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

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ABSTRACT
Agriculture is the economic back-bone 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
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).

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**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 (KNO₃)                | 0.2 |
| Calcium Nitrate Ca(NO₃)₂                 | 0.8 |
| Potassium dihydrogen phosphate (KH₂PO₄)| 0.2 |
| Magnesium sulfate heptahydrate (MgSO₄·7H₂O) | 0.2 |
| Ferric Phosphate (FePO₄)                | 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; Kurilick 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; Ole 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.

| 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 lighting 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 Haizt 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 Shradha, 2013). It’s a farming system that reduces labor demands since it doesn’t require weeding, fumigating pests (Graft, 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 regions 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 farming 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.

REFERENCES

Alkon, H.A. and Norgaard, K.M. (2009). Breaking the food chains: An investigation of food justice activism. Sociological Inquiry. 79(3): 289-305.

Anonymous (1940). Hydroponics- a novel alternative for geoponic cultivation of medicinal plants and food crops. What’s become of hydroponics? pp. 38-39.

Aydogan, A. and Montoya, L.D. (2011). Formaldehyde removal by common indoor plant species and various growing media. Atmospheric Environment. 45(16): 2675-2682.

Baumgartner, B. and Belevi, H. (2001). A systematic overview of urban agriculture in developing countries. EAWAG/SANDEC, Dübendorf.

Benton, J. (1982). Hydroponics: Its history and use in plant nutrition studies. Journal of Plant Nutrition. 5(8): 1003-1030.

Brock, A. (2008). Room to grow: Participatory landscapes and urban agriculture at NYU. New York University, New York.

Brooke, N. (2016). Solar powered agric could be the future of agriculture.

Brown, C.S., Schuering, A.C. and Sager, J.C. (1995). Growth and morphomorphogenesis of pepper plants under red light emitting diodes with supplemental blue or far-red lighting. Journal of the American Society for Horticultural Science. 120(5): 808-813.

Bula, R.J. et al (1991). Light-emitting diodes as a radiation source for plants. Horticulture Science. 26(2): 203-205.

Butler, J.D. and Oebker, N.F. (2006). Hydroponics as a hobby: growing plants without soil. Circular. 884.

Caplow, T. (2009). Building integrated agriculture: Philosophy and practice. Urban futures 2030: Urban development and urban lifestyles of the future. Heinrich Boill Foundation, Berlin,Germany.

Christina, S. (2011). Effects of lighting time and lighting source on growth, yield and quality of greenhouse sweet pepper.

Cope, K. and Bugbee, B. (2013). Spectral effects of three types of white light-emitting diodes on plant growth and development: absolute versus relative amounts of blue light. Horticulture Science. 48(4): 504-509.

Craig, D.S. and Runkle, E.S. (2013). A moderate to high red to far-red light ratio from light-emitting diodes controls flowering of short-day plants. Journal of American Society of Horticulture Science. 138(3): 167-172.

Demers, Dorais.M., Wien. H. and Gosselin. A. (1998). Effects of supplemental light duration on greenhouse tomato (Lycopersicon esculentum Mill.) plants and fruit yields. Journal of Horticultural Science. 74(4): 295-306.

Department of Agriculture Forestry and Fisheries, (2011). Hydroponic vegetable production, Republic of South Africa.

Despommier, D. (2011). The vertical farm: Controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. Journal of Consumer Protection and Food Safety. 6(2): 233-236.

Duong, N., Hong, A., Watanabe, H., Goh, M. and Tanaka. M. (2002). Growth of banana plantlets cultured in vitro under red and blue light-emitting diode (LED) irradiation source. Acta Horticulture. 575(10): 117-124.

Fahey, C. (2012). Rooftop hydroponic Agriculture.

FAO (2013). Good Agricultural Practices for greenhouse vegetable crops;Principles for Mediterranean climate areas., Food and Agriculture Organization of the united nations, Rome.

Folta, K.M., Deng, N. and Maruhiich, S.A. (2007). Green light: A signal to slow down or stop. Journal of Experimental Botany. 58(12): 3099-3111.

Gericke, W.F. (1937). Hydroponics- Crop production in liquid culture media. Science. 85(2198): 177-178.

González, E.G. (2012). LEDs for general and horticultural lighting, Aalto University, Finland, 64.

Graff, G. (2009). A greener revolution: An argument for vertical farming. Plan Canada. 49(2): 49-51.

Gruda, J. and Schnitzler, W.H. (2006). Wood fiber substrates as a
Hanger, B. (1993). Hydroponics: The Worlds Australian and South Pacific Islands Scene. A Guide for Growers.

