dispar* L. (Lepidoptera: Lymantriidae) and *Leptinotarsa decemlineata* Say. (Coleoptera: Chrysomelidae). *Journal of Pest Science* 75(1):19-25.
- Zin ZM, Abdul-hamid A, Osman A (2002). Antioxidative activity of extracts from Mengkudu (*Morinda citrifolia* L.) root, fruit and leaf. *Food Chemistry* pp. 227-231.

Full Length Research Paper

Determination of tomato drying conditions with solar energy family type shelf dryer

Bekir YELMEN

Adana Metropolitan Municipality, Water and Sewage Authority, Department of Wastewater Treatment, Adana, Turkey.

Received 18 August, 2018; Accepted 18 September, 2018

In this study, working parameters of the system consisting of air heaters and dryer with solar energy of 0.20 m² with a space of 0.72 m² and 10 pieces in the cabin were investigated experimentally. Average atmospheric air temperature and relative humidity values during the dry daylight hours were measured at 49°C and 35%, respectively. As a result of the examination of the test results, the atmospheric air temperature of 56°C was reached in the dryer depending on the solar radiation and environmental conditions. In addition, the accuracy of solar radiation data in the design of solar energy systems was extremely important. Six different models and MBE, RMSE and t-stat comparison methods were used to calculate the amount of global solar radiation on the horizontal surface. The best results were given by Model-3 with values of MBE=0.130 and RMSE=1.401, while the best result from t-statistics was with t-ist=0.282 with Model-5. When the equations are evaluated statistically, it has been shown that the solar-powered family type shelf dryer and tomato drying conditions can be used for Aksaray province.

Key words: Solar energy, shelf dryer, tomato, solar radiation, relative humidity.

INTRODUCTION

Drying, which is one of the methods applied for long-term storage of agricultural products, is the oldest method and the largest application area (Yagcioglu, 1996). Drying can be defined as the removal of water or liquid in a substance. The purpose of the drying process is to stop the development of biochemical reactions and microorganisms that may occur in the products by removing free water in wet products and thus reducing the amount of food that can not be bred so that the foodstuffs can last for a long time without deterioration. In a world where conventional energy sources are limited, intensive work is being done to introduce new and renewable energy sources. Among them, solar energy is

more preferred than other energy sources because solar drying is a cheap method that does not require any energy and maintenance costs. Approximately 12.6 million tons of tomatoes are produced in Turkey (FAO, 2018). Dried tomato production in Turkey began in small areas in the early 1980s. However, in recent years, it has rapidly increased the production of dried tomatoes (Aksoy and Kaymak, 2016). Nearly all of the tomatoes are dried by spreading on the ground in Turkey (Condori et al., 2001). Drying companies usually process red, spotless, and medium sized tomatoes, which they have collected, through washing, sorting, boiling, cutting, sulphurizing and salting. They are then dried in the sun for drying

E-mail: bekiryelmen@gmail.com. Tel: +90-322-428-8950.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

purposes. Areas used as tomato spreading are covered with cover materials and the products that are laid are surrounded by curtains in order to prevent dust, garbage, etc. (Vural and Duman, 2000). These curtains do not prevent the product from being contaminated with various materials even if they hold some of the foreign materials. Companies that trade dried tomatoes are doing different applications (Madhlopa et al., 2002). Some companies dry tomatoes after they have finished all the process. In addition, because of the drying process carried out by the outside, it is not always possible to obtain high quality products due to the weather conditions and direct effects on the product quality (Fuller and Charters, 1997). Since the process of drying the tomatoes on the sun takes a long time, the dried product is affected by the pollutant factors in the environment and also has considerable loss of nutritional properties. Therefore, solar energy dryers have a big precaution in order to shorten the drying time of the product, to obtain the product with the desired moisture content, to make the products cleaner and better quality and not to lose its nutritive properties.

The use of traditional energy sources in the drying process, which is an energy intensive process, causes significant increases in product cost (Ivanova et al., 2003). The use of renewable energy sources such as solar energy is necessary to reduce product costs (Sopian et al., 2000).

The aim of this study was to investigate the drying conditions of tomatoes, which are produced intensively in the province of Aksaray, determine its performance in drying with a shelf type solar dryer that is manufactured for the drying of agricultural products by utilizing solar energy. At the same time, this research aims to expand the use of different types of sun-dried dryers with a simple structure and low cost, which can be manufactured with local facilities, and the drying of tomatoes, other vegetables, and fruits (Ozdemir, 2003). Therefore, a family type dryer is designed, and the results of preliminary experimental studies are given.

MATERIALS AND METHODS

Herkul F1 (SF / 03), one of the tomato varieties produced in Turkey, was used in this study as drying material. All the samples used in the drying experiments were obtained from the same production site. Drying experiments were carried out in a sun-dried shelf dryer under the conditions of the province of Aksaray. In addition, simultaneous drying in the open-air footed and wire-braided trays under the same irradiation conditions was also taken as a control.

The shelf type dryer in which the drying experiments were made consisted of the air flow solar collector, solar chimney and drying chamber sections (Figure 1). The task of the air solar collector is to convert the incoming solar radiation into heat energy and transfer it to the drying air. The heated air enters the drying chamber under the effect of thermal force and is placed in shelves and passes through drying trays with tomatoes. In the meantime, the product takes moisture and goes out from the chimney.

The air solar collector is 60x120 cm in size, and the wooden case is made of black painted and metal holding element and a



Figure 1. Side view of the shelf type dryer.

transparent cover which keeps the sunlight. The retaining element is composed of 3 pieces of perforated sheet with 1 cm intervals, and the transparent cover consists of two pieces of glass material. The task of the air solar collector is also to send the heated air to the drying chamber by the action of the thermal force and move out of the dryer through the perforated rails, which the products are placed and dampened from the adjustable air outlet openings located on both surfaces.

There are 10 pieces shelves with the dimension of 34x60 cm in the dryer room. Shelf casings are made of wood material, and steel mesh is used to facilitate air passage. A hinged lid is placed on the rear wall so that the shelves can be placed in the dryer. Schematic view of a solar powered shelf dryer used in the experiment is shown in Figure 2 (Scanlin et al. 1999).

In order to determine the effect of the drying process on the drying characteristics of the tomatoes under different drying periods and environments, solar energy shelf dryers were used in the conditions of Aksaray. The experiments of tomato drying were carried out between 24th July, 2017 and 25th August, 2017. At the beginning of the first experiment, the test materials were weighed and placed on the shelves after the pre-treatments were made by cutting the halves and salting the cut top. The temperature of the air passing through the dryer and the humidity varied depending on the weather conditions at different times during the day and on different days. Tomatoes were simultaneously placed on shelves in three stages in order to properly utilize the air distribution between the shelves. The air collector had an area of 7200 cm² and there were 10 pieces 0.20 m² shelves in the cabin. The aim of this study was to shorten the drying period in tomato drying systems and to improve the quality and hygienic conditions. Experimental data were obtained by selecting samples from the total. The sample was placed in a specially prepared mesh so that it would not mix with other products. Climatic changes were taken into consideration during the drying experiment. Properties of dried products such as drying time, color, quality, taste and relative humidity were

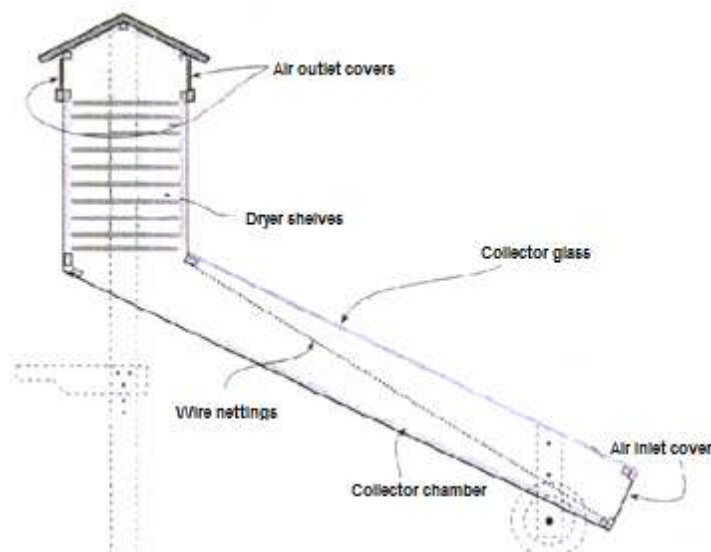


Figure 2. Schematic view of a solar powered shelf type dryer.

