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REVIEW PAPER

Prospects for soilless farming in Africa: A review on the aids of plant growth-promoting rhizobacteria inoculants in hydroponics

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Abstract

Due to the growing population in Africa, there is need to identify farming systems that can increase food productivity for the increasing population. Hydroponic farming presents a viable option for sustainable and climate resilient agricultural production especially in areas faced with environmental challenges such as; limited arable land and has the ability to realize global food security the rising population and urbanization in Africa. However, the supply of plant nutrients in sufficient and sustainable quantities at affordable costs is one of the critical and limiting factors in adoption of hydroponics. Chemical hydroponic fertilizers that are often used are not only environmentally unfriendly but also costly and less-readily available. As such, alternative crop fertilization mechanisms like the use of plant growth-promoting rhizobacteria (PGPR) as inoculants in hydroponics are not only an environmentally feasible but also economical solution for countries in Africa. There are numerous studies regarding this crop-fertilization mechanism, but these mainly refer to controlled environment such as; green-houses, and field tests. Their use in hydroponic farming is still largely unexploited. This review highlights the nutrient requirements, types and benefits of hydroponics in addition to unraveling the potential that PGPR inoculants hold as a sustainable and economical fertilizer alternative in hydroponics.

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Introduction

There has been increasing rates of population across the globe of which majority of these people move to urban centres due to various reasons such as: search for employmet opportunities. This increasing population aroud urban areas which has resulted intor the growing food demand especially in under-developed states has roused interest in alternative crop farming systems due to the reducing arable land visa viz the increasing food demands.

It it worth noting that crop cultivation has over time heavily relied on conventional agricultural practices which unfortunately has stimulated the emission of major greenhouse gases (GHGs) like Nitrous oxide (Di Benedetto *et al.*, 2017). Accompanying this, is the deterioration in arable land because of industrialization, urbanization and increase in population (Hlophe *et al.*, 2019;mgbemene *et al.,* 2016) especially in African urban settings. Furthermore, soil-based farming is constantly affected by pests and diseases, and the effects of climate change, for example, water scarcity and flooding resulting from low and heavy rainfalls (Depardieu *et al.,* 2016).

Researchers presume that the solution to these challenges could be realized with the adoption of environmentally friendly crop cultivation techniques such as; hydroponic farming (Aini *et al.*, 2019). This soil-less farming system does not only improve the efficiency of land, water, and nutrients usage but also the quality and quantity of plant yields (Barbosa *et al.,* 2015).

One critical factor in hydroponic farming is the effective supply and management of plant nutrients (Aini *et al.,* 2019). Chemical fertilizers that are normally used in hydroponic farming are often costly, unsustainable and contribute to the emission of GHGs (Amgai *et al.,* 2017; Di Benedetto *et al.,* 2017) thus calling for alternative options. One of such options are; the PGPR that have also been associated with improved plant growth, facilitation of plant nutrient availability and uptake in addition to synthesis of plant growth-promoting (PGP) hormones in the rhizosphere (Ahemad and Kibret, 2014; Hayat *et al.,* 2010). These microorganisms have been used in agriculture as bio fertilizers, bio-control agents, and bioremediation both in soil and soil-less (hydroponic) systems (Lee and Lee, 2015). However, most of these studies have dwelled on conventional farming in soils, while little is known about their use in hydroponic systems (Paradiso *et al.,* 2017). The aim of this review is to unravel the potential that PGPR have as inoculants in hydroponic farming.

The review revisits hydroponics as a climate-smart agricultural option, pinpoints some of the short-comings and evaluates the potential of PGPR inoculants in the provision of essential nutrients in these systems while promoting sustainable agriculture. Some of the advances that have been made concerning rhizobacterial inoculation in hydroponic systems are also articulated. Finally, the review assesses the prospects of these inoculants in hydroponic systems and the overall contribution of their usage in soil-less farming as an option for sustainable agriculture and environmental management.

Materials and methods

Literature search and assessment was done using online data sources including: Web of science, Science Direct, Scopus data base and Google scholar. The key words used for the review of articles upto 2022 data included; vegetable farming, hydroponics, soiless farming, PGPR inoculants, hydroponics and sustainable agriculture

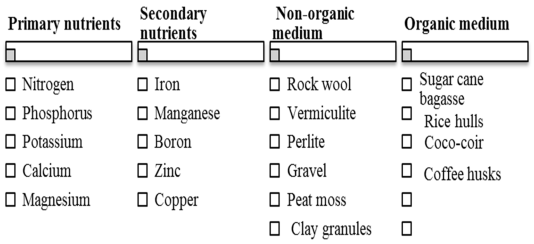
Discussion

What is hydroponics

Hydroponic farming is a method of growing crops under soil-less conditions by dipping the roots in a water solution composed of chemical nutrients to support plant growth (Nisha *et al.,* 2018; (Barbosa *et al.,* 2015). The technology highly favors crop production in areas with non-arable soils and offers more efficient use of resources like water which undoubtedly highlights the advantages of hydroponic farming (Kinoshita *et al.,* 2016). The efficiency and effectiveness in supply of plants nutrients in hydroponics is critical to plant growth. Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and