Hao, X. and Papadopoulos, A. (1999). Effects of supplemental lighting and cover materials on growth, photosynthesis, biomass partitioning, early yield and quality of greenhouse cucumber. Horticultural Science. 80: 1-18.

Hershey, D.R. (1991). Digging deeper into Helmont's famous willow tree experiment. The American Biology Teacher. 53 (8): 458-460.

Hewitt, E.J. (1966). Sand and Water Culture Methods Used in the Study of Plant Nutrition., Commonwealth Agricultural Bureaux, Commonwealth Agricultural Bureaux.

James, L., Richard, S., Kenneth., K. and Gardner-Hughes (2000). Organic Disease Control Elicitors. Agro Food Industry Hi-Tech. 11(5): 32-34.

Jensen, M. (1999). Hydroponics Worldwide International Symposium on Growing Media and Hydroponics, Ontario, Canada, 719-729 pp.

JohnKhan, M., Shoji, Goto, F., Hahida, S. and Yoshihara, T. (2010). Blue light-emitting Diode light irradiation of of seedlings improves seedling quality and growth after transplanting in red leaf lettuce. Horticultural Science. 45: 1809-1814.

Kang, J.H., Krishnkumar, S., Atulba., S., Jeong, R. and Hwang, J. (2013). Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system. Horticulture Environmental Biotechnology. 54(6): 501-509.

Keith, R. (2003). How to hydroponics, 59. The Future garden press.

Kibiti, J.G. and Gitonga, A.K. (2017). Factors influencing adoption of urban hydroponic farming: A case of Meru town, Meru county, Kenya. International Academic Journal of Information Sciences and Project Management. 2(1): 541-557.

Kim, J. et al. (2008). Efficiency of volatile formaldehyde removal by indoor plants: Contribution of aerial plant parts versus the root zone. Journal of American Society of Horticultural Science. 133(4): 521-526.

Knop, W. (1865). Quantitative Untersuchungen uber die Ernahrungs process der Pflanzen. LANDW. VERSTATT, 7(93).

Kopsell, D. and Sams, C. (2013). Increases in shoot tissue pigments, glucosinolates and mineral elements in sprouting broccoli after exposure to short-duration blue light from light emitting diodes. Journal of the American Society for Horticultural Science. 138(1): 31-37.

Kurilcik, A. et al. (2008). In vitro culturing of Chrysanthemum plantlets using light-emitting diodes. Central European Journal of Biology. 2(2): 161-167.

Lakkireddy, K., Kasturi, K. and Rao, S. (2012). Role of Hydroponics and Aeroponics in Soilless Culture in Commercial Food Production. Journal of Agricultural Science and Technology. 1(1): 26-35.

Lefsrud, M., Kopsell, D. and Sam, C. (2008). Irradiance from distinct wave length light-emitting diodes affect secondary metabolites in Kale. Journal of Horticulture Science. 43: 2243-2244.

Mamta and Shraddha (2013). A review on plant without soil-Hydroponics. International Journal of Research in Engineering and Technology. 2(3): 299-304.

Max (2017). 20 Advantages and Disadvantages of Hydroponics that you should know.

Milton, D.K., Glencross, P.M. and Walters, M.D. (2000). Risk of sick leave associated with outdoor air supply rate, humidification and occupant complaints. Indoor Air. 10: 212-221.

Mougeot, L.J. (2008). Urban Agriculture: Definition, Presence, Potentials and Risks.

Murali, M., Soundaria, M., Maheswari, V., Santhakumari, P. and Gopal (2011). indira nagar, gorimedu, puducherry. International Journal of Pharmarcy and Biological Sciences. 2(Apr-June): 605.

Naluyima, E. (2015). Hydroponics, Uganda.

Nelson, J.A. and Bugbee, B. (2014). PLOS. Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures, 9(6). e99010.

Oh, G., Jung, G. and Seo, M. (2011). Experimental study on variations of CO₂ concentration in the presence of indoor plants and respiration of experimental animals. Horticulture Environment and Biotechnology. 52(3): 321-330.

Olle, M. and Virlise, A. (2013). The effects of light emitting diode on greenhouse plant growth and quality. Agriculture Food Science. 22(2): 223-234.

Omics (2017). Nutrient Film Technique.

Park, A., Kim, G., Yoo, H., Oh, M. and Son, C. (2010). Comparison of indoor CO₂ removal capability of five foliage plants by photosynthesis. Korean Journal of Horticultural Science and Technology. 28(5): 862-870.