examined. During the tests, inlet temperature and relative humidity distributions in the dryer, outlet temperature and relative humidity, and total solar radiation from the horizontal surface were continuously measured. Mass losses of dried tomatoes were monitored regularly. Prior to experimental work, the vegetables were immersed in a citric acid solution (2.5 to 5 min). The tomato/solution ratio was taken as 1/3 (Anonymous, 2016). Moreover, average daily and monthly total solar radiation values from the horizontal surface given in the literature for the province of Aksaray (latitude: N 38° 22' 7.054" longitude: E 34° 1' 46.92" and altitude: 980 m) is calculated using a variety of linear, the second and third order equations. In addition, a third-order equation is developed for the daily average solar radiation account in the province of Aksaray. These equations were derived from the average daily and monthly solar irradiance and sunshine values obtained from the measurements taken by the General Directorate of State Meteorology Affairs between 1997 to 2017 and on the horizontal surface and for the province of Aksaray (GDSM, 2017). In the literature, there are various test methods used to evaluate solar radiation prediction models statistically. In this study, the results obtained from different models were compared using Mean Bias Error (MBE), Root Mean Square Error (RMSE) and t-stat (t-ist) methods. The MBE and RMSE values were calculated using the following equations (Machler and Iqbal, 1984).

$$MBE = \frac{1}{n} \sum_{i=1}^n (y_i - x_i) \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_i - x_i)^2}{n}} \quad (2)$$

In these equations, x_i , i is measured value, y_i , i is calculated value, and n is the total number of observations. MBE is a measure of the performance of a model over the long term and it is desirable that the value is low. Positive values indicate that the model has a

higher value than the real value, while negative values indicate that it gives lower values. The RMSE values give information about the short-term performance of the correlations by showing the deviation between the calculated and measured values. The smaller the RMSE value, the higher the performance of the model. As can be seen from the above explanations, it is clear that each test (RMSE and MBE) alone is not sufficient to show the model performance. It is possible for a model to have a small MBE value versus a large RMSE value. On the other hand, it is also possible that a model has a very small RMSE value but a very small MBE value (Stone, 1993). Therefore, t-statistics were used in addition to the study. A statistical indicator, t-statistics, is used to compare models, as well as whether the values calculated from the models have statistical significance at a certain level of confidence. The t-statistic is calculated according to the values of MBE and RMSE as follows:

$$t - \text{statistic} = \left(\frac{(n-1)MBE^2}{RMSE^2 - MBE^2} \right)^{1/2} \quad (3)$$

In this method, the smaller the t-ist value, the better the performance of the model. The t-critical value must first be determined from the statistical tables in order to determine whether the modeled values are statistically significant. Thereafter, the value of $ta/2$ is found at $n-1$ degrees of freedom and at α importance level. The t-ist value calculated should be smaller than the t-critical value so that the statistical significance of the calculated values in the $1-\alpha$ confidence level can be determined. For Aksaray province, the daily total solar radiation from the horizontal surface is calculated from some models available in the literature, and from an equation developed in this study, the results are compared with various comparative methods. Modal-1: Page (Angstrom, 1924), Modal-2: Rietveld (Rietveld et al., 1978), Modal-3: Kilic and Ozturk (Kılıç and Ozturk, 1983), Modal-4: Akinoglu and Ecevit (Akinoglu and Ecevit, 1990), Modal-5: Bahel (Bahel and Bakhsh, 1987), and Modal-6: Louche (Louche et al., 1999). For Aksaray province, the monthly average daily global solar irradiance values and the MBE, RMSE and t-statistic values from the horizontal surface calculated with different models are given in Table 1. According to the models, the comparison of the measured and estimated values of the

Table 1. MBE, RMSE and t-Statistic Values ($\alpha=0.01$ for $n=12$ and $t\text{-Critical}=3,106$ for $n=12$) of the models with monthly average global solar radiation ($\text{MJ}/\text{m}^2\text{-day}$) coming to the horizontal surface for Aksaray province.

Z = 980 m Aksaray province		$H_{\text{Estimated}}$ ($\text{MJ}/\text{m}^2\text{-day}$)					
Months	$H_0(\text{MJ}/\text{m}^2\text{-day})$	Model 1 (Page)	Model 2 (SolerRietveld)	Model 3 (Kılıç and Öztürk)	Model 4 (Akinoğlu and Ecevit)	Model 5 (Bahel)	Model 6 (Louche)
January	7.86	8.17	9.06	7.72	8.70	7.06	8.40
February	11.17	9.02	9.41	8.87	9.38	8.46	9.07
March	14.85	13.09	14.20	13.19	13.85	12.54	13.33
April	17.51	16.87	18.41	17.37	17.01	16.27	17.25
May	21.013	21.43	22.86	21.81	22.78	21.09	22.17
June	23.24	25.51	27.59	25.32	26.67	25.61	26.71
July	23.36	25.69	27.40	25.31	26.66	25.02	26.07
August	21.28	23.81	25.69	23.24	24.55	24.10	25.04
September	17.04	18.03	20.76	18.44	19.75	19.05	19.85
October	12.83	14.14	15.41	13.60	14.81	14.18	14.79
November	8.01	8.12	8.65	7.74	8.60	7.79	8.28
December	6.31	5.69	5.82	5.35	5.80	5.25	5.68
r^2		0.919	0.801	0.932	0.870	0.901	0.853
MBE		0.336	1.570	0.130	1.087	0.149	0.928
RMSE		1.545	2.550	1.401	2.012	1.808	2.147
t - ist		0.747	2.591	0.320	2.131	0.282	1.591

monthly average daily total solar radiation changes per month from the horizontal surface for Aksaray province is shown in Figure 3.

RESULTS AND DISCUSSION

Tomato samples of Herkul F1 (SF/03) cultivated in Aksaray province were pre-processed and dried in a shelf-type dryer. During the test process, the temperature and humidity distributions of the dried products in the dryer, outdoor temperature and humidity, along with total solar radiation from the horizontal surface were continuously measured. Temperature and humidity change during the daytime in the dryer performed in the tomato drying experiments are given in Figure 4. The

average atmospheric air temperature and relative humidity values during dry daylight hours were 49°C and 35%. The change in the inlet and outlet atmospheric air temperatures of the drying air and the solar radiation values on the system in the solar energy air heater is shown in Figure 5 and values. Results showed that the temperature of the dryer reached 56°C due to solar radiation and environmental conditions. It has been seen that the dryer can be brought to a better usable condition by implementing different designs on the dryer cover system, the shelf system and the absorber. It has also been seen that the shelf solar dryer provides a partial drying advantage over the open-air tomato drying. This advantage has been observed to provide a higher drying temperature in the dryer during daytime hours and

a rapid weight loss in the lower shelves (Third and fourth shelves).

Considering the fact that the dried tomatoes in the shelf dryer protect from adverse environmental conditions such as rain, dust, etc, it has also been seen that they are cleaner than the open areas in terms of cleanliness. The tomato samples on the top shelf have been exposed to oxidative reactions causing changes in color by reacting with oxygen in the air because they dry up longer and lose moisture more slowly. The temperature in the drying air has changed depending on the drying period and it has been observed that there is decrease in the temperature of the drying air and the increase in the elongation and discoloration of the drying time.

