REVIEW ARTICLE Agricultural Reviews, Volume 41 Issue 2: 139-145 (June 2020)

Memoir and Farming Structures under Soil-Less Culture (Hydroponic Farming) and the Applicability for Africa: A Review

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10.18805/ag.R-137

ABSTRACT

Agriculture is the economic back-borne of majority of developing countries worldwide. The sector employs over 50% of the working population and contributes about 33% of the Gross Domestic Product (GDP) in majority of African states. However, such contribution by the agricultural sector is likely to be affected by climate change, increasing human population and urbanization which impact on available agricultural land in various ways. There is thus an urgent need for developing countries to create or adopt technologies such as; soil-less farming that will not only address climate change challenges but also enhance crop production for improved food security. This paper reviews the science, origin, dynamics and farming systems under the soil-less agriculture precisely hydroponic farming to assist in widening the scope of knowledge of the hydroponic technologies and their implementation in Africa.

Key words: Hydro culture, Hydroponic lighting conditions, Hydroponic nutrients, Types of hydroponic farming.

The United Nations Population Fund (UNPF, 2007) estimated that the world population will increase by 72% in 2050 and reach 9.2 billion people. This growth in population will lead to increased urbanization in the least developed countries (LDCs), where the population is projected to grow from 2.7 to 5.1 billion people. This growth will create increasing demand for food to humans to levels that remain anonymous globally. For instance, in 2011, the United Nations Food and Agriculture Organization (UNFAO, 2011) noted that the demand for food, especially ensuring sufficient, timely and cost-effective food supply that can meet the need of the increasing population is a critical challenge that the world currently faces. As a way forward, different crop productions have been developed and are practiced across the world. For example, Yeh and Chung (2009) indicated that people in urban areas have embarked on indoor crop production in order to meet the rising food needs. One of the fastest growing indoor farming systems that has been reported to attract many urban dwellers is use of soil-less culture commonly known as; hydroponic farming.

The science of hydroponic farming

Hydroponics also known as: "*Hydro culture*", "*Nutri-culture*", "*soil-less culture*", "*soil-less agriculture", "water culture" "tank farming"* or *"chemical culture*" (Lakkireddy *et al.*, 2012) is an agricultural science, which involves the cultivation of crops in a water-based solution rather than soil and this agri-system was substantiated by Jean Boussingault in 1860. The term "Hydro" generally refers to "water" while Ponics refers to "working (Rajkumar *et al.*, 2018). The water-based solution is composed of artificial chemical nutrients, which support crop growth (Steinberg *et al.*, 2000) and the crops can be cultivated with or without a medium which is used to provide support to the plant (Hanger, 1993; Jensen, 1999). The medium used include organic substances (Fig 1) such as; rock wool and inorganic materials such as; vermiculite, perlite, volcanic porous rock, expanded clay granules as well as synthetic materials (Gruda and Schnitzler, 2006; Lakkireddy *et al*., 2012). In addition to the varieties of medium used, there are also factors and characteristics that should be considered while selecting the medium for crop production (Table 1).

Due to its nature of being practiced in controlled environments, hydroponic farming can be practiced in countries with intense arid areas including Algeria, Eritrea, Tanzania, Ethiopia, Kenya, North and South Sudan and South Africa (Seawater Greenhouse Limited., 2010). Hydroponics has been used to grow a number of plants (Table 2).

The history of hydroponics and hydroponic nutrients

Hydroponic farming dates back to 1699 when scientist John Woodward started adopting water culture without using any concrete substance (Hewitt, 1966). Hershey recognized Woodward as the first individual-English Physician to

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How to cite this article: Gumisiriza, M.S., Ndakidemi, P.A. and Mbega, E.R. (2020). Memoir and Farming Structures under Soil-Less Culture (Hydroponic Farming) and the Applicability for Africa: A Review. Agricultural Reviews. 41(2): 139-145.