Pearson., L., Linda, P. and Pearson, C. (2010). Sustainable urban agriculture: stocktake and opportunities. International Journal of Agricultural Sustainability. 8(1-2): 7-19.

Puri, V. and Caplow, T. (2009). How to grow food in the 100% renewable city: Building-integrated agriculture. Earth Scan, London.

Railey, R. (2018). How to Grow Marijuana/Grow weed.

Rajkumar, G. Dipu, M. Lalu. K. Shyama. K and Banakar, P.S. (2018). Evaluation of hydroponics fodder as a partial feed substitute in the ration of crossbred calves. Indian Journal of Animal Research. 52(12): 1809-1813.

Robert, M. (2008). LED Lighting in Horticulture. Journal of Horticultural Science and Technology. 43(7): 1947-1950.

Runia, W.T. (1995). A Review of Possibilities for Disinfection of Recirculation Water From Soilless Cultures. Acta Horticulture. 382: 25.

Russell, W.E., 1953. Soil Conditions and Plant Growth. Longmans, Green and Company, London.

Sabzalian, M., Heydariadegh., P., Zahedi., M. and Boroomand., A. (2014). High performance of vegetables, flowers and medicinal plants in a red-blue LED incubator for indoor plant production. Agronomy for Sustainable Development. Springer, 34(4): 879-886.

Sandlers, J. (2016). What is deep water culture system.

Sardare, M. and Admane, S. (2013). A Review on plants without soil-hydroponics. International Journal of Research in Engineering and Technology. 2(3): 299-304.

Seawater Greenhouse Limited. (2010). A New Approach: Restorative Agriculture.

Seppänen, O., Fisk, W.J. and Lei, Q.H. (2006). Ventilation and performance in office work. Indoor Air. 16(1): 28-37.
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Shaughnessy, R.J., Haverinen-Shaughnessy, U., Nevalainen, A. and Moschandreas, D. (2006). A preliminary study on the association between ventilation rates in classrooms and student performance. Indoor Air. 16(6): 465-469.

Shaw, C., Wright, M. and Meadows, C. (2004). What is a LED. LEDS magazine, USA.

Singh, S. and Singh, B.S. (2012). Hydroponics—A technique for cultivation of vegetables and medicinal plants, 4th Global conference on Horticulture for Food, Nutrition and Livelihood Options, Odisha, India, pp. 220.

Sonneveld, C. (2000). Effects of Salinity on Substrate Grown Vegetables and Ornamentals in greenhouse horticulture., University of Wageningen, The Netherlands.

Specht, K. et al. (2013). Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings. Agriculture and Human Values. 31(1): 33-51.

Steigerwald, D. et al. (2002). Illumination with solid state lighting technology. IEEE Journal on Selected Topics in Quantum Electronics. 8(310-320).

Steinberg, S.I. et al. (2000). Wheat Response to Differences in Water and Nutritional Status between Zeponic and Hydroponic Growth Systems. Agronomy Journal. 92: 353-60.

Stoner, R.J. and Clawson, J.M. (1995). Alternatives to Methyl Bromide: Research Needs for California, Department of Food and Agriculture, Sacramento, California.

Tehrani, F., Majd, H., Mahmoodzadeh and Satari, N. (2016). Effect of Red and Blue Light-Emitting Diodes on Germination, Morphological and Anatomical; Features of Brassica napus. Advanced Studies in Biology. 8(4): 173-180.

UNFAO (2011). An Introduction to the Basic Concepts of Food Security, United Nations Food and Agriculture Organisations.

UNPF (2007). The Promise of Urban Growth, United Nations Population Fund.

Walsh, B. (2009). America’s food crisis and how to fix it. Time Magazine. 174(8): 1-2.

Wilcox, G.E. (1982). The future of hydroponics as a Research Method and Plant Production Method. Journal of Plant Nutrition. 5(8): 1031-1038.

Yanagi, T. and Okamoto, K. (1997). Utilization of super-bright light emitting diodes as an artificial light source for plant growth. Acta Horticulture. 418(30): 223-228.

Yano, A. and Fujiwara, K. (2012). Plant lighting system with five wave length-band light-emitting diodes providing photon flux density and mixing ratio control. Plant Methods. 8: 46.

Yeh, N. and Chung, J.P. (2009). High-brightness LEDs-energy efficient lighting sources and their potential in indoor plant cultivation. Renewable Sustainable Energy Reviews. 13(8): 2175-2180.