As a result, it is recommended to use solar

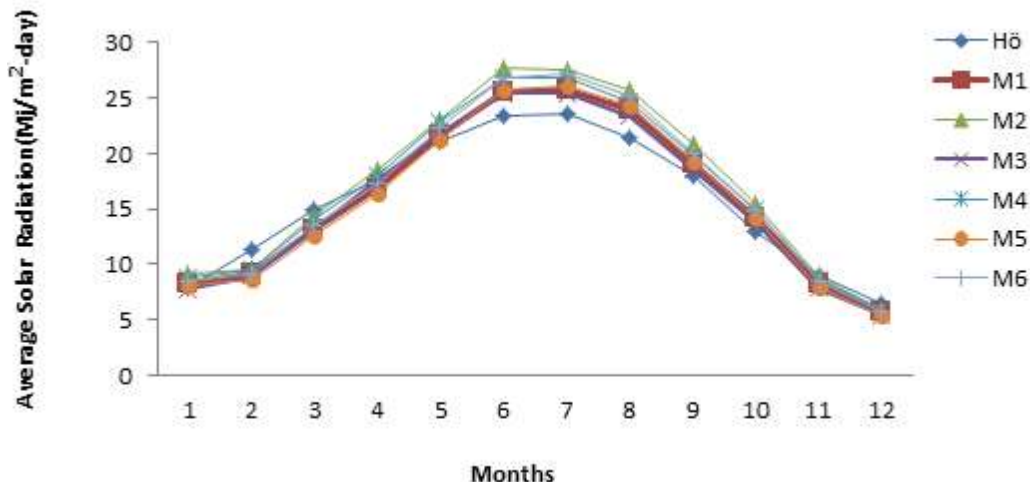


Figure 3. Comparison of measurement and estimation values for Aksaray province by models.

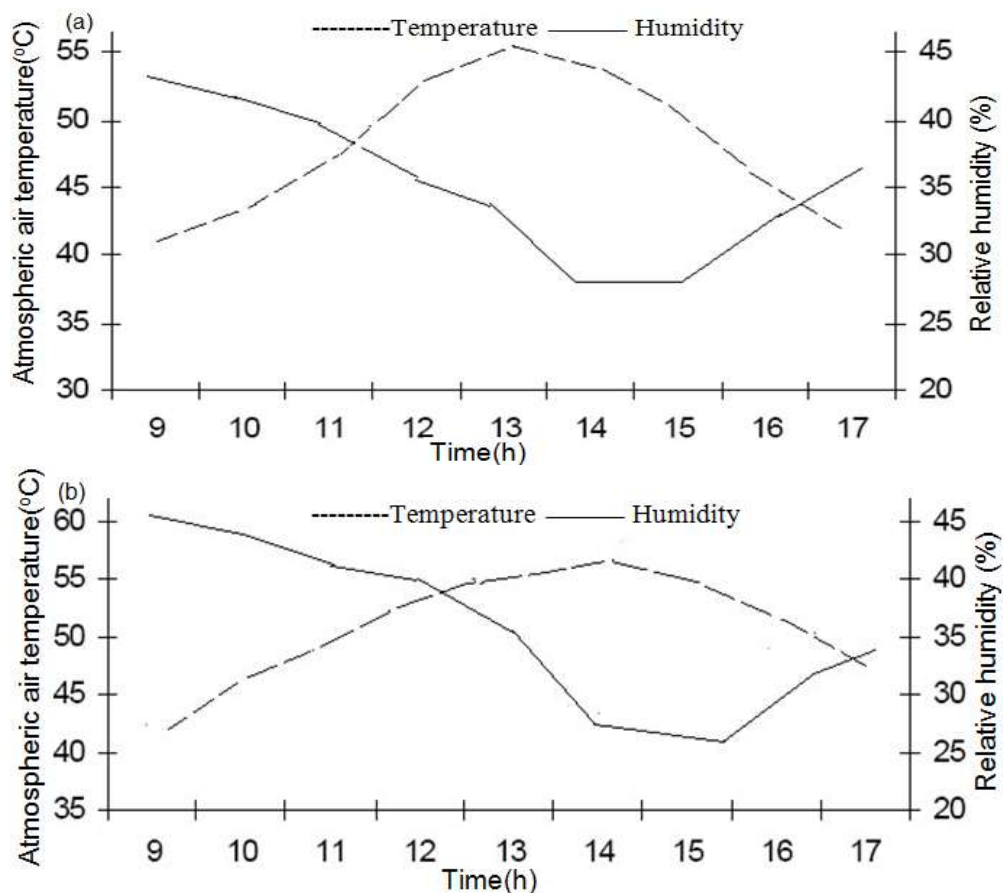


Figure 4. Change in dryer temperature (a:24.07.2017, b:25.08.2017) in the tomato drying experiments.

energy shelf dryers in Aksaray province conditions. Instead of using only 10 pieces shelves, it is recommended to use 2-3 shelves when considering color

formation and drying speed. In addition, an additional heater can be placed in the lower part of the drying chamber where the shelves are located so that the nights

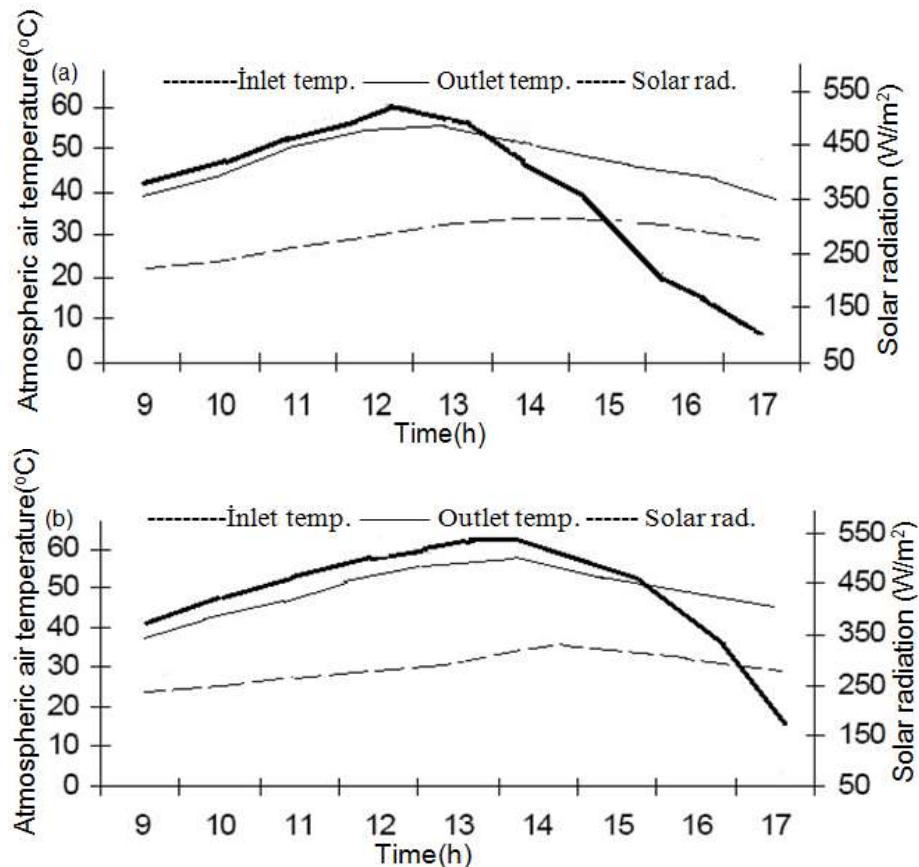


Figure 5. Change of air heater operating parameters in tomato drying experiment (a:24.07.2017, b:25.08.2017).