Submitted: 24-01-2020 **Accepted:** 16-04-2020 **Published:** 25-06-2020

practice water culture in 1699 after Woodward researched on Helmont's theory which stated that plant components are exclusively formed out of water (Hershey, 1991). After Woodward's discovery, other scientists namely Boussingault, De Saussure and Wilhem Knop carried out research and identified the nutrients that supported plant growth and Knop's hydroponic nutrient composition was the most famous (Table 3) which had been used for a number of years worldwide under soil-less culture (Benton, 1982).

Later on, a modified hydroponic nutrients composition (Table 4) necessary for plant growth was discovered during the mid-1900s' (Russell, 1953).

Plant pathologist Fredrick. W. Gericke from the University of California finally popularized the hydroponic system in the 1930s' (Gericke, 1937). He initially named this system aquiculture but later re-named it hydroponics because aquiculture mainly involved growing of aquatic plants. According to Anon (1940), hydroponics was first successfully practiced on the Wake Island in the 1930s with the growth of fresh vegetables since it was the only solution for vegetable production on the Island. Later on in the 1960s and 70s, commercial hydroponic farms were established in different countries, that is: Italy, Denmark, Russia, Holland, German, Iran, United Arab Emirates, Japan, United States of America, Belgium etc after which many automated farms were established worldwide in the 1980s followed popularization of home-made systems in 1990s (Mamta and Shraddha, 2013).

Much as hydroponics was initially developed mainly to cater for the production of fresh produce in the non-arable areas of the world (Murali *et al.*, 2011), some congested cities such as; New York in the United States of America (USA) and Montreal in Canada, have advanced the technology to the extent that it can be easily performed on apartment rooftops (Fahey, 2012). This is a form of hydroponics called "vertical farming", that is; growth of crops on vertically inclined planes or on skyscrapers (Despommier, 2011). Developed countries such as; The Netherlands have already benefited from hydroponics, in terms of increased crop quality and yield (Stoner and Clawson, 1995).

In Africa, hydroponic farming has been reported in South Africa for production of high-quality vegetables (Baumgartner and Belevi, 2001; Gruda, 2009). Recently, in the 2000s, farmers in East Africa, Kenya, Tanzania and Uganda have adopted the technology mainly for fodder (barley) and vegetable (spinach, lettuce, etc.) production on a small scale (Kibiti and Gitonga, 2017; Naluyima, 2015).

Types of hydroponic farming

Wick system

This system also known as passive technique uses a wick to draw the required nutrients from the tank into the growing medium. Much as it is the simplest and inexpensive system, it is more suitable for small plants which do not require a lot of nutrients since the wicks do not offer quick supply of the nutrients (Keith, 2003).

Ebb and Flow (Flood and Drain)

This is a system which works by flooding the plant tray with the nutrient solution using a pump connected to the solution pool at given time intervals with the use of a timer. The solution is then drained back to the nutrient storage tank or vessel.

Table 1: Factors to consider when selecting media for crop production.

Characteristics	Factors for consideration
Stable structure	Type of hydroponics adopted
Low volume weight	Access to information on properties of the medium
No pests and diseases	Cost of the medium
Right PH suitable for the crop	Re-usability
Good rehydration properties	

Source: (FAO, 2013).