Magnesium (Mg) are considered as the primary nutrients required for plant growth (Maneejantra *et al.,* 2016) while Manganese (Mn), Iron (Fe), Zinc (Zn), Boron (B), and Copper (Cu) are the supplementary micronutrients (Fig.1) which support the healthy growth of plants under hydroponic farming. The composition of these nutrients plays a crucial role in determining the electrical conductivity (EC) of the solution.

The Potential of Hydrogen (pH) of the nutrient solutions is also a vital factor in hydroponic farming where the solution must contain ions that can be absorbed by the plants. A pH range of 5.5-6.5 is generally ideal for nutrient availability in these farming systems but this can keep fluctuating as the crop grows and different crops have different pH requirements (Alexopoulos *et al.,* 2021). With this agricultural technology, crops can be grown with or without the support of a medium (Fig.1) that not only acts as a conduit for nutrients and water but also offers plant support (Gumisiriza *et al.,* 2020). Fig. 1 summarizes the nutrients and media considered beneficial for effective hydroponic farming while Table 1 describes the different farming systems under hydroponics.



Primary nutrients	Secondary nutrients	Non-organic medium	Organic medium
☐ Nitrogen	☐ Iron	☐ Rock wool	☐ Sugar cane bagasse
☐ Phosphorus	☐ Manganese	☐ Vermiculite	☐ Rice hulls
☐ Potassium	☐ Boron	☐ Perlite	☐ Coco-coir
☐ Calcium	☐ Zinc	☐ Gravel	☐ Coffee husks
☐ Magnesium	☐ Copper	☐ Peat moss	☐
		☐ Clay granules	☐

Fig. 1. Summary of nutrients and essential medium for hydroponic farming.

Table 1. Forms of hydroponic farming.

	System	Mode of flow	Description	Benefits	Drawbacks	References
Low technology & cost	Wick system (Passive technique)	Non-circulating system	This system uses a wick to draw the required nutrients from the nutrient reservoir into the growing medium.	Simple to build. It is cheap.	Favors small plants with low nutrient necessities. No recirculation of nutrients. Susceptible to algae.	(Nisha,2018)
	Deep Water Culture (Direct Water Culture)	Non-circulating system	The plants are put in small baskets (net cups) fitted with growing medium and roots are suspended directly in a highly oxygenated nutrient solution.	Easy to build and operate. Presence of enough dissolved energy. It is cheap.	Roots are prone to rotting if not cleaned often. Requires solution refilling. Slow rate of growth.	(Nisha, 2018)
	Ebb and Flow (Flood and Drain)	Circulating system	The system works by flooding the plant plate with a nutrient solution using a pump that is connected to the solution tank. The solution is pumped at given time intervals with the use of a timer and then drained back to the nutrient tank.	Low maintenance costs.	Susceptible to algae Malfunctions can lead to crop failure. Prone to blockage.	(Seungjun Lee and Jiyoung Lee, 2015)
	Nutrient film technique (NFT)	Circulating system	Plant roots are supplied with nutrients by dipping them in channels filled with the nutrient-rich solution and the system doesn't need a timer.	Plant roots receive enough nutrients, water, and oxygen. No need for a timer.	Malfunctions can lead to crop failure. Prone to blockage.	(Domingues *et al.*, 2012; Jones, 2016; Mamta and Shraddha, 2013; Omics, 2017; Wilcox, 1982)
High technology & cost	Aeroponics	Circulating system	Plant roots are suspended in air and nutrients are supplied to them in form of mist with the use of a timed pump which ensures release of mist after every few minutes.	Does not require any growing medium. Ensures adequate nutrient absorption.	Pump interference can lead to root drying. High and expensive technology. Consumes time. Malfunctions can lead to crop failure.	(Mazhar,2020)

Benefits of hydroponic farming

Hydroponic farming has a number of benefits over conventional farming. It is more efficient in water utilization and favors the production of high and consistent yields in soil-less areas (Gruda., 2019; Gumisiriza *et al.,* 2022).