can continue to dry. Six different models along with MBE, RMSE and t-stat comparison methods were used to calculate the amount of global solar radiation on the horizontal surface. When a general evaluation was made between all equations according to all three comparison methods, the best results were given by Model-3 with values of MBE=0.130 and RMSE=1.401, while the best result from t-statistics was with t-ist=0.282 with Model-5. When the equations are evaluated statistically, it has been shown that the solar family type shelf dryer and tomato drying conditions can be used for Aksaray province if all the equations in the models are below the acceptable t-critical=3.106 value at $\alpha=0.01$ statistical significance level.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

- Akinoglu BG, Ecevit A (1990). Construction of aquadratic model using modified angström coefficients to estimate global solar radiation. *Solar Energy* 45:85-92.
- Aksoy A, Kaymak C (2016). Outlook on Turkish Tomato Sector. *Iğdır University Journal of the Institute of Science and Technology* 6(2):121-129
- Angstrom AK (1924). Solar and atmospheric radiation. *Journal of Royal Meteorological Society* 20:121-126.
- Anonymous (2016). Sun dried tomato production. Ege University, Food Engineering Department, Seminar Notes.
- Bahel V, Bakhsh H (1987). A correlation for estimation of global solar radiation. *Energy* 12:131-135.
- Condori M, Echazu R, Saravia L (2001). Solar drying of pepper and garlic using dryer. *Renewable Energy* 1:447-460.
- FAO (2018). FAOSTAT, Food and Agriculture Organization of the United Nations. FAO/United Nations Comtrade. Faostat Agricultural Database Web Page. Report, www.fao.org/statistics/en/ (18.01.2018).
- Fuller RJ, Charters WS (1997). Performance of a solar tunnel dryer with microcomputer control. *Solar Energy* 59:151-154.
- GDSM (2017). Daily and monthly solar irradiance values. General Directorate of State Meteorology. Archives. URL Link: <https://mgm.gov.tr/eng/forecast-cities.aspx?m=AKSARAY>
- Ivanova D, Enimanev R, Andonov K (2003). Energy and economic effectiveness of a fruit and vegetable dryer. *Energy Conversion and Management, Academic Press* pp. 763-769.
- Kılıç A, Öztürk A (1983). *Solar Energy, Kipaş Distribution, İstanbul* pp. 19-83.
- Louche A, Muselli M, Nottton G (1999). Design of hybrid - photovoltaic power generator, with optimization of energy management. *Solar Energy* 65:143-157.
- Machler C, Iqbal M (1984). Statistical comparison of models for

- estimating solar radiation on inclined surfaces. *Solar Energy* 31:313-317.
- Madhlopa A, Jones SA, Kalenga JD (2002). A solar air heater with composite-absorber systems for food dehydration. *Renewable Energy* pp. 27-37.
- Ozdemir K (2003). Development of a family-type solar dryer. Ege University Mechanical Engineering Department Completion Thesis. Academic Press pp. 35-37.
- Rietveld MR (1978). A new method for estimating the regression coefficients in the inquisition. *Solar radiation to sunshine. Agricultural Meteorology* 19:243-252.
- Scanlin D, Renner M, Domermuth D (1999). Improving solar food dryers. *Home Power* 69:24-33.
- Sopian K, Liu HT, Kakac S, Veziroğlu TN (2000). Performance of a double pass fotovoltaic thermal solar collector suitable for solar drying systems. *Energy Conversion and Management, Academic Press* pp. 353-365.
- Stone RJ (1993). Solar radiation estimation models. *Solar Energy* 51:291-298.
- Vural H, Duman I (2000). Sun dried tomato production. *Tigem Magazine Issue* 81:65.
- Yagcioglu A (1996). Product processing technique, EUZF Publications 536:348.

Full Length Research Paper

Effects of seed tuber size on growth and yield performance of potato (*Solanum tuberosum* L.) varieties under field conditions

Sadik Ebrahim¹, Hussien Mohammed² and Tewodros Ayalew^{2*}

¹Agarfa, Agricultural Technical and Vocational Education and Training College, Ethiopia.

²School of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, Ethiopia.

Received 22 July, 2018; Accepted 21 August, 2018

Potato (*Solanum tuberosum* L.) is an important food and cash crop in Ethiopia; serving, as a food security crop due to its nutrition content, wider adaptability and early maturing behavior. However, the yield of the crop is constrained by a number of factors. Among which unspecified seed tuber size and limited availability and distribution of improved varieties are among the important limiting factors. A field experiment was conducted to study the effects of seed tuber size on growth and yield performance of potato varieties at *Agarfa*, Agricultural Technical and Vocational Education and Training College experimental field during 2017. The treatments consisted of three potato varieties (*Gudenie*, *Jalene* and *Kellacho*) and three seed tuber sizes (25-34, 35-45 and 46-55 mm). The experiment was laid out in a randomized complete block design with a factorial arrangement and replicated three times. The results showed that, seed tuber size and varieties significantly affected phenological parameters, stem number, leaf area index, stem density, marketable, unmarketable and total tuber yield, shoot fresh and dry weight, underground fresh weight, and medium weight of tuber size. Leaf number, and underground dry weight and tuber size were significantly affected only by seed tuber size. Varieties and seed tuber size interact to influence plant height, leaf area, number of tuber per plant, dry matter concentration and harvest index. *Gudenie* and *Jalene* produced the highest total tuber and marketable yields. Large seed tuber size (46-55 mm) produced higher marketable tuber yields than medium and small tuber sizes. In conclusion, *Gudenie* variety and large seed tuber size showed superior performance both for tuber yield and tuber dry matter concentration compared with the remaining varieties and small tuber size. Therefore, farmers are encouraged to produce *Gudenie* or *Jalene* variety with the use of medium to large seed tuber size for potato production.

Key words: Agarfa, *Gudenie*, *Jalene*, potato, seed tuber size and tuber yield.

INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the nightshade or Solanaceae family and originated in South

America (Asfaw, 2016). Globally, potato is the third most important food crop in terms of consumption after rice

*Corresponding author. E-mail: tednet2011@gmail.com.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

and wheat (De Jong et al., 2011; Birch et al., 2012; Hancock et al., 2012). The global cultivation exceeds 19.34 million hectares of land in more than 158 countries across the world with an estimated annual production of 364 million tons (FAOSTAT, 2014). It is an important tuber crop grown widely in the humid tropics and used as a source of carbohydrates for many people in tropical and sub-tropical regions (Bilate and Mulualem, 2016).

Potato is a high potential food security crop in Ethiopia due to its high yield potential and nutritional quality tuber, short growing period, and wider adaptability (Ayalew et al., 2014). Potato plays a major role in national food security, nutrition, poverty alleviation and income generation (Ayalew, 2014; Gedif et al., 2013). The crop also provides employment opportunity in the production, processing and marketing sub-sectors (Menza et al., 2014). It is grown in over 3.5 million smallholder farmers in the highland areas and known to buffer food deficit during the months of limited food supply (July to August) before the grain crops are being harvested (Tebabal, 2014). Ethiopia is among the top potato producing countries in Africa, with 70% of the arable land suitable for potato production (FAOSTAT, 2008).

Potato production and productivity is low due to several constraining factors such as inappropriate planting materials, prevalence of disease and pests, poor soil fertility (Menza et al., 2014), variability in climatic patterns, shortage of water, shortage of agricultural input, and poor post-harvest handling practices (Tesfaye et al., 2011). Similarly, in Ethiopia absence of improved varieties, dependency on traditional management practices and improper seed tuber size are among the important factors challenging small scale potato producing farmers.