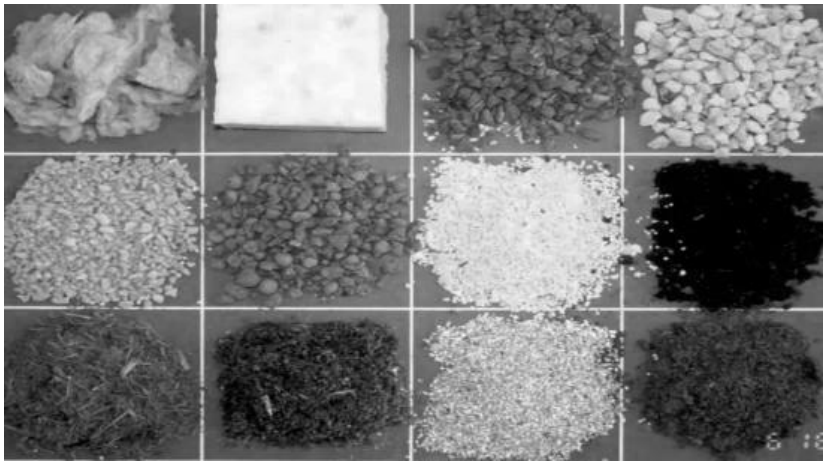

Fig 1: Substances used as growing media; Left to right and top to bottom: rock wool, polyurethane foam, expanded shale, volcanic material, open porous clay granulate, expanded clay, perlite, black peat, coarse wood fibre, fine wood fibre, vermiculite and light peat. Source: (FAO, 2013).

Table 2: A Selection of plants that can be produced commercially using soil-less culture.

Herbs	Fruits	Vegetables	Flowers	Fodder
Hiercium pilosella	Cantaloupes	Tomatoes, Peppermint	Roses	Sorghum
Anethum gravel	Watermelon	Green pepper	Marigold	Alfalfa
Hypericum	Strawberries	Peas, coriander	Carnations	Barley
Aloe vera,chives		Lettuce, squash		Bermuda grass
Ocimum basilium, Hypericum perforatum		Cabbage, salad greens, Spinach		Carpet grass

Source: (Murali *et al.*, 2011; Puri and Caplow, 2009; Sardare and Admane, 2013).

Table 3: Components of Knops' nutrient solution.

Component	g/l
Potassium Nitrate (KNO_3)	0.2
Calcium Nitrate $Ca(NO_3)_2$	0.8
Potassium dihydrogen phosphate (KH_2PO_4)	0.2
Magnesium sulfate heptahydrate ($MgSO_4.7H_2O$)	0.2
Ferric Phosphate ($FeP0_4$)	0.1

Source: (Knop, 1865; Lakkireddy *et al.*, 2012).

Nutrient film technique (NFT)

With this technique developed by Allen Cooper in the 1960s', channels/tubes where the plant roots are immersed are used to constantly supply them with water rich in dissolved nutrients required for plant growth without a timer (Wilcox, 1982). It has an advantage of the exposing the plant roots to sufficient supplies of nutrients, oxygen and water and doesn't require a timer (Omics, 2017).

Aeroponic Hydroponic System

This method doesn't require any growing medium for crop production (Runia, 1995). The nutrients and moisture are supplied to the plant roots suspended in air in form of mist with the use of a pump that is timed. The timer ensures that after every few minutes, mist is released. The disadvantage with this system is that any interference with the pump can lead to drying of the plant roots (Murali *et al.*, 2011).

Deep water culture (Direct Water Culture)

Under this system, the plants are put in baskets/net cups and roots are suspended directly in a highly oxygenated nutrient solution. The plants are able to survive because of addition of dissolved energy (Sandlers, 2016). It is easy to construct and operate (Railey, 2018).

Source of lighting under hydroponic farming

LED (Light Emitting Diodes) lighting

LED lights were first identified as a source of light for indoor agriculture (Robert, 2008) that is practiced under controlled environments (Yano and Fujiwara, 2012) in 1980s'. They were invented by Engineer Henry Joseph Round in 1907 (González, 2012). A LED is a semi-conductor source of light which has capability of converting electricity to light when an electric current (electrons) is applied (Shaw *et al.*, 2004).

Studies have revealed that LED lights offer a high source of visible radiation (Bula *et al.,* 1991) for cultivating agronomic and horticulture crops indoors especially with the use of white, blue or red-blue LED lights (Brown *et al.*, 1995; Duong *et al.,* 2002; Kurilcik *et al.,* 2008; Yanagi and Okamoto, 1997). Red and blue light play a key role during plant development, photosynthesis and physiology (Kopsell and Sams, 2013; Olle and Virsile, 2013).