This farming system is also less labor-intensive as it requires no weeding and land preparation like most conventional farming practices (Pignata *et al.,* 2017). According to several researchers, hydroponic systems may also be used to improve vegetables and fruits both in terms of nutrition, quality, and shelf life according to the market and consumer needs (Amalfitano *et al.,* 2017; Buchanan and Omaye, 2013; Islam *et al.,* 2018; Selma *et al.,* 2012; Sgherri *et al.,* 2010). There is reduced use of pesticides and fungicides since the system is often practiced under a climate-controlled environment (Benke and Tomkins, 2017). Despite the mentioned benefits, the technology requires adequate technical knowledge and high investment costs which include; PVC pipes, timers, hydroponic fertilizers etc… (Nisha, 2018, Gumisiriza *et al.,* 2022a). Hydroponic systems can also be prone to pathogens, and fungal infections (Constantino *et al.*, 2013; Li *et al.,* 2014; Song *et al.,* 2004). The media used in hydroponic farming to deliver the nutrients to the plant roots are not rich with microorganisms that can boost the availability and uptake of nutrients by plants (Hatice *et al.,* 2012).

Rhizobacteria and plant growth promotion

Rhizobacteria are plant root-colonizing bacteria that can stimulate plant development by promoting root growth (Grover *et al.,* 2011). For several decades, researchers have highlighted the importance of PGPR in plant mineral nutrition (Pii *et al.,* 2015). The Food and Agriculture Organistation (FAO) estimates that the demand for Nitrogen fertilizers will exceed 130 million tons per year which is environmentally unsuitable especially since their production largely depends on the use of fossil fuels (Kliopova *et al.,* 2016). Many PGPR have attracted the attention of researchers as plant inoculants due to their capacity to increase nutrient uptake in crops by the production of PGP hormones like indole acetic acid (IAA) and Gibberellic acids (GA) (Choudhary *et al.*, 2018; Vejan *et al.,* 2016). These hormones have been associated with increased foliage and root elongation (Hassen *et al.,* 2016; Vacheron *et al.,* 2015).

There is no doubt that these bacterial substances can significantly increase crop yields and open up a new horizon for sustainable plant productivity. Iron (Fe) is an important micronutrient needed for plant growth (Saha *et al.,* 2016). It's unavailability is a major plant-growth limiting factor in crop production systems (Arora and Verma, 2017; Singh *et al.,* 2019).

Some bacteria have special mechanisms for Fe-acquisition by synthesizing low molecular weight metabolites known as siderophores (Maheshwari *et al.,* 2019) with high affinity for Fe in low-Fe conditions (Mhlongo *et al.,* 2018; Tank *et al.,* 2012). This way, the siderophores function as Fe-chelators and bind most of the available Fe in the rhizosphere (Singh *et al.,* 2019). Furthermore, literature advances that siderophore-producing bacteria and the subsequent Fe-unavailability in plant rhizospheres may also prevent the proliferation of plant pathogens (Mitter *et al.,* 2013; Olanrewaju *et al.,* 2017).

A lot of studies have shown the ability of different rhizobacterial species to produce siderophores and the enhancement of Fe nutrition in different crops (Emami *et al.,* 2019; Ghavami *et al.,* 2017; Liaqat and Eltem, 2016). Siderophore production is a typical example of how rhizobacterial inoculants can establish themselves in the rhizosphere and enhance Fe nutrition. Due to its indisputable importance, it should be given more attention (Aloo *et al.,* 2019).

Advances in hydroponic vegetable production using rhizobacterial inoculation

Research studies have shown instances where the use of PGPR inoculants has demonstrated positive effects on plant growth in hydroponics. For instance, lettuce seedlings grew well when microbial culture solution was used in hydroponics (Shinohara *et al.,* 2011).

Some PGPR like *Pseudomonas* spp., *Bacillus* spp. have successfully improved the growth, yield, and quality of vegetables like; cucumber, lettuce, and tomato under hydroponic farming (Lee and Lee, 2015). In a study by Pii *et al.*, 2018).

Other instances where rhizobacterial inoculations have successfully been shown to promote the growth of different vegetables under hydroponic farming are summarized in Table 2.

Table 2. Studies demonstrating the growth promotion of different vegetables using rhizobacterial inoculants in hydroponic systems.

Crop	Inoculant	Effects on growth	Reference
Tomato and pepper	*Bacillus licheniformis*	Increased fruit yield	(Garcia *et al.,* 2004)
Tomato	*Pseudomonad fluorescens, Serratia marcescens, Bacillus* sp.	Increased fruit yield Increased water efficiency	(Kıdoğlu *et al.*, 2009)
Tomato	*P. fluorescens, P. Putida*	Increased weight and number of fruits	(Gul *et al.*, 2012)
Lettuce	*Pseudomonas* sp.	Increased root and shoot mass	(Cipriano *et al.,* 2014; Tahmasbi *et al.,* 2014)
Tomato, cucumber, lettuce, and Irish potato	*Pseudomonas* sp.	Increased shoot and root weight	(Peer and Schippers, 1989)
Tomato	*P.fluorescens, Burkholderia cepacian, Stenotrophomonas maltophilia, (P. fluorescens, S. maltophilia*	Rapid growth and increased number of leaves	(Alsanius and Gertsson, 2004)
Tomato	*Azotobacter chroococcum, Azospirillum brasilense, Pseudomonas flourescens, and Bacillus subtilis*	Increased yield and quality	(Aini *et al.,* 2019)
Tomato	*Not mentioned*	Increased growth biometrics	(Dasgan *et al.,* 2017)
Lentils	*Rhizobium strains*		(Zafar *et al.,* 2012)