The productivity of potatoes in Oromia region, Bale zone is less than the national average 11.8 t.ha^{-1} (CSA, 2014). Among the factors contributing to this low production and productivity is the use of local varieties that are low in yield and susceptible to disease (Asefa, 2015). And also seed tuber size is a limitation for potato production in the area. Therefore, there is an urgent need to determine proper seed tuber size for potato varieties grown in the area. In general, potato seed tuber size and varieties in the South Eastern highland of Ethiopia have not been sufficiently evaluated for increasing higher yields of appropriate seed tuber size. Considering the above limited research work, it is important to identify optimum tuber size and varieties for maximum potato production. Therefore, the objective of this study was to evaluate the growth performance and yield response of potato varieties to variable seed tuber sizes.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Agarfa Agricultural Technical Vocational Education and Training (ATVET) College experimental

site. The site is located at $7^{\circ} 17' 0''$ North latitude; $39^{\circ} 49' 0''$ East longitude. The altitude is 2330 m.a.s.l. It is about 458 km away from the capital city of the country. The average annual rainfall is 829.4 mm and has a bi-modal distribution pattern. The mean maximum and minimum annual temperature are 24.75 and 7.10°C , respectively. The soil of the area is a silty loam, black vertisol and clay soil having a pH value of 6.12 (Mesfin et al., 2014). The current experiment was conducted under rain-fed conditions supplemented with irrigation during the 2017 cropping season (April to August).

Description of experimental materials

The experiment was conducted using two improved (Jalene and Gudeine) and one local (kellacho) potato varieties. Jalene and Gudeine were released by Holetta Agricultural Research Centre and Kellacho was a farmers' variety. The varieties were selected based on their adaptability, yielding potential, tolerance to late blight and preference of the producers and consumers.

Treatments and experimental design

The treatments consisted of three potato varieties (Jalene, Gudeine and local) and three tuber sizes (25-34, 35-45 and 46-55 mm in diameter). These tuber sizes 25 - 34, 35 - 45 and 46 -55 mm were considered as small, medium and large, respectively (Mulugeta et al., 2013). The experiment was laid in a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. Gross plot size was 3 m x 3 m. The spacing between adjacent plots was 1 m and a distance of 1.5 m was maintained between blocks. Spacings between rows and plants were 75 cm x 30 cm, respectively. There were four rows per plot and 10 plants in each row, and a total of 40 plants per plot. Data were collected from the two middle rows.

Experimental procedures and cultural practices

The experimental plots were cultivated to the depth of 15 to 20 cm. The land was leveled and ridges were made by hand based on spacing between rows. Planting was done by selecting well sprouted seed tubers in each seed tuber size category according to the specified treatments for each varieties. Weeding, cultivation and earthing-up and ridging were done at the appropriate time to facilitate root, stolon as well as tuber growth and development. Late Ridomil MZ 63.5% WP at the rate of 2 Kg ha^{-1} and Mancozeb at the rate 3 Kg ha^{-1} were applied for late blight (EARO, 2004).

Data collection

Data on growth performance, yield and quality were recorded from five sample plants per plot.

Phenological parameters

Days to 50% emergence: Days to emergence was recorded when 50% of planted tubers were emerged from the soil.

Days to flowering: Days to flowering was recorded when 50% of the plant population in each plot produced flowers.

Days to maturity: Days to maturity were recorded when 90% of the plants in each plot become ready for harvest as indicated by the senescence of the haulms. The days were counted from emergence to maturity.

Growth parameters

Plant height (cm): Was measured from the soil surface to the top most growth point of the plant at physiological maturity.

Number of stems per hill: Actual number was recorded at 50% flowering. Then an average was taken. Only stems that emerged independently above the soil as single stems were considered.

Leaf number/plant: The number of leaves was counted per plant at 50% flowering and the average was taken.

Leaf area: Was determined by the product of the leaf width (W) and length (L) based on pre-measured width and length from randomly selected five plants of leaves and multiplied by a constant (0.674).

Leaf area (LA) = $W \times L \times 0.674$. Where 0.674 is the correction factor according to Sakilova (1979) as cited by Djilani and Senoussi (2013).

Leaf area index: Was determined, first leaf area was calculated, then multiplied the average leaf area with the respective leaf number of the plant and obtained total leaf area. Then, dividing total leaf area to the respective land area occupied by plants.

$$LAI = \frac{\text{Leaf area} \left(\frac{\text{cm}^2}{\text{plant}} \right) * \text{Leaf number}}{\text{Land area} \left(\frac{\text{cm}^2}{\text{plant}} \right)}$$

Stem density: Was taken by counting stem population per square meter (m^2); then calculated the sum of stem density per m^2 .

Yield and biomass components

Total tuber yield (t ha^{-1}): The whole tubers harvested from the two central rows were weighed and converted in to t ha^{-1} .

Unmarketable tuber yield (t ha^{-1}): Including diseased, deformed tubers and weighing less than 25 g and converted into t ha^{-1} .

Number of tubers per plant: Was recorded as counting of the actual number of tubers collected from five plants at harvest.

Shoot fresh weight (t ha^{-1}): Leaves, branches and stems were taken. Then weighed soon after harvest and converted to t ha^{-1} .

Shoot dry weight (t ha^{-1}): Was obtained after drying the samples taken for determination of the shoot fresh weight in open sun for 7 to 9 days and then oven dried at 72°C for 48 h to a constant weight and convert to t ha^{-1} .

Underground fresh weight (t ha^{-1}): Roots, tubers, withered stolons and parts of the stem remaining underground were taken. Then weighed soon after harvest and converted to t ha^{-1} .

Underground dry weight (t ha^{-1}): Was obtained after drying the samples taken for determination of the underground fresh weight in open sun for 7 to 9 days and then oven dried at 72°C for 48 h to a constant weight and convert to t ha^{-1} .

Harvest index: Was the ratio of tuber dry weight to the total dry weight of the plant after harvest.

Quality parameters

Marketable tuber yield (t ha^{-1}): All tubers which were free from

diseases, insect pests and other damages and greater than or equal to 25 g in weight were weighed and converted to t ha^{-1} .

Tuber size distribution in weight: At harvest, tubers were collected from two central rows in each plot, and categorized into small (25-38 g), medium (39-75 g) and large (>75 g). Then converted to t ha^{-1} and % for each of the three categories.

Tuber dry matter concentration (%): Five potato tubers were randomly selected from each plot, chopped into small 1-2 cm cubes, mixed thoroughly and two subsamples each weighing at least 200 g was weighed. The exact weight of each sub sample was determined and recorded as fresh weight. Each subsample was placed in a paper bag and put in an oven at 65°C for 72 h until constant dry weight was attained. Each subsample was immediately weighed and recorded as dry weight. Then, percent dry matter concentration for each subsample was calculated following the procedure developed by the International Potato Center (CIP), (CIP, 2006). The dry matter percent was calculated following the formula suggested by William and Woodbury (1968).

$$\text{Dry matter (\%)} = \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100\%$$

Statistical analysis

The collected data were subjected to Analysis of Variance (ANOVA) using the proc mixed Model of the SAS package (SAS version 9.0, 2002). The mean separations were done using the (LSD) test at 5% probability level when there was a significant ANOVA effect. And Pearson correlation coefficients were made in determining association of parameters.

RESULTS AND DISCUSSION

Phenological parameters of potato

Days to emergence

The analysis of variance showed that seed tuber size had a highly significant effect ($P < 0.001$) for days to 50% emergence. Also, varieties significantly ($P < 0.05$) affected days to 50% emergence. However, the two main factor's interaction did not significantly affect the days to 50% emergence. Local variety (Kellacho) took the longest time to emerge from the soil over the two improved varieties (Gudenie and Jalene) (Table 1).

Similarly, seed tuber size affected days to emergence of potato varieties. Larger seed tubers (46-55 mm) took the shorter time to emerge as compared to the smaller seed tubers. This may be due to the fact that large tubers had sufficiently more stored reserve food compared to smaller seed tubers to provide an optimal supply of carbohydrate for the emerging seedling of the larger tuber.

Days to flowering

The analysis of variance showed that seed tuber size had a highly significant effect ($P < 0.01$) on days to 50%

Table 1. Days to emergence, flowering and maturity of potato as influenced by variety and seed tuber size.