For example, the quality of blue light can be used to control plant shape, height and influence photosynthesis (Cope and Bugbee, 2013). LED systems have been reported to have minimal red radiation, which affects flowering time for short day crop species (Craig and Runkle, 2013). Results from a study by Sabzalian *et al.* (2014) indicated that plants grown under LED lighting exhibited better flowering and productivity than those grown in a greenhouse.

They further highlighted that blue and red wavelengths play a role in controlling the closure and opening of the stomata, which affects the height and size of the plant as also indicated by Folta *et al.* (2007). An experimental study carried out by Tehrani *et al.* (2016) further revealed that 2 hours of red light resulted into maximum germination (83%) as compared to 8 hours of blue light (59%). None the less, blue light further plays a role in stimulating; Vitamin C;

Table 4: A modified list of elements of the current hydroponic solution.

Macro elements		Micro elements	
Element	Researcher and year of discovery	Element	Researcher and year of discovery
Nitrogen	Not known -1750	Boron	Sommer, A.L- year not known
Phosphorus	Liebig -1839	Chlorine	Broyer, Carlton, Johnson and Stout-1954
Potassium	Birner and Lucanus -1866	Copper	Sommer, A.L -1931
Calcium	Knop-1860	Iron	Gris -1843
Magnesium	Not-known-1860	Manganese	Gabriel Bertrand -1897
Sulphur	Knop-1860	Molybdenum	Broyer Carlton, Johnson and Stout – year not known
		Zinc	Sommer, A.L.- 1927

Source: (Russell, 1953).

polyphenol and carotenoid components (JohnKhan *et al*., 2010; Lefsrud *et al*., 2008). On the contrary, green LED light has the potential to drive photosynthesis (Folta *et al*., 2007; Kang *et al*., 2013).

LED lights have benefits of; having a long-life span; providing ideal light spectrum for growth of crops/plants (Murali *et al.,* 2011); producing limited heating compared to high- intensity light sources (Bula *et al.,* 1991); and producing quality yield among vegetables (Demers *et al.*, 1998; Hao and Papadopoulos, 1999). Nevertheless, they have a drawback of being costly compared to other lightening systems such as; High-Pressure Sodium (HPS) (Nelson and Bugbee, 2014).

However, Scientist Robert (2008) highlighted LED lights as having the potential of being cost-effective in the long-run due to their long-life span as compared to other horticultural lamps. Likewise, according to Haitz law, LED light costs have dropped by a factor of 10 each decade as their performance keeps doubling (Steigerwald *et al*., 2002).

Hydroponic farming under solar lighting

This hydroponic farming system can take place either indoors or under a green house. The green house can be set up outside or on top of mixed-use buildings to maximize interactions between building environments and agriculture-like energy (Caplow, 2009). Indoor farms are further divided into; store front glasshouses (double skin building) and leveled indoor farms (Specht *et al.*, 2013) which majorly favor shade-tolerant plants (Brock, 2008). These indoor growth systems use the natural energy from the sun instead of LED lights for food production and are thus more eco-friendly and energy-efficient. This necessitates access to a window in order to access solar energy (Brooke, 2016).

High-pressure vapor sodium (HPS) lamps are also used as a lighting source in greenhouse production because of their high efficiency besides offering a suitable light spectrum required for photosynthesis (Christina, 2011). Greenhouse hydroponics is categorized under urban agriculture because it assimilates environmental and urban economics especially in the growth of horticultural crops (Mougeot, 2008; Pearson. *et al*., 2010). Farmers can also cultivate high-quality vegetables (Gruda, 2009) and flowers with solar powered hydroponics.

Soil-less culture vs. Soil culture

Hydroponics, when compared to soil culture systems has been considered superior in terms of plant nutritional balance in its composition and other attributes (Table 5).