While testing various commercially-available bio fertilizers containing various rhizobacterial inoculants like; *B. subitilis*, *Azotobacter vinelandi* and *Clostridium pasteurianum* to replace chemical fertilizers in hydroponically grown squash (*Cucurbita pepo*) in Turkey, (Dasgan *et al.*, 2012), significant increases in leaf area and nutrient uptake were observed in the bio fertilizer-treated plants than the chemically-treated plants.

It was concluded that the bio-fertilizers could be used in soilless squash production to reduce chemical fertilization resulting in less environmental impact. For years, several efforts have been made to demonstrate endophytic and associative N_2 fixation in crops using free-living diazotrophs (Ahemad and Kibret, 2014; da Silva *et al.*, 2012; Santoyo *et al.,* 2016). However, the contribution of symbiotically-fixed N to hydroponically-grown plants remains largely unestablished and deficient. Previous studies on hydroponically-grown soybean have demonstrated BNF by *Ochrobactrum* bacteria (Paradiso *et al.,* 2017; Paradiso *et al.,* 2015; Paradiso *et al.,* 2014), where inoculation seemed to promote the growth of root system, likely enhancing the capability of nutrient uptake. The use of rhizobacterial inoculants in soilless culture is becoming more and more common (Paradiso *et al.,* 2017).

In a study by Phibunwatthanawong and Riddech (2019) on the formulation of liquid organic fertilizers for growing vegetables under hydroponic conditions using rhizobacterial inoculants, it was shown that all formulations contained IAA whose quantities increased with incubation up to 59.53mg L^{-1}. The production of IAA, increased grain yield, root length and number of nodules per plant has also been shown under hydroponic farming conditions (Zafar *et al.,* 2012). The production of IAA and other PGP hormones has especially been linked to the increased uptake of different nutrients by plants.

The future prospects of rhizobacteria inoculation in hydroponic systems

Rhizobacterial inoculants are advantageous and unique forms of organic fertilizers because of their abilities to synthesize PGP hormones that do not occur in chemical fertilizers (Phibunwatthanawong and Riddech, 2019). However, majority of the studies related to their importance in plant growth have been carried out in soil-based systems, while very little is known about their potential in hydroponic systems where their efficiency also depends on the ability to proliferate and colonize plant roots (Lee and Lee, 2015). The experimental evidence on their efficacy at the field level is still grossly inadequate.

This calls for more research to reveal their efficiency and increase their usability in hydroponic systems. This and related information will certainly help in understanding their use as bio inoculants for practical purposes (Teotia *et al.,* 2016). The productivity and quality of crops grown in hydroponic systems are markedly dependent on the adequate supply, availability and uptake of plant nutrients (Valentinuzzi *et al.,* 2015). The mechanisms underlying nutrition in plants, their regulation and the bio-geochemical cycles of nutrients in hydroponic systems need to be understood to fully develop PGPR strategies for the optimization of the hydroponic crop cultivation (Sambo *et al.,* 2019).

Biological nitrogen fixation offers a viable option for minimizing the use of chemical fertilizers in hydroponic systems. As such, more research in this area is required for vegetables to promote this option for sustainable agriculture especially in low developed countries such as; Africa. This will also play a huge role in reducing the utilization of chemical fertilizers and artificial growth regulators in hydroponic systems (Prathap and Ranjitha, 2015) as well as increase food production to meet the demands of the growing population especially in urban centres.

Concluding remarks and recommendations

Hydroponics is an evolving field of urban agriculture especially in Africa that presents an ultimate solution to many of the contemporary challenges of soil-based farming. Nevertheless, the provision of appropriate nutrients at a low cost and in an organic and environmentally-friendly manner remains a huge hinderance in the adoption of this farming system. Some studies have explored the role of organic fertilizers like animal manures such as; bat, pig, cow, fish and chicken dung in hydroponic farming. However, only few have considered the use of rhizobacteria yet these can also improve plant nutrient availability and uptake in these systems. There is need for more research into this aspect to lower the costs of hydroponic farming in terms of hydroponic fertilizers, reduce the environmental impacts associated with chemical fertilizers and promote organic hydroponic farming. These and more initiatives can eventually increase the adoption of this technology for urban agriculture as well as environmental sustainability. This will also address the increasing concerns across the globe on whether hydroponics is an organic farming system by highlighting the role of rhizobacteria as an organic fertilizer substitute in hydroponic farming.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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