Variety	Days to emergence	Days to flowering	Days to maturity
Jalene	12.7 ^b	62.8 ^a	105 ^a
Gudenie	12.8 ^b	57.8 ^b	96 ^b
Kellacho	14.2 ^a	61.3 ^a	102 ^a
LSD (0.05)	1.15	3.18	3.83
Tuber size (mm)			
46-55	11.6 ^b	57.4 ^b	98 ^b
35-45	13.5 ^a	60.1 ^b	101 ^b
25-34	14.6 ^a	64.3 ^a	105 ^a
LSD(0.05)	1.15	3.18	3.83
CV%	8.43	5.11	3.68

Means followed by the same letter (s) within a column are not significantly different at a 5 % level significance. LSD = least significant difference, CV = coefficient of variation.

flowering. Moreover, varieties significantly ($P < 0.05$) affected days to flowering. However, interaction did not influence the days to 50% flowering. Jalene and Kellacho required a longer time to reach flowering as compared to Gudenie (Table 1). Gudenie flowered earlier by 3.56 and 5 days than Kellacho and Jalene, respectively. It is known that earliness in flowering is controlled by many factors including genetic and environmental factors. With regard to seed tuber size, smaller tuber sizes (25-34 mm) required significantly more number of days to reach flowering stage whereas, larger seed tuber sizes (46-55 mm) required significantly smaller number of days to reach flowering stage (Table 1).

Days to maturity

The analysis of variance revealed that varieties and seed tuber size both had a highly significant effect ($P < 0.001$) on days to maturity. However, the interaction of varieties and seed tuber size did not influence days to maturity. Jalene and Kellacho were late varieties to reach physiological maturity as compared to the Gudenie variety (Table 1). Gudenie matured by about 2.44 and 9.34 days earlier than Kellacho and Jalene, respectively. Jalene and Kellacho had similar maturity periods. The perusal of data presented in Table 1 showed that the use of large seed tuber size shortened the time required to reach maturity. Medium seed tuber size (35-45 mm) had a similar effect on maturity of potato varieties (Table 2). Smaller seed tuber size (25-34 mm) required the longest time to mature physiologically.

Growth parameters of potato

Plant height

The analysis of variance showed that the interaction of

seed tuber size and varieties significantly ($P < 0.05$) influenced plant height. Large tuber size (46-55 mm) of the Gudenie variety resulted in the tallest plants. Whereas, the shortest plants were recorded from small tuber sizes (25-34 mm) of the local variety (Kellacho). However, small seed tubers from improved varieties (Gudenie and Jalene) did not show a statically significant difference for plant height (Table 2).

Leaf area per hill

The analysis of variance showed that interaction of seed tuber size and varieties significantly ($P < 0.05$) influenced the leaf area. Jalene variety with large (46-55mm) seed tuber size produced the highest leaf area per hill. Whereas, planting the Kellacho variety with small (25-34mm) seed tuber size produced the numerically lowest leaf area per hill (Table 2). Gudenie variety with large (46-55mm) and medium (35-45mm) seed tuber size relatively produced the highest leaf area per hill. On the other hand, the local variety (Kellacho) with medium and large seed tuber size gave a similar response as that obtained for an improved variety with small seed tuber size.

Stem number per hill

The analysis of variance showed that two main factors (the seed tuber size and varieties) had highly significant ($P < 0.01$) effects on stem number. However, the interaction did not influence this parameter. Gudenie variety produced maximum stem number per hill compared with Jalene and Kellacho varieties (Table 3). This is probably due to a greater number of sprouts observed in Gudenie variety during emergence that might have resulted from its genetic potential for sprouting capacity. The perusal of data presented in Table 3

Table 2. The interaction effect of variety with seed tuber size on plant height and leaf area of potato at Agarfa during 2017 cropping season.

Varieties	Tuber size (mm)	Plant Height (cm)	Leaf Area (cm ²)
Jalene	25-34	65.20 ^d	15.93 ^{de}
	35-44	71.46 ^c	16.81 ^c
	45-55	75.93 ^b	18.74 ^a
Gudenie	25-34	62.53 ^d	16.09 ^{de}
	35-44	77.93 ^b	17.61 ^b
	45-55	83.73 ^a	18.15 ^b
Kellacho	25-34	58.06 ^e	14.45 ^e
	35-44	63.33 ^d	16.25 ^d
	45-55	69.93 ^c	15.85 ^{de}
LSD(0.05)		3.01	0.53
CV%		4.21	3.13

Means followed by the same letter (s) within a column are not significantly different at 5 % level of significance. LSD = least significant difference, CV = coefficient of variation.

Table 3. Stem number, Leaf number, Stem density and Leaf area index as influenced by variety and seed tuber size.

Varieties	Stem number (hill ⁻¹)	Leaf Number (hill ⁻¹)	Leaf area index (hill ⁻¹)	Stem density (m ⁻²)
Jalene	6.87 ^b	471.47	3.60 ^a	25.45 ^a
Gudenie	7.73 ^a	479.62	3.68 ^a	25.30 ^a
Kellacho	5.93 ^c	460.78	3.18 ^b	23.48 ^b
LSD(0.05)	0.51	NS	0.27	1.32
Tuber size (mm)				
46-55	7.65 ^a	491.13 ^a	3.83 ^a	26.62 ^a
35-45	7.01 ^b	480.51 ^a	3.60 ^a	25.02 ^b
25-34	5.87 ^c	440.22 ^b	3.03 ^b	22.60 ^c
LSD(0.05)	0.51	26.76	0.27	1.32
CV%	7.35	5.53	7.64	5.19

Means followed by the same letter (s) within a column are not significantly different at 5% level significance. LSD = least significant difference, CV = coefficient of variation.

showed that use of large seed tuber size (46-55 mm) gave maximum stem number per hill. Whereas, using small seed tuber size (25-34 mm) resulted in only a limited stem number per hill. The general trend indicated by these data is that as the tuber seed size increased the number of stems per plant also increased.

Leaf area index

The analysis of variance showed that two main factors the seed tuber size and varieties had a highly significantly ($P < 0.01$) effect on leaf area index. However, the interaction did not influence this parameter. Local variety (Kellacho) had the minimum leaf area index per hill as

compared to the Gudenie and Jalene varieties (Table 3). Jalene and Gudenie varieties had similar leaf area index values. With regard to seed tuber size, smaller tuber size (25-34 mm) produced the lowest leaf area index compared to large (46-55 mm) and medium (35-45 mm) sized seed tubers. However, use of larger (46-55 mm) and medium (35-45 mm) seed tuber sizes resulted in maximum leaf area index values and their effect was similar (Table 3).

Leaf number per hill

The analysis of variance showed that seed tuber size had a highly significant ($P < 0.01$) effect on leaf number.

Table 4. Total and unmarketable tuber yield as affected by variety and seed tuber size.

Varieties	Total tuber yield (t ha ⁻¹)	Unmarketable tuber yield (t ha ⁻¹)
Jalene	45.32 ^a	6.29 ^b
Gudenie	48.79 ^a	6.07 ^b
Kellacho	38.96 ^b	8.59 ^a
LSD(0.05)	5.38	0.98
Tuber size (mm)		
46-55	49.52 ^a	5.75 ^c
35-45	45.62 ^a	6.79 ^b
25-34	37.93 ^b	8.41 ^a
LSD(0.05)	5.38	0.98
CV%	11.82	13.72

Means followed by the same letter (s) within a column are not significantly different at 5% level significance. LSD = least significant difference, CV = Coefficient of variation.

However, varieties and the interaction did not significantly influence leaf number. Smaller tuber size (25-34 mm) resulted in the lowest leaf number per hill compared to larger (46-55 mm) and medium (35-45 mm) seed tuber sizes. Larger (46-55 mm) and medium (35-45 mm) seed tuber sizes gave similar leaf numbers per hill (Table 3). Thus, increasing seed tuber size from 25-34 to 46-55 mm resulted in the production of maximum leaf number per hill.