Advantages of hydroponic farming

Hydroponic farmers are not affected by climate change conditions since they have control over climatic conditions such as; humidity, temperature, light among others (James *et al*., 2000). This enables them to have all year round food production thus increasing their profit margin (Max, 2017). Since it is a soil-less farming system, there are no soil-borne diseases and pests under this technology (Mamta and Shraddha, 2013). It's a farming system that reduces labor demands since it doesn't require weeding, fumigating pests (Graff, 2009) or cultivating the land in preparation for planting (Max, 2017). Studies have shown that hydroponic farming system has the potential of removing atmospheric carbon dioxide (Park *et al*., 2010). This air which is produced through human respiration and Volatile organic compounds (VOCs) heavily contaminates indoor surroundings (Aydogan and Montoya, 2011; Kim *et al*., 2008; Oh *et al*., 2011). Carbon dioxide is a narcotic (Milton *et al*., 2000) which has been associated with decline in student academic performance and work performance when increased in circulation (Seppänen *et al*., 2006; Shaughnessy *et al.,* 2006).

As earlier noted, the technology was first developed for non-arable areas thus it is a favorable technology for regions without soil or areas without fertile land (Sonneveld, 2000). In Uganda and Kenya, hydroponic gardening has been reported to be consistent with fodder production mechanism (Naluyima, 2015).

However, it is important to note that hydroponics has a limitation of necessitating careful observation of the system

Table 5: Differences between soilless and soil culture farming systems.

Soil-less culture (Hydroponics)	Soil culture (Geoponics)
Fertilizer formulations contain balanced nutrient composition.	The nutrient composition may be unbalanced unless laboratory analysis is done.
Availability of nutrients all the time	Requires nutrient supply to the crop
Automatic irrigation of plants	Requires consistent crop irrigation
Produces high and consistent yields	Yields vary with environmental conditions
Requires no soil	Requires good disease free topsoil with good drainage
Eliminates soil-borne diseases	Soil diseases can develop in the soil
Produce is non-organic since artificial nutrients are used under soilless conditions	Use of organic fertilizers such as manure can result in production of organic crops
Farming can take place in areas without soil for instance; snow covered areas	Requires good soils to produce good yields
There is full control of the root system since it can be seen	Root system can't be controlled since its hidden underground
It can have automatic fertilizing of crops/plants with the use of a timer	Crops are fertilized manually
Requires no wedding	Necessitates weeding

Source: (Department of Agriculture Forestry and Fisheries, 2011; Murali *et al*., 2011) .

as it does not offer opportunity for making rapid changes (Singh and Singh, 2012). The system also requires heavy financial capital and adequate knowledge to effectively implement (Sonneveld, 2000).

The prospect of hydroponic faming in Africa

There is already a plea from the scientific community for the potential of application of hydroponic farming technology in Low developed countries which are faced with water scarcity challenges (Butler and Oebker, 2006). The current food insecurity challenges presented by climate change coupled with inadequate access to healthy foods in urban centers (Alkon and Norgaard, 2009) call for strategic research and studies that could help fast track the adaptation of hydroponic farming systems in African countries. Hydroponics has the capacity to feed huge numbers of people in Africa where there is a scarcity of water and crops (Kibiti and Gitonga, 2017). The urgent need for hydroponic-based urban farming is further motivated by the assertion that 70% of the world's population will live in urban areas by 2050 (Walsh, 2009). However, the initial costs of setting up the technology still remain a barrier to its implementation (Mamta and Shraddha, 2013).

CONCLUSION

Climate change continues to impact on Africa's major economic sector (agriculture) which also accounts for food security and sustainable development. The issue of climate change impacts is coupled with population increase and the high rates of rural-urban migration both which reduce the available arable land. These challenges call for interventions that will make African states continue to produce food that can meet the demands of the growing population while being tolerant to the changing climate. This entails the intervention of the research community and policy makers to devise solutions that address some of the challenges that are hindering adoption of the technology in Africa for instance; high costs of inputs, limited technical knowledge among farmers, lack of equipment among others. The adoption of the technology in some of the African countries already shows promising results.

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