Stem density

The analysis of variance revealed that varieties and seed tuber size were highly significant ($P < 0.01$) in effects on stem density. However, the interaction did not significantly affect stem density. Local variety (kellacho) produced minimum stem density or number of stem population per meter square whereas improved varieties (Gudenie and Jalene) produced the maximum stem density or number of stem population per meter square (Table 3). Seed tuber size significantly affected stem density such that the maximum stem densities were recorded from larger seed tuber size (46-55 mm), while the minimum stem densities were recorded from smallest seed tuber size (25-34 mm).

Yield and yield components

Total tuber yield

The analysis of variance showed that seed tuber size and varieties had a very highly significant ($P < 0.001$) influence on total tubers yield in tonnes per hectare. However, the interaction did not to influence the total tuber yield produced in tonnes per hectare (Table 1). The improved varieties (Gudenie and Jalene) produced the higher total tuber yield than local variety (Kellacho). Gudeine and Jalene varieties gave similar total tuber yield ton per

hectare (Table 4). With regard to seed tuber size, medium to large sizes resulted in higher total tuber yield than the small tuber size (25-34mm) (Table 4).

Unmarketable tuber yield

The analysis of variance revealed that seed tuber size and varieties had highly significantly ($P < 0.01$) effects on unmarketable tuber yield per hectare. However, there were no significant interaction effects. Local variety (Kellacho) produced maximum unmarketable tuber yield compared to the improved (Gudenie and Jalene) varieties. And both improved varieties were similar in producing unmarketable tuber yield (Table 4). With regard to seed tuber size, seed tuber size significantly affected unmarketable tuber yield. The maximum unmarketable tuber yields were recorded from smaller seed tuber size (25-34 mm), while the minimum unmarketable tuber yields were recorded from larger seed tuber size (46-55 mm) (Table 4).

Number of tubers per plant

The analysis of variance results showed that the interaction between seed tuber size and varieties was highly significantly ($P < 0.01$) affect number of tubers per plant (Table 5). Gudenie variety produced the highest number of tubers per plant when planted from large seed tuber size (46-55 mm). While minimum number of tubers per plant were produced when Kellacho variety was planted using small seed tuber size (25-34 mm) (Table 5).

Harvest index

The analysis of variance showed that the interaction of

Table 5. The interaction effect of variety and seed tuber size on number of tuber per plant and harvest index of potato at Agarfa during 2017 cropping season.

Varieties	Tuber size (mm)	Number of tubers (plant ⁻¹)	Harvest index
Jalene	25-34	14.73 ^d	0.246 ^{ab}
	35-44	17.26 ^c	0.197 ^c
	45-55	18.23 ^b	0.182 ^{cd}
Gudenie	25-34	14.75 ^d	0.256 ^a
	35-44	17.23 ^c	0.191 ^c
	45-55	21.20 ^a	0.218 ^b
Kellacho	25-34	13.78 ^e	0.223 ^b
	35-44	16.73 ^c	0.220 ^b
	45-55	16.01 ^{cd}	0.193 ^{cd}
LSD(0.05)		0.76	0.012
CV%		4.49	5.88

Means followed by the same letter within a column are not significantly different at the 5% level of significance. LSD = Least significant difference and CV = coefficient of variation.

two main factors such as tuber size and varieties factors highly significantly ($P < 0.01$) affected the harvest index values (Table 2). The interaction of Gudenie and Jalene varieties with small seed tuber size (25-34 mm) produced numerically highest harvest index values; whereas, Jalene variety with large seed tuber size (46-55 mm) produced numerically the lowest harvest index value (Table 5).

Shoot fresh weight

The analysis of variance result showed that seed tuber size highly significant ($P < 0.001$) affected shoot fresh weight; and variety significantly ($P < 0.05$) affected shoot fresh weight. However, the two main factor interaction did not significantly influence shoot fresh weight. Gudenie variety produced the numerically maximum shoot fresh weight; whereas, Jalene and Kellacho varieties produced minimum shoot fresh weight, but the difference was not statistically significant (Table 6). The results also showed that improved Gudenie variety recorded the highest vegetative growth compared to the other varieties.

Seed tuber size significantly affected shoot fresh weight per hectare. Medium to large seed tuber size resulted in larger shoot fresh weight. Whereas, small seed tuber size (25-34 mm) attributed to only a small fresh weight. Medium seed tuber size (35-45 mm) had a similar impact as the larger seed tuber size (46-55 mm) on production of shoot fresh weight (Table 6).

Shoot dry weight

The analysis of variance revealed that the main factors

had a highly significant ($P < 0.01$) influence on shoot dry weight. However, the interaction did not significantly influence this parameter. Kellacho variety produced the minimum shoot dry weight per hectare compared to Gudenie and Jalene varieties. The Gudenie and Jalene varieties produced maximum shoot dry weight per hectare (Table 6).

Seed tuber size significantly influenced shoot dry weight per hectare. The maximum shoot dry weights were recorded from larger seed tuber size (46-55 mm), while the minimum shoot dry weight were recorded from the smaller seed tuber size (25-34 mm) (Table 6). The use of medium seed tuber size as a planting materials showed a statistically significant effect in producing shoot dry weight.

Underground fresh weight

Seed tuber size and varieties had highly significant ($P < 0.01$) effects on underground fresh weight (Table 1). However, the interaction factors of two factors did not affect underground fresh weight. The highest underground fresh weights were recorded from Gudenie and Jalene varieties compared to the local variety (kellacho). Kellacho variety produced the lowest underground fresh weight. Gudenie and Jalene had similar underground fresh weights (Table 6). The lowest underground fresh weight (tonnes per hectare) was recorded from small seed tuber size (25-34 mm). Larger and medium seed tuber size produced the highest underground fresh weight. Medium seed tuber size (35-45 mm) had a similar impact as the larger seed tuber size (46-55 mm) on producing underground fresh weight (Table 6).

Table 6. Shoot fresh weight, Shoot dry weight, Underground fresh weight and Underground dry weight of potato as affected by variety and seed tuber.

Variety	Shoot fresh weight (t ha ⁻¹)	Shoot dry weight (t ha ⁻¹)	Underground fresh weight (t ha ⁻¹)	Underground dry weight (t ha ⁻¹)
Jalene	0.36 ^b	0.093 ^a	1.05 ^a	0.18
Gudenie	0.46 ^a	0.089 ^a	1.10 ^a	0.19
Kellacho	0.41 ^{ab}	0.077 ^b	0.95 ^b	0.17
LSD(0.05)	0.065	0.0066	0.081	NS
Tuber size (mm)				
46-55	0.43 ^a	0.096 ^a	1.11 ^a	0.20 ^a
35-45	0.46 ^a	0.089 ^b	1.08 ^a	0.19 ^a
25-34	0.34 ^b	0.074 ^c	0.91 ^b	0.15 ^b
LSD(0.05)	0.065	0.0066	0.08	0.021
CV%	15.4	7.36	7.64	11.32

Means followed by the same letter within a column are not significantly different at the 5% level of significance. LSD =Least significant difference and CV = coefficient of variation.

Table 7. Marketable tuber yield (t ha-1), Small, Medium and Large size as influenced by varieties and seed tuber size.

Varieties	Marketable tuber yield (t ha ⁻¹)	Small size weight (%)	Medium size weight (%)	Large size weight (%)
Jalene	39.03 ^a	18.67 ^b	34.65	46.67 ^{ab}
Gudenie	42.38 ^a	21.68 ^a	34.3	44.01 ^b
Kellacho	28.48 ^b	17.05 ^b	35.19	47.76 ^a
LSD(0.05)	3.82	2.32	NS	2.73
Tuber size(mm)				
46-55	43.32 ^a	18.78	35.32	45.89
35-45	38.05 ^b	20.34	34.26	45.39
25-34	28.52 ^c	18.28	34.56	47.15
LSD(0.05)	3.82	NS	NS	NS
CV%	10.17	11.84	5.12	5.77

Means followed by the same letter within a column are not significantly different at the 5% level of significance. LSD = Least significant difference and CV = coefficient of variation.

Underground dry weight

Seed tuber size had a highly significant ($P < 0.01$) effect on underground dry weight. However, varieties and the interaction of two factors did not significantly affect underground dry weight. The larger and medium seed tuber size produced the highest underground dry weight; whereas, the lowest underground dry weight were recorded from small seed tuber size (25-34 mm) (Table 6).

Quality parameters

Marketable tuber yield

The analysis of variance results showed that seed tuber

size and varieties had a highly significant ($P < 0.001$) effect on marketable tubers yield (tonnes per hectare). However, the two factors interaction was not statistically significant. Improved varieties (Gudenie and Jalene) produced higher marketable tuber yield as compared to the local variety (Table 7). The large seed tuber size (46-55 mm) scored highest marketable tuber yield; whereas, the small seed tuber size (25-34 mm) scored the lowest marketable tuber yield (Table 7).

Tuber size distribution

The analysis of variance showed that variety had a significant ($P < 0.05$) effect on small and large tuber size parameters. However, seed tuber size had no significant effects for the overall tuber size distribution. Variety had a

Table 8. The interaction effect of varieties and seed tuber size on dry matter concentration of potato varieties at Agarfa during 2017 cropping season.

Varieties	Tuber size(mm)	Dry matter concentration (%)
Jalene	25-34	27.31 ^b
	35-45	26.01 ^b
	46-55	25.70 ^{bc}
Gudeine	25-34	26.05 ^{bc}
	35-45	25.93 ^{bc}
	46-55	31.26 ^a
Kellacho	25-34	22.83 ^c
	35-45	25.26 ^{bc}
	46-55	23.56 ^c
LSD(0.05)		1.69
CV%		6.35

Means followed by the same letter within a column are not significantly different at the 5% level of significance. LSD (5%) = Least significant difference and CV (%) = coefficient of variation (%).

significant difference in response to tuber size. Gudenie produced the highest small size tuber whereas Jalene and Kellacho (local variety) produced the lowest small sized tuber weight (Table 8). Local variety produced a larger proportion of the large sized tuber weight compared to Gudenie (Table 7). Gudenie variety produced the highest proportion of small size tubers due to the fact that it produced a larger number of tubers per plant. Although Gudenie produced a larger proportion of small tubers and a lower proportion of large tubers, the variety also had highest marketable yield that still makes it preferable.

Tuber dry matter concentration (%)

The analysis of variance showed that interaction of varieties and seed tuber size had a highly significant ($P < 0.01$) effect on tuber dry matter concentration. Gudenie variety with large seed tuber size (46-55 mm) produced the highest tuber dry matter concentration. Potato varieties grown from large (46-55 mm), medium (35-45 mm) and small (25-34 mm) seed tuber sizes across three varieties produced a similar response for tuber dry matter concentration, except Gudenie variety with large seed tuber size (Table 8). However, numerically Kellacho variety with small tuber size produced the lowest dry matter concentration.

Conclusion

The results of this experiment revealed that planting any of the two improved varieties (Jalene and Gudenie), using any of large (46-55 mm) or medium (35-45 mm)

seed tuber sizes resulted in the highest total tuber yield of potato. Similar results were also observed for marketable tuber yield, with the exceptions that large seed tuber size resulted in better results. Therefore, it is wise to advice for farmers in the study area, and areas having similar agro-ecology, to use improved varieties Gudenie and/or Jalene with medium to large seed tuber sizes so as to boost the yield and quality of the potato crop.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Asefa G (2015). Genetic variability for yield, yield related traits and reaction to late blight in potato (*Solanum tuberosum* L.) genotypes at Sinana, South Eastern Ethiopia. M.Sc Thesis Submitted to the School of Plant Sciences, Haramaya University.
- Asfaw F (2016). Effect of integrated soil amendment practices on growth and seed tuber yield of potato (*Solanum tuberosum* L.) at Jimma Arjo, Western Ethiopia. *Journal of Natural Sciences Research* 6(15):38-63.
- Ayalew T (2014). Analysis of Seed Potato (*Solanum tuberosum* L.) with special focus in Ethiopia. *Asian Journal of Agricultural Research* pp. 1819-1894.
- Ayalew T, Paul CS, Adane H (2014). Characterization of seed potato (*Solanum tuberosum* L.) storage, pre-planting treatment and marketing systems in Ethiopia: The case of West-Arsi Zone. *African Journal of Agricultural Research* 9(15):1218-1226.
- Bilate B, Mulualem T (2016). Performance evaluation of released and farmers' potato (*Solanum tuberosum* L.) varieties in Eastern Ethiopia. *Sky Journal of Agricultural Research* 5(2):034-041.
- Birch PRJ, Bryan G, Fenton B, Gilroy E, Hein I, Jones JT, Prashar A, Taylor MA, Torrance L, Toth IK (2012). Crops that feed the world. Potato are the trends of increased global production sustainable? *Food Security* 4:477-508.
- Central Statistical Agency (CSA) (2014). Agricultural sample survey

- 2013/2014. Volume I Report on area and production of crops Addis Ababa, Ethiopia.
- De Jong H, Joseph BS, De Jong W (2011). The complete book of potatoes what every grower and gardener needs to know. pp.11. http://www.timberpress.com/books/complete_book_potatoes/de_jong/9780881929997
- Djilani GA, Senoussi M (2013). Influence of organic manure on the vegetative growth and tuber production of potato (*Solanum tuberosum* L var spunta) in a Sahara desert region. Algeria, International Journal of Agriculture and Crop Sciences 5(22):2724-2731.
- Ethiopian Agricultural Research Organization (EARO) (2004). Directory of released crop varieties and their recommended cultural practices. Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia pp. 1-36.
- Food and Agriculture Organization data of statistics (FAOSTAT) (2014). One hundred fifty eight countries data base.
- Food and Agriculture Organization data of statistics (FAOSTAT) (2008). Food and Agriculture Organization data of statistics. One hundred fifty eight countries data base.
- Gedif M, Yigzaw D, Tsige G (2013). Genotype-environment interaction and correlation of some stability parameters of total starch yield in potato in Amhara Region, Ethiopia. Journal of Horticulture, Forestry and Biotechnology 17(4):56-64.
- Hancock RD, Morris WL, Ducreux LJM, Morris JA, Usman M, Verrall SR, Fuller J, Simpson CG, Zhang R, Hedley PE, Taylor MA (2014). Physiological, biochemical and molecular responses of the potato (*Solanum tuberosum* L.) plant to moderately elevated temperature. Plant Cell Environment 37:439-450.
- International Potato Center (CIP) (2006). Procedures for standard evaluation trials of advanced potato clones. An International Cooperators' Guide. Peru, Lima P 124.
- Menza M, Girmay G, Woldeyes F (2014). Enhancing household food security through irish potato production in Gamo Highlands of Southern Ethiopia. Scholarly Journal of Agricultural Science 4(7):410-419.
- Tebabal T (2014). The impact of international potato center's nutrition project on smallholder farmers' income and adoption of improved potato varieties, Tigray region, Northern Ethiopia. <https://opendocs.ids.ac.uk/opendocs/handle/123456789/4465>
- Tesfaye A, Githiri M, Tolessa D (2011). Subsistence farmers' experience and perception about the soil, and fertilizer use in Western Ethiopia. Journal of Applied Science 2(2):61-74.
- William MA, Woodbury GW (1968). Specific gravity dry matter relationship and reducing sugar change affected by potato cultivar, production area and storage. American Potato Journal 45(4):119-131.

Related Journals:

