Vertical vegetable gardening for urban areas

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ABSTRACT

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The proportion of the world's poor living in cities is growing, not only because the poor urbanize faster than the non-poor, but also because many existing and new urban residents are forced into poverty by conditions in the cities. Food insecurity is one of several pressing development issues raised by these demographic and economic shifts. Most poor urban dwellers are failing to meet their daily nutrient intake requirements leading to hidden hunger and obesity as a result of eating high calorie but low nutrient content type of food every day. South Africa is known for its national food security, but according to the latest statistics food inadequacy is still a problem at household level as not all households have adequate access to food. At household level, one in five households in South Africa experience food insecurity. Food insecurity is thus a chronic threat for a large proportion of South Africa's population.

Urban farming which is the production of food (plants and animals) within a town or city, for the benefit of the people residing in that town is an umbrella for a variety of farming systems with varied intentions. Some people do farming solely for household consumption, or commercial farming, or for processing. Goods produced are mostly perishables with high turnover crops such as vegetables, spices, and dairy products. The most important trait of urban Agriculture is not the

location but the fact that it is an integral part of the urban economy, it uses the city's resources to produce food to feed the city's people and it affects the urban food security status.

It is argued that urban agriculture has the potential to alleviate poverty by subsidizing food expenditure, generating income through the sale of products and working on urban farms, and influencing prices by supplying lower-cost products to the market. Furthermore, urban agriculture is argued to provide far-reaching social benefits.

When one thinks of Agriculture and specifically vegetable production, the issue of limited horizontal space is often why urban dwellers cannot produce their own vegetables. Vertical farming is currently a hot topic worldwide, but these systems are highly technical, energy consuming and knowledge demanding in terms of their operation and maintenance. For an urban dweller who is already poor, these vertical hydroponic systems are not an option. It was thus the aim of this project to develop an affordable vertical hydroponic system through implementation of growth media based hydroponic systems.

Vertical gardening has been a common practice for ages. Vertical farming is the practice of artificially stacking vegetables and micro-herbs on top of one another. With the technology and methods that comes with vertical farming, this system has the potential to reduce the harm that traditional open field agriculture does, it also has the potential to replace industrial agriculture. Vertical farming is one of the highly recommended farming systems for landless or nearly landless people because it can be practised even on a small patch of homestead land, and it yields higher per square meter of land. Unfortunately, the use of this system seems not to be popular amongst small scale farmers because of the installation and maintenance costs involved. Therefor there is a need to devise a strategy for producing a variety of vegetables by making use of locally available material, to construct affordable vertical hydroponic structures.

To attain this objective, a field study was conducted over two growing seasons to test a few highly nutritious vegetable crops in terms of their adaptability to a mixed vertical hydroponic system and a laboratory analysis was done to identify the vegetables nutritional quality in terms of iron (Fe) and zinc (Zn).

The field study was conducted at Innovation Africa at UP (IA@UP) formally known as the Hatfield Experimental farm of University of Pretoria. This trial comprised of vertical wood structures with two cardinal orientations (E -W). Two different growth media (compost and soil) were tested for suitability by growing three different vegetables: beetroot (Crimson globe), garden pea (Sugar snap) and Swiss chard (Fordhook giant). Half of these vegetables were treated with 1 ml of foliar Trelmix (micronutrient rich liquid fertilizer) spray once a week with the other half serving as control plants. The plants were irrigated using a pressure compensated drip system. Parameters evaluated were plant height, leaf area, number of leaves, size of edible roots, number of pods, fresh and dry masses, and yield.

Growth media and plant tissue were tested for nutrient quality especially Fe and Zn at the Soil Science laboratory on the Hatfield campus of the University of Pretoria. Growth media was tested before planting and after trial termination. For plant tissue analysis, the whole plant excluding the roots was grinded, digested and tested for the content of iron and zinc.

Growth media and season had a significant effect on the yield and yield parameters of all three vegetables. Compost grown plants produced better yields compared to soil. Cardinal orientation and foliar micronutrient increased the yields of the vegetables, but the effect was insignificant. Foliar micronutrient application increased the macro and micronutrient contents of beetroot, garden pea, and Swiss chard in this study, but the differences were not significantly higher than that of the control plants. The plant tissue content of Fe, Zn and K increased while plant P decreased as a result of foliar micronutrient treatment.

The study's findings indicate that compost is the suitable growth media for crop production and Trelmix can be used as a biofortification fertilizer to increase the content of Fe and Zn. In addition, all three crops can be produced with success in this type of vertical production system. This vertical production system could easily be adapted by resource poor households and even small scale producers in urban areas where horizontal space is limited.

Keywords: Micronutrient, vertical farming, foliar treatment

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DECLARATION

I, Thobile Londiwe Shongwe, hereby declare that this dissertation for the degree of the MSc in Agronomy at the University of Pretoria is my own work and has never been submitted by myself to this or any other University. I certify that no plagiarism was committed in the writing of this work, except where duly acknowledged.

Signature ______________________________ Date ____________________________

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DEDICATION

This work is dedicated to my parents Mr Bhekithemba and Mrs. Mary Shongwe.

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LIST OF SYMBOLS AND ABBREVIATIONS

Fe - Iron

Zn - Zinc

MNs - Micronutrients

MND - Micronutrient deficiency

IDA - Iron deficiency anemia

VAD - Vitamin A deficiency

VF - Vertical farming

P - Phosphorus

K - Potassium

NH_4^+ - Ammonia

NO_3^- - Nitrate

LAN - Limestone ammonium nitrate

EC - electrical conductivity

S1 - Season one

S2 - Season two

E - East

W – West

mg kg^{-1} - milligram per kilogram

CHAPTER 1

GENERAL INTRODUCTION

Rapid global population growth, urbanization, and climate change all have significant implications for global food production and food security (Kopittke et al. 2019). The world's population is expected to exceed 9 billion by 2050, but current statistics show that over 600 million people worldwide lack adequate access to nutritious food (Ehrlich and Harte 2015). According to Mlambo (2018), about 80% of the population will be living in towns and cities by 2050. The alarming increase in urban population is because of rural to urban migration with developing countries such as the sub–Saharan African countries with South Africa taking a lead. The percentage of South Africans that will live in urban areas by 2030 is estimated to be 71.3% (Mlambo 2018a) of the population. The major rural to urban migration drivers are job hunting and seeking better-quality services such as education, health care, and infrastructure. It has been observed that upon getting to the city most people prefer not to go back to rural areas, adding to the urban population.

The proportion of the world's poor living in cities is growing, not only because the poor urbanize faster than the non-poor (Tacoli et al. 2012), but also because many existing and new urban residents are forced into poverty by the conditions in the cities. Food insecurity is one of several pressing development issues raised by these demographic and economic shifts.

According to Maxwell (1999), food insecurity and poverty are still widely perceived as a rural issue. This is despite the findings of some studies that a sizable urban food insecure population do exist. The South African and southern African figures highlighting the prevalence of urban food security are supported by research by Ahmed et al. (2007), who discovered that the incidence of urban food insecurity was the same or higher than rural food insecurity in 12 of 18 sampled low-income developing countries. This was despite the higher income for urban households. According to the 2008 South African Social Attitudes Survey, 20.5% of urban households and 33.1% of rural households are food insecure. Research has proven that most poor urban dwellers are failing to meet their daily nutrient requirement intake leading to hidden hunger and obesity due to the daily intake of high calorie, filling food which is low in nutrient density. In severe cases the number of meals taken per day are reduced.

Urban farming which is the production of food (plants and animals) within a town or city, using its infrastructure for the benefit of the people residing in that town (Deelstra and Girardet 2000) is an umbrella for a variety of farming systems with varied intentions. Some people do farming solely for household consumption, or commercial farming, or for processing (Pfeiffer et al. 2015). Goods produced are mostly perishables such as vegetables, spices, and dairy products. The most important trait of urban Agriculture is not the location but the fact that it is an integral part of the urban economy, it uses the city's resources to produce food to feed the city people and it affects the urban food security status (Specht et al. 2014). Poor urban dwellers especially women in developing countries do farming for a living (Orsini et al. 2013). Workers have been seen to practice it on their office balconies, rooftops, and walls while some participate in community gardens outside working hours (Mendes et al. 2008). It is argued that urban agriculture has the potential to alleviate poverty by subsidizing food expenditure, generating income through the sale of products and working on urban farms, and influencing prices by supplying lower-cost products to the market (Mougeot 2006). Furthermore, urban agriculture is argued to provide far-reaching social benefits (Dunn 2010, Reynolds and Cohen 2016). In the African Food Security Urban Network (AFSUN) baseline survey of poor areas in 11 southern African cities, only 22% of the households polled said they normally grew some of the food they consumed (Crush et al. 2010). Less than 5% of the households sampled in Cape Town obtained any food from urban agriculture. Nonetheless, despite urban residents' limited participation in urban agriculture and the growing role of formal markets as food sources, development agencies, governments, and academics continue to envision an urban peasantry willing and able to meet their food security needs through urban agriculture.

When one thinks of Agriculture and specifically vegetable production, the issue of limited horizontal space is often why urban dwellers cannot produce their own vegetables. Vertical farming is currently a hot topic worldwide, but these systems are mostly highly technical and energy consuming as these systems make use of hydroponic principles. For an urban dweller who is already poor, these vertical hydroponic systems are not an option. It was thus the aim of this project to compare soil versus soilless based vertical garden system. The main objective of study was to develop a vertical hydroponic system that will allow for the production of a mixture of vegetable for South African urban settlers. In this study two growth media and three vegetable types that can be produced in this system will be evaluated while the possibilities and limitations of this system in fighting food security and alleviating poverty in general will be addressed.

The study's primary hypotheses were that soil will be a suitable alternative to compost as growth media. Secondly, leafy, rooting and fruiting vegetables can successfully be produced simultaneously in a single vertical system. Thirdly, foliar application of Fe and Zn will increase the plant tissue nutrient content (Fe, Zn, P, K) over control plants. Lastly, cardinal orientation will have an impact on the growth and yields of vegetables, with west facing plants performing less than the east facing counterparts.

CHAPTER 2

LITERATURE REVIEW

2.1 Food security

Food security exists when all people have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life at all times (UNICEF 2020). Food security exists at two levels: national and household. The national level refers to the conditions under which a country can produce, import, and store food. Since one or more of these aspects are in always in play in South Africa, South Africa is seen to be food secure on a national level. In contrast, not all individual households in South Africa are food secure. At the household level, there is food security if all household members always have access to safe, adequate, and nutritious food in sufficient supply to meet dietary needs. The definition of food security touches on four important areas which are food physical availability, economic access, food safety and nutrition. Food security is influenced by food quality and quantity, if one of the two is compromised it can result in food insecurity or hidden hunger (Coates 2013). Food accessibility and nutritional status are crucial for some age and gender groups where a shortage or deficiency can lead to adverse effects.

South Africa, a middle-income country, is known for its national food security, but nutrition levels are not the same at home and individual levels (Du Toit 2011). At national level, one in five households in South Africa experience food insecurity (Labadarios 2007). According to national-level nutrition surveys, approximately 24% of children under the age of five are stunted, and approximately 57% of children under the age of five show signs of wasting (Drimie and McLachlan 2013). Micronutrient malnutrition, particularly deficiencies of Vitamin A, iron, and zinc, has an impact on the health, growth, and learning ability of young children, as well as the population's productivity. At the same time, and often in the same communities and households, overweight and obesity contribute significantly to the prevalence of chronic diseases such as diabetes, cancer, and coronary artery diseases. Food insecurity is thus a chronic threat for a large proportion of South Africa's population, linked to insufficient food, health, and caring behaviours, as well as specific economic, social, political, and institutional factors.

Even though South Africa’s economy is rising, yearly reports from previous studies indicate that about 51.6%, equivalent to one out of two households, is still experiencing hunger with one out of three households being at risk of hunger. In South Africa, hunger is most prevalent in the Eastern Cape, North Cape, and Limpopo provinces. Households are classified as at-risk based on their monthly income and on how much money they spend buying food. The absolute number of food-insecure households in South Africa's urban areas likely outnumbers those in rural areas, based on the proportion of sampled urban populations experiencing food insecurity. According to case studies, the urban poor spends between 60% and 80% of their total household income on food (Maxwell 1999). This reliance on the market, both formal and informal, as a source of food exposes households to food price inflation (Baiphethi and Jacobs 2009) as well as a loss of purchasing power due to job loss (Eriksen and Silva 2009).

According to Crush et al. (2010), urban households in SSA often buy most of their food, hence their food security is correlated with income from employment and urban food systems that include inexpensive food vendors around the city. It is crucial to explicitly take food accessibility into account when analysing the connection between urban food systems and family food security. Access to food in cities is mostly a function of price.

According to an urban food security baseline survey (UFSBS) conducted in 2008 to measure household food security levels among urban poor households in three South African cities (Cape Town, Johannesburg, and Msunduzi). In Cape Town, a total of 1060 households were sampled from Ocean view, Phillipi and Khayelitsha. From Msunduzi 556 households were sampled and from Johannesburg a total of 996 households were sampled from the inner city, Alexandra and Orange farm. Food insecurity levels were reported to be 42%, 80%, and 87%, respectively, for Johannesburg, Cape Town, and Msunduzi (Durban Metro). The sampled homes in the three cities had median household incomes of R3500 for Johannesburg, R1600 for Cape Town, and R1000 for Msunduzi, respectively. As a result, Johannesburg had the lowest levels of food insecurity because its household incomes are the greatest. On average, one in five households amongst the urban poor in the three cities are food secure. Urban agriculture is practiced by 1% of households in Cape Town, 3% in Johannesburg, and 11% in Msunduzi (Battersby-Lennard et al. 2009).

2.2 Consequences of food insecurity

Food insecurity has ramifications for health and well-being, including effects on nutritional status, chronic disease incidence and management, infectious disease exposure, and mental health (Dietz 1995, Drewnowski and Specter 2004, Kempson et al. 2003).

2.2.1 Food insecurity and nutritional status in children

Food insecurity can bring on more health problems in children than in adults. Except for weight for length z-score and wasting, which were in the predicted direction, Frongillo et al. (2003) demonstrated a clear dose-response association between markers of food insecurity and weight gain, height gain, and anthropometric indicators. In lower-income environments, food insecurity is associated with poor nutrition in children. In KwaZulu-Natal, South Africa a low fruit and vegetable intake by school going children was reported by Faber et al. (2013). In high-income environments, however, there doesn't seem to be a consistent main effect of household or child food insecurity. Undernutrition is frequently linked to insecure food access in low-income urban and rural contexts; however, in high-income environments, this association is probably weaker (Tacoli 2020). A recent estimate by Akhtar et al. (2013), 852 million of the world's 870 million undernourished people or 12.5% of the population live in developing nations. When compared to other kids, children who are food insecure are twice likely to be in a bad health. In children food insecurity is correlated with the occurrence of anaemia and asthma.

2.2.2 Food insecurity, infectious and chronic disease

Household food insecurity can increase a person's risk of contracting HIV and other sexually transmitted infections by encouraging behavioural changes that raise the risk of sexually transmitted infections, the speed at which HIV transforms into AIDS, and affect the uptake and adherence to antiretroviral therapy (ART) (Miller and Welch 2013, Weiser et al. 2010). In a study by Dunkle et al. (2007) using a sample of 3 982 non-pregnant women in Soweto, South Africa, they discovered that transactional sex was linked to HIV infection in multivariate models and that women who reported experiencing hunger in their households had 1.6 more chances of doing so. Food shortage was linked to a higher risk of sex exchange, intergenerational sexual partnerships, inconsistent condom usage with a non-primary partner, and loss of control in sexual relationships in women. When compared to females who had access to enough food, food-insecure females had five times more the likelihood of irregular condom use.

Numerous studies indicate that having limited access to food is a very stressful circumstance, and ethnographic research has connected food insecurity with mood disorders, signs of anxiety and depression, and dysthymia (Hadley and Crooks 2012). The relationship between food insecurity and symptoms of common mental disorders in a cohort of low-income volunteer health workers in an urban developing country was investigated by (Maes et al. 2010). Due to the social and biological importance of food, having insecure access to it causes stress, which raises the risk of developing common mental disorders.

2.2.3 Hidden hunger/ Micronutrient malnutrition

The term "hidden hunger" refers to a condition when the body is deficient in important vitamins and minerals (such as iron, zinc, and iodine) and is unable to maintain optimal health and growth (Biesalski 2013a). Poor diet (lack of micronutrient-rich foods), health issues including illnesses, infections, or parasites, and higher micronutrient requirements at stages of life, such as during pregnancy, and breastfeeding can all contribute to hidden hunger. Increased mortality rates, particularly in women and children; poor pregnancy outcomes; increased morbidity; increased burden on the health system and caregivers; impaired mental and physical development in children; and decreased adult job productivity are all effects of micronutrient deficiency (Miller and Welch 2013). The micronutrients of concern are iron (Fe) and zinc (Zn).

2.2.3.1 Iron deficiency

With over 2 billion people affected, iron insufficiency is by far the most common nutrient deficit in the world (Tulchinsky 2010). Anaemia is a consequence of severe iron deprivation (Camaschella 2015). Young children and women of reproductive age are most at risk for iron deficiency and IDA (Iron deprived anaemia), particularly during pregnancy. Haemoglobin levels below 110 gm/L for children under the age of five and pregnant women, below 120 gm/L for non-pregnant women, and below 130 gm/L for men are the most often used cut-off points for anaemia.

2.2.3.2 Zinc deficiency

More than 30% of people worldwide are Zn deficient. The recommended daily intake of zinc for individuals is 15 mg. The human body will experience hair loss, memory loss, skin issues, and muscle weakness because of Zn deficiency. The foetus's brain development is similarly hindered during pregnancy when there is insufficient Zn consumption. In men, zinc deficiency causes infertility (Hafeez et al. 2013). In 2008, about 43.3% of South Africa's of youngsters nationwide were having low zinc levels (Labadarios et al. 2008).

2.2.4 Micronutrient malnutrition (MND) combating strategies

a) Food and nutrient Supplementation

This is a short-term strategy for preventing hidden hunger that is a part of routine immunization, maternal health, and integrated management of childhood diseases. Either all children of a specified age group and other elected groups in a community receive doses of vitamin A at a certain time per a pre-established schedule, or vitamin A can be provided as a universal supplement (Abeshu and Geleta 2016).

b) Long-term approaches

Long-term tactics, such as food-based approaches, education on health and nutrition have several social, economic, and health advantages that promote the availability, access, and year-round consumption of sufficient nutrient levels. Below are long term strategies to combat MNDs.

i) Health and Nutrition Education

One of the greatest ways to address micronutrient deficiencies is to combine community development initiatives with federal initiatives to reduce malnutrition and promote the consumption of a variety of foods (Burchi et al. 2011).

ii) Upgrading the sanitation

Proper digestion of food, as well as the absorption, utilization and access to clean water for drinking, good sanitation, and hygiene practices, as well as prompt medical attention in the event of illness (Burchi et al. 2011) are all strategies to prevent MNDs.

iii) Food-based techniques

Food-based approaches have the potential to solve some issues regarding the consumption and bioavailability of micronutrients including vitamin A, iron, and others among communities living in poverty. They primarily attempt is to increase the production, accessibility, and consumption of foods high in micronutrients, as well as the concentration of specific trace minerals, vitamins, and absorption-promoting elements in the diet (Bhandari and Banjara 2015).

a) Dietary diversification - eating a variety of foods to satisfy nutrient needs (Faber et al. 2002). Most nutritionists think that incorporating micronutrient-rich foods like fruits, vegetables, and livestock products into diets is the only logical and justifiable strategy to treat micronutrient deficiency due to the logistical challenges associated with tactics like supplementation. Local foods that are high in micronutrients must be recognized, and efforts must be made to encourage the intake of these foods (Akhtar et al. 2013). Unfortunately, the majority of South Africa's urban and tribal regions, particularly in KZN, have a diet that is deficient in dietary variety (Govender et al. 2017). They eat foods poor in energy and lacking in nutrition.

b) Reducing nutrient losses - Vitamin deterioration is influenced by a variety of exposure factors, including oxygen, temperature, light intensity, moisture content, pH, and the length of heat treatment. Cooking with a lid on, reducing the cooking time and not having an extended period before prepared foods are consumed can all result in minimum losses with improved nutrient retention. The availability of micronutrients in the daily diet can be increased by washing produce before peeling, using little water when cooking, chopping produce into large pieces, barely heating produce, and covering the vessel with a lid to reduce exposure to light and ambient oxygen (Yousuf et al. 2020).

c) Food Fortification- Fortification, according to Codex Alimentarius, is the act of adding one or more necessary nutrients to food, even if they are already present, to prevent or treat micronutrient deficiencies in the general population (Mannar and Hurrell 2018). In countries with a lack of micronutrients, fortification of commonly used food has become extremely popular since it is more practical, affordable, and socially acceptable (Bendich and Deckelbaum 2001). In 1994, the joint UNICEF/WHO Committee on Health Policy adopted the universal salt iodization (USI) policy to permanently eradicate iodine deficiency (Hetzel 2012, Yousuf et al. 2020). It was decided to add 20–40 parts per million (ppm) of iodine to salt to meet the population's iodine needs. The vitamin A for Africa (VITAA) effort promotes the cultivation and consumption of orange-fleshed sweet potatoes in Sub-Saharan nations, particularly South Africa, to combat vitamin A deficiency (Laurie et al. 2018).

d) **Biofortification-**This is a genetic or agronomic process of increasing the micronutrient content in edible parts of food crops (Melash et al. 2016). Genetic biofortification can be carried out either by conventional breeding or through genetic engineering. Crops that have been developed to contain more micronutrients, seeds that have been micronutrient-treated, and the usage of inorganic fertilizers are all examples of agronomic fortification. Mineral element deficiencies in food crops may result from a variety of factors, including mineral-deficient soils, lowered mineral availability to plants due to factors like alkaline soils, reduced distribution/translocation of minerals, and mineral accumulation in parts of food crops that are not edible. Therefore, it is crucial to address these concerns to raise the mineral levels in the crop plants' edible sections. Quick and effective ways to increase micronutrients in crop plants includes application of both inorganic and organic fertilizers together with micronutrient fertilization.

e) Home gardens- Most homes in developing nations have backyard plots where they grow fruits and vegetables to complement a diet high in carbohydrates from cereal, with a few also attempting to increase household income (Hillve Scheller 2013). The micronutrient status of most people can be improved through agronomic fortification of the crops produced in these gardens. In South Africa, using home gardening as a strategy helped to significantly reduce vitamin A deficiency (VAD). Vitamin A status of a rural community in KwaZulu-Natal known to have a high prevalence of low vitamin status, was increased through introduction of home-based food production project by the Medical Research Council (MRC) of South Africa, in conjunction with the Agricultural Research Council. The program was promoting the production and consumption of b-carotene-rich fruits and vegetables in children aged 2-5 years (Faber et al. 2002). The amount of vitamins consumed by children from homes with project gardens was much higher than those without project gardens.

2.3 Food security coping strategies

Maxwell et al. (2008) identified a "common" pattern of coping responses that is related to food use rather than adapting livelihoods through which food is obtained. Their findings suggest that households limit meal size first, then reduce the number of meals as well as eating less preferred foods. If the crisis persists, adults will reduce their intake, presumably to protect younger people. Households will begin to consume wild foods, followed by borrowing food from others and, finally, using credit to buy food. When these avenues of action become exhausted or insufficient, households will skip entire days of food consumption and eat into their seed stock, send family members away, and, if that is still insufficient, resort to begging. Other coping strategies are food stretching and substitution techniques (such as using water instead of milk in breakfast cereals), intake of expired and nearly expired foods, limited meal size, meal diversity, and meal frequency, changes to less expensive foods and preparing one big pot of food to eat for many days (Hadley and Crooks 2012, Nisbet et al. 2022, SANUSI et al. 2018). Consumption of roadkill; hunting and fishing; consumption of discarded foods; participation in research studies or donating blood to earn money for food; and intentionally being jailed to ensure three meals a day are additional and less common coping strategies (Kempson et al. 2003).

Newer data suggest that, in the face of insecure food access, households may engage in trade-offs between competing food and non-food demands (Davies 2016, Ellis and Manda 2012, Napier et al. 2018).

Ways to cope differ by class and location, though few studies have explicitly addressed this issue in the same study. Overall findings from Bekele (2009) in urban and rural South Wollo, Ethiopia, is that urban dwellers had fewer options for coping with food insecurity than rural dwellers, but the measures available in the peri-urban/urban sites were relatively reversible and less severe, such as cutting the number of daily meals or taking out loans. Some coping strategies, such as small-scale trading or asset sales, were only available to those with the necessary capital at the start of the crisis, resulting in higher levels of inequality.

Overall, Sorenson and Bekele (2009) reported that coping strategies implemented was significantly less damaging to urban households and was less likely to erode their livelihood base as compared to rural households. Thus, even universal patterns of coping can have disparate effects on livelihoods and food security, and even when one group has fewer options, the consequences of using those options can be benign.

2.4 Strategies to mitigate household food insecurity

In an attempt to avoid the dire effects of household food insecurity, preventative methods such as vegetable gardening for households/individuals with farm lands, food distribution, and nutrition education can be explored.

1. Job and income generation

Programs that expand or develop alternative sources of income, whether through employment or small business growth, are crucial in this area because of the essential role that livelihoods play in the outcomes of food security. In places with acute or chronic food insecurity, solutions like food-for-work or pay-for-work are frequently implemented. Distribution of food in exchange for labour on public works projects (such as roads or schools) can be helpful for helping households cope with immediate food deficits as well as developing community infrastructure that may serve as a buffer against future shocks in areas where there are dramatic shortages of food and where market systems are not functioning (Sassi et al. 2018). In situations where food markets are operating and food price inflation is not a worry, cash-for-work is probably a preferable solution. The effectiveness of microcredit programs in promoting income development and livelihood diversification has been extensively discussed in the literature (Ellis 1998). To aid in the launch of new firms, social and educational components are frequently incorporated into the programs.

2. Development of human capital

Human capital development, or "human capital development," programs, enable people to pursue better career prospects and to reach their full financial potential. Nutrition education can enhance meal preparers' knowledge and behaviours regarding infant feeding, food selection, and sanitation practices. It is frequently combined with other interventions, such as food distributions, and may be helpful for promoting healthy food choices in settings where excessive consumption is of concern. By removing the customary fees that households would often make at these facilities, service fee exemptions are also used to promote kid attendance at schools or health clinics, an intervention that has been tried in El Salvador (Rose 2008) .

3. Food based assistance

Due to their greater nutritional needs and the long-term effects of nutritional insults, maternity and child health clinics frequently target pregnant women, babies, and children for supplemental food distribution (Triunfo and Lanzone 2015). These programs are prevalent in the developing world, but interestingly, this type of intervention has also been adopted in high income countries - for example the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) in the U.S. as a form of social protection, and has been shown to improve birth outcomes and reduce hospital costs due to a reduction in low-birth weight babies (Black et al. 2004). School feeding programs provide extra food to students in the form of meals or take-home rations for their families. In numerous nations, it has been demonstrated that these initiatives boost enrolment and enhance dietary or educational outcomes. Programs like food stamps or vouchers are helpful in addressing issues with temporary food poverty (Barrett and Lentz 2010). Although these initiatives have a significant administrative overhead, they have the advantage of giving participants more flexibility than direct food distributions and supporting food marketing systems.

4. Agricultural production

Improvements in agricultural production, which have historically been linked to increasing a population’s access to food, continue to be a crucial tool for achieving the Millennium Development goal of reducing poverty and hunger, particularly when focused on small scale farmers (Aryal et al. 2022). Agriculture plays a key role in rural economies, and economic growth and poverty reduction are unlikely to be achieved without improvements in agricultural production (Kimenyi 2002). This strategy is likely to be more important in Africa and Asia where rural populations are relatively large and where land is less unequally distributed. To boost agricultural production, a number of interventions have been utilized. The distribution of seeds and tools to low income farmers in a disaster area may be one of the most frequently employed strategies in situations following a climatic shock (Harvey 2009, Rose 2008). By enabling farm households that have lost their crops to resume profitable production, this intervention has the potential to lessen some effects of weather shock depending on the time of shock and the speed of distribution and this will only work for households with farm land. Agricultural research and extension can have a significant impact on the adoption and growth of high yielding crops (Abdu-Raheem and Worth 2011).

Food insecurity at the family level can be mitigated by growing one's own food, especially vegetables with improved nutritional value, however there is a problem with lateral space. By producing vegetables that yield more with fewer plants, like peas and spinach, or nutritionally rich crops that yield one harvest per plant, like carrots and beets, households can still enhance their family's nutritional status, even in areas with limited agricultural space. Regardless of the size of the land, crop production can be maximized (Trevor 2014) and this can be done by;

a) Growing seasonal varieties - Some crops like peas, beans and potatoes have seasonal varieties (early, mid, and late season varieties). Growing different varieties will ensure year round production and reduced crops losses due to pest and diseases (Anderson et al. 2020).
b) Succession planting - Making the most of your available space and sustaining a steady growth of vegetation are the key objectives of succession planting. Four fundamental strategies — two or more crops in succession, relay planting, intercropping (two or more crops on the same piece of land), and intercropping (several varieties with different maturity dates can be utilized depending on the crop type, growing season length, and environment (Urama and Ozor 2011)) can be used.
c) Increase the season while defending the crops - Use greenhouses, cold frames, or a hoop house to prolong the growing season can an ensure you have far more success with sensitive crops like tomatoes, cucumbers, and melons in cold weather. Also, they will aid in defending your crops against pests like birds, small mammals, and deer as well as unseasonal weather conditions like wet summers (Mishra et al. 2010).
d) Cultivate calorie-rich plants - Calorie rich crops are foods that are satisfying and high in carbohydrates. The top five calorie-containing foods include winter squash, potatoes, maize, beans, and perhaps grains like wheat. These crops offer a wide range of culinary uses, are highly versatile, full you up, need a lot less work than other crops, and preserve well for a long time (Massawe et al. 2016).

Some vegetables that can be produced by households/individuals with limited space, their nutritional content and importance in human diet

Garden peas

The Leguminaceae family's garden pea, or *Pisum sativum* L., is the third-most significant pulse crop worldwide (Ambrose 2008). It is a cool-season annual herbaceous crop that was once only planted in the Near East and the Mediterranean basin but is now grown all over the world. As one of the most nutrient-dense legume vegetables, garden peas are high in vitamins, minerals, phytonutrients, antioxidants, proteins, fibre, and ascorbic acid. They also have a little amount of good-quality fat. It protects against stomach cancer, arthritis, Alzheimer's, diabetes, aging, and other diseases while also boosting immunity (Kumari and Deka 2021). Due to its high protein, vitamin, mineral, and prebiotic carbohydrate content it is sometimes referred to as "poor man's meat." Garden pea is rich in iron and zinc and it can be used can address the deficiency of these two micronutrients (Erbersdobler et al. 2017). Garden peas are a leguminous crop that fix nitrogen in the soil, making them advantageous not only for human health but also for agricultural fields.

Swiss chard

Swiss chard (*Beta vulgaris* L. var. *cicla*) which is commonly referred to as "stem chard," is a member of the Chenopodiaceae family, which also includes spinach and garden beets (Inman 2011). Along the Mediterranean coast, beets, which are wild variations of *B. vulgaris*, are common. It is cultivated for its leaves and was first referenced in Mesopotamian literature from the ninth century (Elbersen and Oyen 2010). Vitamins A, B, and C, as well as calcium, iron, and phosphorus, are abundant in Swiss chard (Ninfali and Angelino 2013). Swiss chard has a large volume of nutrients and is low in sodium, cholesterol, fat, and calories. It offers a wide range of nutrients, including vitamin K, iron, potassium, magnesium, and vitamin E. Nutritional benefits of Swiss chard includes but is not limited to lowering the risk of cardiovascular diseases, decreases chances of developing chronic diseases such as cancer and heart diseases, repair damaged cells, and promoting better blood sugar regulation (Gamba et al. 2021).

Beetroot

Beta vulgaris, often known as red beetroot, is an herbaceous biennial (flowering in the second year of growth) or, occasionally, a perennial plant that may grow to a height of 120 cm (up to 200 cm in the second year), however most cultivated versions are biennial. The roots of the domesticated varieties are dark red, white, or yellow, and they are either moderately to highly swollen and fleshy.

Biologically active compounds found in beetroot include betalains, carotenoids, phenols, B-vitamins (B1, B2, B3, and B6 and B12), folate minerals, fibers, and sugars with a low energy value as well as inorganic nitrate (Ceclu and Nistor 2020). Moreover, according to Abdo et al. (2020) it is a good source of calcium, magnesium, copper, phosphorus, sodium, and iron. Each component of this plant has a variety of therapeutic benefits, including antioxidant, anti-depressant, anti-microbial, anti-fungal, anti-inflammatory, and cardiovascular health defender.

2.5 The Function of Vegetables in Human Health and the Potential Impact of Biofortification

Plant foods make up a large component of the human diet and they provide most of the calories, minerals, and bioactive chemicals necessary to retain a healthy status and prevent diseases. One of the foundational components of a healthy plant-based diet is vegetables, which offer dietary fiber, phytochemicals (such as vitamins and antioxidants), and minerals (Liu 2013). Since humans cannot produce minerals, it must be received through diet. Minerals are regarded as necessary nutrients. Vegetables played a crucial role in the diet that allowed humankind to evolve, and a lack of them is one of the causes of many non-communicable diseases that are prevalent in Westernized countries (Williams et al. 2021). For instance, nutrients like potassium, calcium, selenium, and iodine, which are found in a diet high in vegetables, can help to maintain healthy blood pressure, strong bones, hormonal production, the heart, and mental health. In a recent UK study, data analysis from more than 40,000 participants revealed that changes in fruit and vegetable consumption may not only benefit physical health over the long term but also short-term mental well-being (Gschwandtner et al. 2022). These benefits were also seen in cancer survivors in addition to the general population. On the other hand, as they may be grown locally and consumed in a wide variety of shapes, sizes, colours, and tastes, vegetables play a significant economic role in battling poverty, hunger, and undernutrition. Undernutrition, sometimes known as "hidden hunger," and suboptimal micronutrient intake can be particularly severe for persons who adopt a restricted diet for moral, religious, or health-related reasons (Lezo et al. 2020). Dietary reference intakes (DRI) have been established by health authorities based on recommended daily allowances (RDA) and acceptable upper ranges (UL) (Kris-Etherton et al. 2009). The DRI for each component must be met without going above the UL as a rule for programs to address vitamin or mineral deficiencies. However, the amount of phytochemicals and minerals that make up the human diet is not solely dependent on the tissue of the plant where they are concentrated (Parada and Aguilera 2007). During passage through the gastrointestinal tract, the micronutrients must be liberated from the food matrix, absorbed into the blood, and delivered to their target tissues. Only the portion released from the plant tissue becomes available and is eventually absorbed. Increasing the bio-accessibility of plant phytochemicals and minerals is a prospective aim of agronomical measures to increase the nutritional quality of vegetables (Septembre-Malaterre et al. 2018). In the coming years, vegetable consumption should rise for both environmental and health reasons (Richard et al. 2011). There will be a need for more sustainable food supplies to address the growing world population (McClements 2020). It makes sense to concentrate the biofortification efforts on tomatoes, cucurbits (pumpkins, squashes, cucumbers, and gherkins), alliums (onions, shallots, and garlic), chillies, spinach, potatoes, carrots, and brassicas as they are the most significant vegetables in the current global economy (Buturi et al. 2021).

2.6 Potential benefits of urban agriculture in combating food insecurity

Urban farming can be used as a strategy to promote dietary diversity and improve urban food security (Khumalo and Sibanda 2019). In addition, it reduces the cost of buying food, especially perishables (fruits and vegetables). As a result of urban farming, communities become self-sufficient (Mancebo and Salles 2016). City farmers are said to share their surplus with friends and needy community members, as well as sell some for a reasonable price (Nugent 2000). Urban gardening can also improve food consumption patterns.

Participating in urban gardening improves mental, physical, and emotional health (Alaimo et al. 2016). Furthermore, it gives urban farmers hope by giving them something to look forward to every day. Community unity is promoted, and healthy relationships are built. Community gardens and rooftop farms bring people together and give them a sense of belonging, it strengthens bonds between people from the same communities or cultures and helps keep farmers healthy by stretching muscles and relieving tension. As food is produced closer to consumers, urban farming promotes community wellness by recycling urban waste and reducing nutrient loss due to post-harvest handling (De Zeeuw et al. 2011).

2.6.1 Social and cultural benefits

Different age groups are brought together for a common purpose. They share their problems and learn from each other. Through informal meetings and collaboration, farmers form relationships. Urban gardening contributes to cultural diffusion. Farmers with a similar heritage, share tips on growing food that keeps them connected to their roots. Urban farming entails projects that benefit the farmers and the community at large (female farmers learn entrepreneurship skills, marketing, and bookkeeping) with the help of external stakeholders (Smit et al. 2006). Leaders and entrepreneurs are developed through urban farming. It also contributes to the eradication of health, social, and environmental injustices. Through urban farming, people can speak out and advocate for issues that affect minorities, such as women and children (giving voice to the voiceless). Urban gardening promotes social cohesion and social capital (Kennard and Bamford 2020).

2.6.2 Environmental benefits

Urban sprawl has resulted in poor waste management and sanitation, but urban farming recycles waste and results in clean cities. Gallaher et al. (2014) found that 70 % of urban solid waste can be composted and used as livestock feed when properly managed. Non-biodegradable waste, such as bottles and cans, can be recycled and traded for cash. Crop irrigation can be done with greywater. Using organic waste as fertilizer reduces the use of synthetic fertilizers. Consequently, methane production and other greenhouse gases produced by burning this waste are reduced. By acting as insulators, rooftop planting helps reduce the energy needed to cool and heat houses. It is possible to revitalize the environment and promote biodiversity in cities through urban gardening (Campbell 2017). Agroforestry practices improve soil health and quality. It also prevents runoff and erosion. During hot days, trees provide shelter and shade to people and animals. On windy days' trees act as windbreakers. Furthermore, trees purify water and reduce the effects of climate change. By capturing carbon dioxide and other greenhouse gases, the plants reduce their carbon footprint and improve air quality (Ackerman et al. 2014).

2.6.3 Economic benefits

Urban agriculture is primarily driven by food security, unemployment, and developing communities. Urban farming boosts household income, creates jobs and stretches household budgets for other necessities (Ackerman et al. 2014). Urban farming can help urban settlers achieve food independence and reduce urban poverty. As most urban food is sourced from rural areas, urban farming will reduce transportation costs (Specht et al. 2014). The use of animal manure for farming reduces fertilizer costs. Farmers who practice urban farming on a large scale have created job opportunities for many unemployed people in communities (McClintock 2010).

2.7 Potential risks and challenges of urban agriculture

1. Urban farming can result in the production of food not being safe for human consumption- Urban air and soil are polluted due to high industrialization. Production that takes place by the roadside and closer to factories increases the risk of food contamination by carbon monoxide and other greenhouse gases (Mougeot 2000).
2. Urban agriculture affects urbanization - Urban farming can take up space that can be used for revenue-generating operations hence it must be practiced in rural areas.
3. Urban farming can be an environmental or health hazard- If practiced wrongly, urban agriculture can be a threat to urban inhabitants (Specht et al. 2014) due to pollution from animal waste and overuse of agrochemicals. Cattle produce methane gas which is one of the greenhouse gases. Runoff from agrochemicals can pollute underground water sources, rivers, and dams, causing eutrophication which can result in the death of water animals such as fish.
4. Challenges of urban farming can be the unavailability of resources such as farming land, farm inputs, and knowledge. A report by Kennard and Bamford (2020) states that most of the people who engage in urban agriculture do not have a farming background making it hard to deal with some problems that may arise such as outbreaks of pests and diseases.

2.8 Vertical farming opportunities in urban settings

The traditional form of agriculture has always been horizontal farming on the surface of the land. As urban population density has increased and there is a greater demand for land in cities for more lucrative uses. In addition a lack of resources that are compatible with the nature and needs of traditional farming practices has led to the introduction of vertical farming as an alternative (Despommier 2010, Khalil and Wahhab 2020).Vertical farming is the practice of artificially growing vegetables and micro-herbs in layers above one another (Fig 2.1 A and B) (Baumont de

Oliveira et al. 2022, Despommier 2010, Thomaier et al. 2015, Touliatos et al. 2016). New technologies and methods used in vertical farming have the potential to alter the way we think about and see agriculture. These technologies make vertical farming to be more efficient as compared to traditional horizontal farming. Vertical farming reduces the harm that traditional open field agriculture does, it has the potential to replace industrial agriculture and even be a better option (Kalantari et al. 2018). Vertical farming in cities can be practised in disused warehouses, inner-city factories, and the surroundings of buildings (Banerjee and Adenaeuer 2014, Beacham et al. 2019). In South Africa, it can even be expanded to abandoned mines if the necessary infrastructure is in place, with the city of Gold serving as the ideal target. A variety of growth systems with different scales, users, technology, locations, and purposes are all included in vertical farming (Orsini et al. 2013). It is most appropriate for the growth of horticultural crops like leafy vegetables (Beacham et al. 2019). The two main types of vertical farming systems (Fig 2.2) are those that use numerous levels of conventional horizontal growth platforms and those where the crop is sown directly on a vertical surface (Pérez-Urrestarazu et al. 2015). Vertical farming can improve the city's food security status, job opportunities, education, leisure, and waste management. Cities have a very high consumer population, and among this group are many poor people who have little to no access to fresh food (Lam et al. 2007, Sauerborn 2011).

Figure 2. 1 A free-standing planter pyramid (www.plantinfo.co.za). B an urban vertical farming structure (green farms)

The food needs of the whole population in a city can be met if greenhouses are added to the tall, multi-story structures that already exist. These vertical farms can serve as education facilities for farming, and as places for leisure.

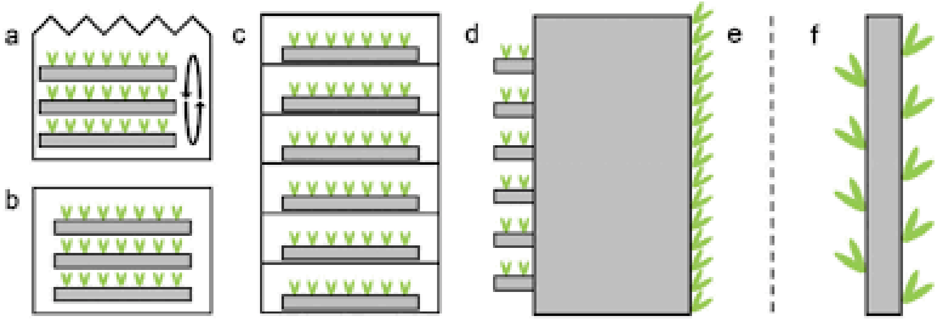


Figure 2. 2 Types of vertical farming (VF) (Beacham et al. 2019). a) Stacked horizontal systems with multiple levels of horizontal growing surfaces and can be in glasshouses, b) incorporated rotation level, or controlled environment (CE) facilities. c) multi-floor towers with each level isolated from the surrounding levels. d) Balcony system e) V green wall positioned on the side of buildings and other vertical surfaces and f) cylindrical growth units with vertical arrangements of plants

2.9 Types of vertical farming

From straightforward two-level or wall-mounted systems to enormous warehouses, vertical farms come in a variety of sizes and configurations. The most popular types of vertical farms are aeroponic, hydroponic, and aquaponic. These systems are all free of soil.

2.9.1 Hydroponics

The most popular system (Jensen 1997). Plants are cultivated in nutrient rich solutions without soil (Fig 3 A and B). The nutrient solution, which is regularly tested and circulated to ensure that the proper chemical composition is maintained, is submerged with the plant roots (Sardare and Admane 2013).

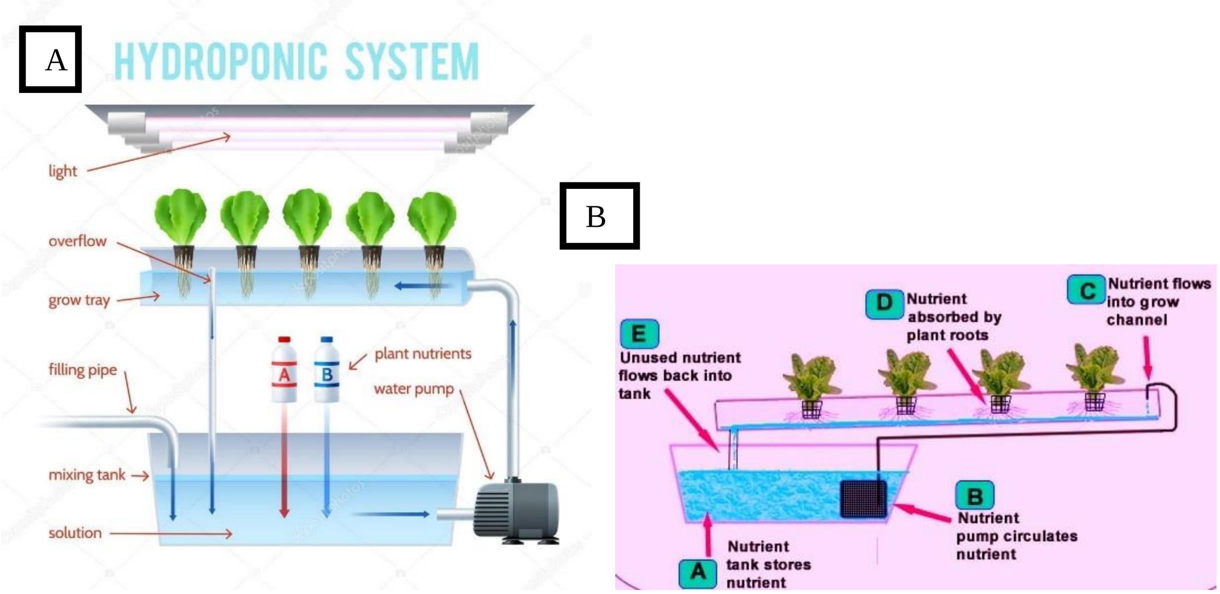


Figure 2.3 A and B Examples of closed hydroponics system (Wise 2020)

2.9.2 Aeroponics

Here, plants are grown without soil and with little amounts water in an atmosphere of mist and air (Fig 2.4 A and B). Although they are still a rarity in the field of vertical farming, aeroponics systems are garnering a lot of attention. It uses up to 90% less water than other vertical farms and is by far the most effective in terms of water use (Birkby 2016). Aeroponic plants have also been shown to absorb more vitamins and minerals, making them potentially healthier and more nutrient-dense (Rameshkumar et al. 2020).

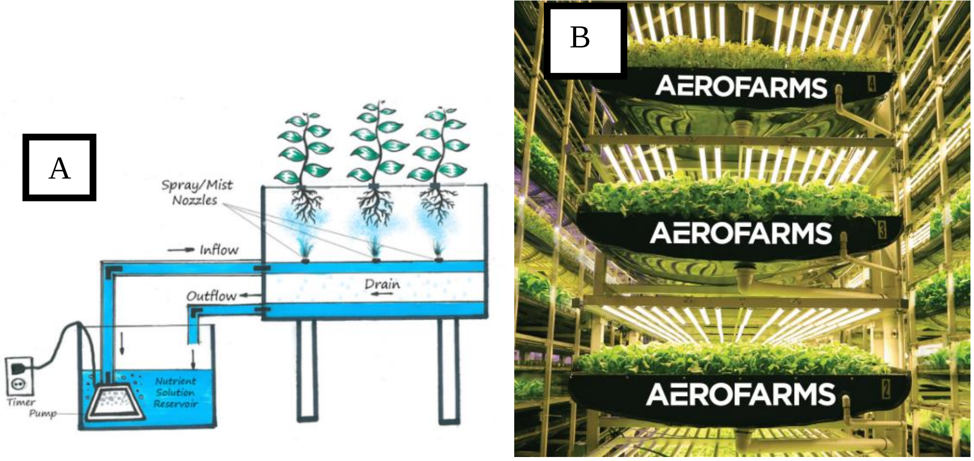


Figure 2.4 A diagram to explain the concept of aeroponics and B an example of a vertical aeroponic system (Agrifarming 2018)

2.9.3 Aquaponics

An aquaponic system expands on the hydroponic system by integrating fish and plants into one environment (Fig 2.5 A and B) (Yep and Zheng 2019). Fish are raised in indoor ponds, and the excrement they produce is nutrient-rich, serving as a source of food for the plants in the vertical farm. The effluent is filtered and cleaned by the plants before being recycled into the fishponds (Boxman et al. 2017).

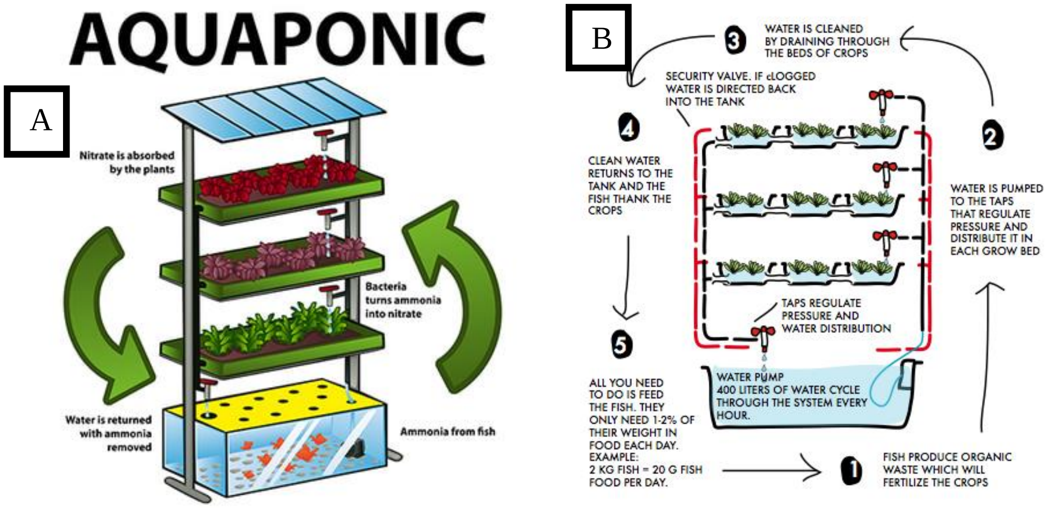


Figure 2.5 A and B Aquaponic basics (Al-Kodmany , Martin et al. 2016)

2.10 Advantages of vertical farming

Increase in production and availability of crops- This farming method confirms that crops may be produced all year long, regardless of the weather. When the number of crops produced per season is taken into account, a single indoor acre of a vertical farm may create a yield equivalent to more than 30 acres of farmland, making it significantly more efficient than horizontal farming (Despommier 2013).

Increase space utilization efficiency- Large expanses of land that is entirely productive are necessary for conventional farming. However, there are no such prerequisites for vertical farming. The stacking growth mechanism of vertical farming is yet another impressive feature. This approach allows you to increase productivity on a relatively small plot of land. Approximately one acre of a vertical farm may sustainably grow the crops that you would have likely grown in 10 to 20 acres of land, depending on the type of crop you intend to grow (Rajan et al. 2019).

Recycling and conserving natural resources- The hydroponic and aeroponic techniques used in vertical farming use much less water than those used in traditional agriculture (Birkby 2016). This aids in the recycling and conservation of water resources. Additionally, municipal sewage waste can be used in vertical farming in composted and recycled forms, which will aid in the further recycling of the resources.

Environment friendly- In addition to assisting in the restoration of trees, vertical farming will lessen our reliance on terrestrial resources (Despommier 2010). Additionally, less equipment use will result in lower CO_2 emissions, aiding in environmental preservation. When used holistically and in conjunction with other technologies, vertical farming will assist metropolitan areas in absorbing the anticipated increase in population while maintaining food security (Thornton 2008). However, because many crops are not suitable for indoor farming, traditional farming will still be practised (Banerjee and Adenaeuer 2014).

2.11 Challenges of vertical farming

Some people were against the whole idea of vertical farming as described by Despommier (2010). For instance, Benke and Tomkins (2017) asserted that this system has some drawbacks, including the restriction on crop varieties suitable for this business model (originally primarily vegetables such as lettuce, strawberries, and tomatoes), the fact that it can only provide for a small portion of the population, and finally the operating expense. Additionally, they claimed that the distribution of light among plants would not be homogeneous, that in a greenhouse setting, only the plants on the top level would benefit from solar radiation, and that photovoltaic energy is insufficient because plants cannot be stacked in vertical arrays. The claims stated by Benke and Tomkins are no longer relevant because technology is still developing. For instance, the development of new inexpensive and energy-efficient LED lighting has made solar panels more effective at producing energy and light exposure more cost-effective. The use of rotating stacked plant arrays inside of a single high-rise cage allows for even more uniformity in the amount of sunlight that each plant receives (Morrow 2008). By comparison with Moore's Law in electronics, the price of storage batteries is falling quickly. Due to the new LED sources' ability to adjust spectrum characteristics with plant type and physiology, they may increase yields in greenhouse environments (Trouwborst et al. 2010). These issues with vertical farming can be summed up (Banerjee and Adenaeuer 2014). The setup of the system can be expensive. If the site is acquired from important business districts, installation costs may be significant. There are not as many crops grown as there are in rural areas. Additionally, broadacre farming has smaller production capacities, and scaling up could be more expensive and difficult. The need to control unrest in the rural sector, acquire investment capital, and develop a qualified workforce are more specific issues.

Despite these issues, vertical farming is one of the recommended farming systems for landless or nearly landless people because it can be practised even on a small patch of homestead, and it yields higher per square meter of land used. Unfortunately, the use of this system seems not to be popular amongst small scale farmers because of the installation and maintenance costs involved. In urban areas numerous studies are being done on vertical farming, and there has even been an increase in the number of vertical farms worldwide, modified to be more affordable (Despommier 2010). Locally accessible planting materials, green manures, "live" fencing, and indigenous pest control techniques can be utilized to minimise gardening expenses. The use of less expensive vertical farming systems (Fig 2. 6 A, B and C) such as stacking old tyres (Fig 2. 6 B), water bottles, sacks and old clothes can be used in urban poor farmer systems. These systems will always have a growth media component, while fertigation is no used, which makes farming cheaper and easier to manage. By making use of these cheaper vertical farming systems, food-poor households which if often excluded from gardening because they lack access to land, water, and technical assistance, can now access food from their own modified and cheap vertical farms.

Figure 2. 6 Vertical structures with easily accessible material such as A- shoe organizer garden, B- stacked tyres, and C- wood crate planters (Wakkary et al. 2013)

CHAPTER 3

METHODOLOGY

3.1 Introduction

With a rise in rural-urban migration, South Africa is expecting to have 80% of its people living in urban areas by 2050 (Mlambo 2018b). Rural-urban migration in South Africa started a long time ago with a few people, especially men. They were leaving their communities to seek employment in towns and cities. Since the end of apartheid in 1994, there is an increase in the number of people moving from rural to urban areas (Van Averbeke 2007). From the year 2000 to 2015, an increase of 12% has been recorded (Ntshidi 2017). Rural-urban migration is the movement of people from the countryside to town seeking better economic gains, education, health care, employment, urban facilities, and a way of life with some running away from conflicts (Xiang et al. 2016). With the scarcity of job opportunities in South Africa like in most developing countries, migration has increased the number of urban poor people and mushrooming of informal settlements. It has also caused several social problems such as increased demand for housing, food shortage, and increased crime rates. In South Africa, urban poverty is most common in metropolitan areas and small towns (Rogerson 1998). These places are occupied mostly by unemployed black people and low-income earners especially women and child-headed families (Montgomery 2009). These places are characterized by poor sanitation, lack of proper housing, unavailability of clean water, issues of food insecurity, and micronutrient malnutrition (Van Averbeke 2007).

One of the survival strategies utilized by the people living under such conditions is urban farming. Urban agriculture has proven to be an effective strategy used worldwide by poor urban settlers to improve their household income and food security status (Thomaier et al. 2015, Zezza and Tasciotti 2010). Urban farming is all farming practices that happen in and around towns and cities. It is an old practice that has evolved for the longest time. Its benefits include but are not limited to an increase in the supply of fresh crops, especially vegetables, the potential to promote food security and sustainable cities, while addressing UN development goals 1 (zero hunger) and 11 (sustainable cities and communities).

In 1996, urban agriculture was estimated to be practiced by 800 million people globally, offering permanent jobs to 150 million people (Cofie et al. 2003). With the issue of urbanization happening, there will soon be no land for crop production hence a need for studies focusing on how to maximize food production with the limited resources available (Ackerman et al. 2014). Previous work done on vertical farming seems to be promising.

Vertical farming is the production of food, animal, and micro herbs by artificially stacking them on top of each other (Despommier 2010). This farming method has not yet been well explored outside greenhouse production systems. Vertical farming practices include the use of enclosed structures (controlled environment production) (Cofie et al. 2003) such as greenhouses, hydroponics, and aeroponics, it also includes the use of open structures such as aquaponics, rooftop planting, green walls, and use of balconies (Touliatos et al. 2016). The main aim of vertical farming is to produce environmentally friendly food in large enough quantities using minimal resources. This study focuses on how vertical farming can be domesticated to South African standards for the benefit of the poor and low-income earning urban dwellers Vertical farming is normally used for high turnover crops such as leafy vegetables and micro herbs (Benke and Tomkins 2017). Vegetables are easy to establish, and they are a cheap source of minerals and vitamins hence this study is focusing on incorporating a wide variety of vegetables (leafy, root, and fruiting types of vegetables) in a vertical farming system to improve the micronutrient intake of South African urban settlers.

Urban poverty and food insecurity in the form of micronutrient malnutrition are the major problems facing South Africa’s urban areas. This comes because of urbanization and rural-urban migration which has led to crowding in town outskirts leaving no land for crop production. Studies on urban vertical farming have proven that using this method can help in combating the issues of food insecurity and hidden hunger. Hidden hunger also known as micronutrient malnutrition is the inability to meet the daily recommended intake of vitamins and minerals needed for growth and development (Muthayya et al. 2013). Poor South African urban dwellers are failing to meet the daily required micronutrient intake putting their health at risk. Micronutrients and vitamins of great concern are iron (Fe), zinc (Zn), and vitamin A (Haberman et al. 2014). Micro-nutrient malnutrition also known as hidden hunger shows no clinical symptoms, yet it is very dangerous, and it can even result in death (Biesalski 2013b). Micronutrient-rich vegetables can be produced using affordable vertical farming structures to alleviate urban poverty and micronutrient malnutrition in South African urban settlers.

The main objective of study was to develop a vertical hydroponic system that will allow for the production of a mixture of vegetable for South African urban settlers. In this study two growth media and three vegetable types that can be produced in this system will be evaluated while the possibilities and limitations of this system in fighting food security and alleviating poverty in general will be addressed.

The study's primary hypotheses were that soil will be a suitable alternative to compost as growth media. Secondly, leafy, rooting and fruiting vegetables can be successfully be produced simultaneously in a single vertical system. Thirdly, foliar application of Fe and Zn will increase the plant tissue nutrient content (Fe, Zn, P, K) over control plants. Lastly, cardinal orientation will have an impact on the growth and yields of vegetables, with west facing plants performing less than the east facing counterparts.

3.2 Materials and Methods

3.2.1 Trial location

The field study was conducted in an open space (Figure 3.1) at Innovation Africa at UP (IA@UP), Phytotron D. The experimental farm is sitting at an altitude of 1372 m and a co-ordinate of 25.450 N and 28.160 E of the equator (Tanner et al. 1999). The plant tissue and soil analysis were done at the Soil Science laboratory at the University of Pretoria, Main Campus.

Figure 3. 1 Open space on IA@UP at Phytotron D where the vertical structures were located

3.2.2 Climate

In the first season (2020-2021) the crops were established in October (2020) and final harvesting was done in January and February (2021). In the second season (2021) crops were established in August (2021) already and final harvesting was done in December (2021) (Table 3.1).

Table 3. 1 Planting and harvesting dates for the vegetables in the two seasons.

Vegetable	**Season 2020-2021**		**Season 2021**	
	Planting date	**Harvesting date**	**Planting date**	**Harvesting date**
Beetroot	01/10/2020	18/02/2021	06/08/2021	10/12/2021
Garden pea	01/10/2020	27/01/2021	06/08/2021	01/12/2021
Swiss chard	01/10/2020	08/02/2021	06/08/2021	01/12/2021

During the trial periods (Table 3.1) there was little variation on average in the weather conditions of the experimental farm (Figure 3.2). The maximum rainfall received in the first season (2020-2021) was 725.2 mm with 632 falling during the trial period and in the second season (2021-22) rainfall recording was 777.4 mm with only 506 mm falling during the trial period (Figure 3.1 A and B). The average temperature was fluctuating in both growing seasons. During the second season, the crops were established two months earlier than in the first season, resulting in the crops experiencing lower maximum temperatures during establishment (23.6°C versus 28.6°C). But for the rest of the growing season the temperatures were similar (around 28°C). However, the minimum temperatures were different, with temperatures starting at 14°C increasing to 17°C in the first season as compared to the lower temperatures (8°C at plant increasing to 15°C at harvest) in the second season.

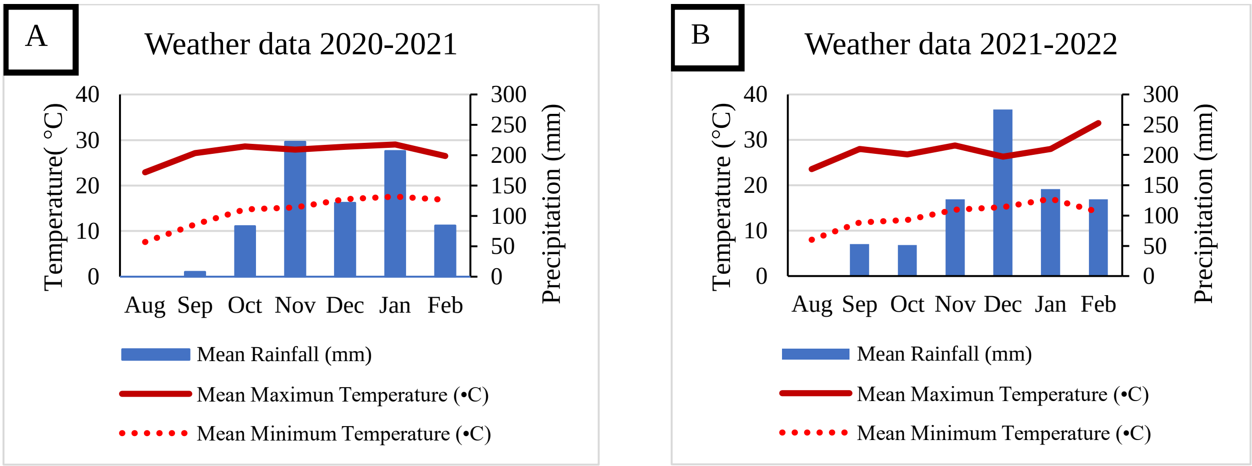


Figure 3. 2 A and B present the temperature and precipitation recordings of the experimental farm during the two growing seasons

3.2.3 Experiment setup

The study was comparing the effect of two growth media with or without the addition of Fe and Zn on the growth and yield of different vegetables. Two winter trials were conducted and will be discussed in detail in this dissertation. The vegetables grown in this trial were; garden peas, Swiss chard, and beetroot. Both trials were evaluating the effect of foliar micronutrient fertilization on the overall chemical composition of the vegetables and to see if it can feed and improve the nutritional status of a family of four (two adults and two children). Treatment effects were evaluated through laboratory analysis. Analysis for the growth media was done before trial establishment and after trial termination. Plant tissue analysis was done after trial termination.

3.2.4 Crop Choice

This experiment was aimed at identifying the suitability of producing nutritional and popular vegetables in a vertical bag farming system. The vegetables grown were beetroot for its leaves and roots, garden peas for its pods, and Swiss chard as a leafy vegetable. Garden peas is a major source of protein and can be used in stews, and for adding colour to rice and potatoes. Swiss chard form part of the diet of most middle- and low-class urban settlers, served as a relish, or as a side dish with meat. It is a rich source of iron and vitamin D. Beetroot is rich in folate, a vitamin that plays a major role in growth, development, and heart health. There are several benefits to eating beetroot, including its nutritional value, delicious taste, and ease of incorporation into the diet. It can be served as a salad, used for making juice, and grated or sliced raw to be eaten raw. For the cool season crop trials, all vegetables were established directly from seeds. Two seeds were planted in each planter bag for the small-seeded vegetables such as beetroot (Crimson Globe) and Swiss chard (Beet Fordhook giant). For the garden pea (Sugar snap), one seed was placed per planting bag. Certified seeds (Figure 3.3) were used hence there were few problems with germination. Reseeding or where possible seedlings that were thinned from one bag were transplanted into those bags where no seeds germinated. This was done two weeks after initial sowing.

Figure 3. 3 Seed packages of the crops and cultivars used during the two cool seasons

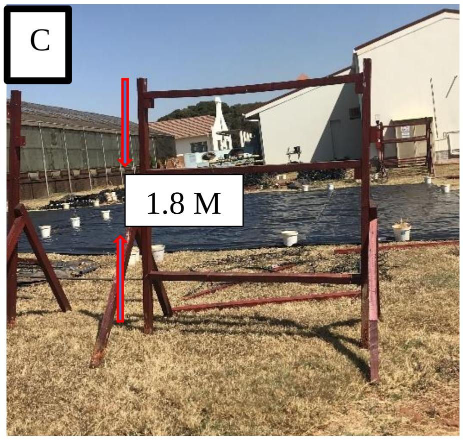
3.2.5 Vertical bag farming system

The trial was established in October 2020 and the experimental design was a factorial in a randomized complete block (Figure 3.4 A). A total of 16 vertical wood structures with three levels (Figure 3.4 B) (Appendix D) were constructed and painted with a varnish paint to protect them against adverse weather conditions. Out of the 16 wood structures, eight were used for this trial and the other eight were for another trial that was running concurrently with this study. The vertical structures were placed on top of a black plastic sheeting to suppress weeds (Figure 3.4 C). The structures had two cardinal orientations (east and west) (Figure 3.4 E). Growth media was randomly allocated to a structure, with 4 structures having compost and the other 4 having soil. Saddle bags (made from shade netting) (Figure 3.4 D) were used to support planter bags at both sides of the vertical structures. Small planter bags (1.25 ℓ, 100x75x200 mm) were placed on the top layer of the vertical structure followed by middle sized bags (9 ℓ, 175x150x350 mm) for the middle and bottom layer. The top layer was 1.8 m above ground and the spaces between the levels was around 60 cm. The length of a horizontal beam was 1.8 m which allowed for 16 small planter bags on each side (32 in total) or eight medium sized bags (16 in total) per level. In total the structure accommodated 64 crop plants, 32 on the eastern side and 32 on the western side.

A

	I	II	III	IV
East	CT	ST_0	CT_0	ST_0
	CT	CT	ST_0	ST
	ST	ST	ST	ST_0
	ST_0	CT	CT	CT_0
	CT_0	ST_0	ST_0	CT_0
	ST_0	CT_0	CT	ST
	ST	CT_0	ST	CT
West	CT_0	ST	CT_0	CT

CT_0= Compost control plants CT= Compost grown plants treated with Trelmix ST_0= Soil control plants ST= Soil grown plants treated with Trelmix



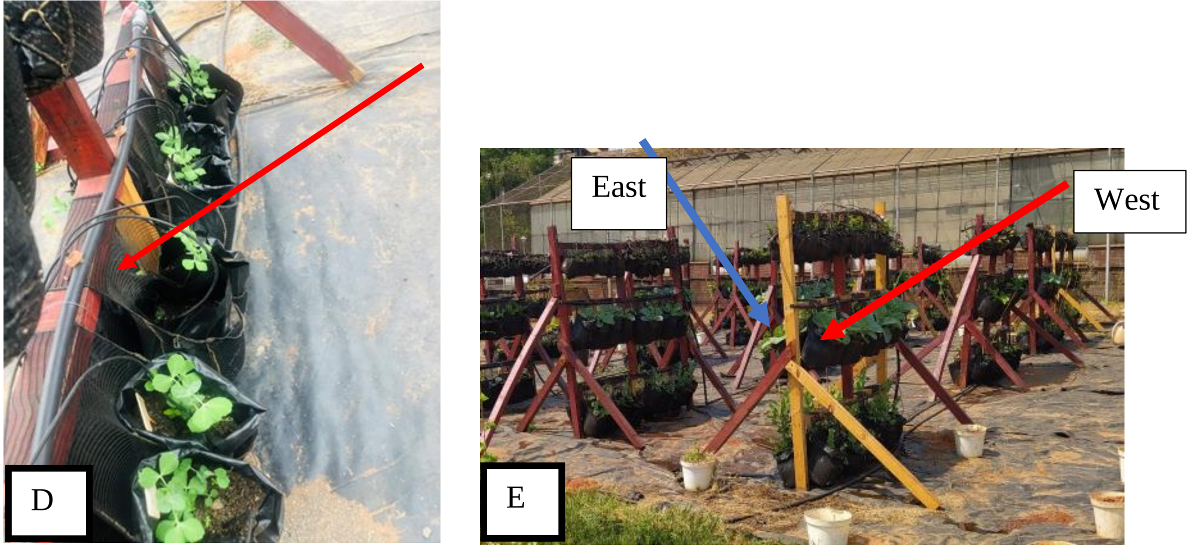


Figure 3. 4 A—field layout B— show the vertical structures, the 3 levels per structure and the black sheeting, C— the height of the structure and the length of the vertical beam D— saddle bags supporting the planter bags with garden pea plants on the lower level of the structure, E— The two-cardinal orientation (east and west)

Due to the heavy weight of the growth media (mainly soil), severe rain and wind storm and gravitational force, some structures collapsed (3.5 B) while some slant dangerously to one side. Therefore, it was decided to add middle and side support beams to give more stability to the structures (Figure 3.5 A).

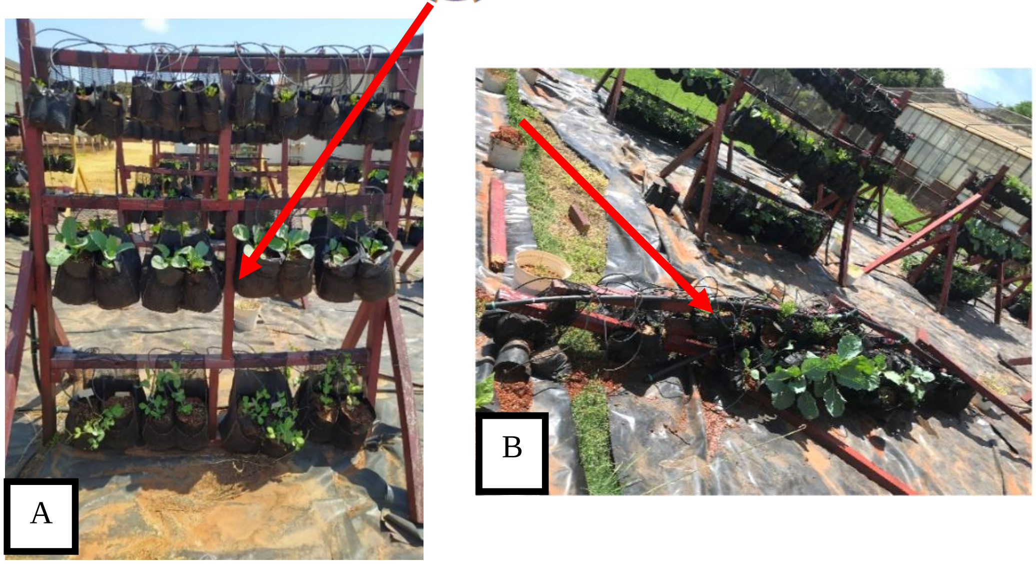


Figure 3. 5A —middle and side beams to support the structures (indicated by the arrows) and B— a collapsed structure

3.2.6 Treatments

This study was evaluating the effect of the following factors:

1. Growth media- two different growth media (soil and compost) were used. Of the eight vertical structures that were used in this study, four were for compost and 4 were for soil. Soil was used since it could be free of charge if collected from around the home, while compost was included as an environmentally sustainable growth media source. The aim was to determine both growth media's suitability for the vertical bag system. Effect of the growth media was tested on the growth and yield of the three vegetables (beetroot, garden pea and Swiss chard).
2. Cardinal orientation- although this was not part of the original proposal, the effect of the direction in which the planter bags were placed had on the growth and yield of the vegetables were evaluated. Equal number of planter bags were placed on either side of the structure and were then compared in terms of growth and yield.
3. Application of Trelmix (a micronutrient rich liquid fertilizer containing Fe and Zn). Equal number plants per side of the vertical structure were randomly selected and marked to be receiving 1 ml of Trelmix once a week. For the top layer, 8 plants were selected per side,

for the middle and the bottom layer, 4 plants on either side were receiving Trelmix. This extra Fe and Zn were an addition to the standard NPK that was applied to all the vegetables.

4. Irrigating using water from two different sources (a storage tank as opposed to a municipal tap water). This was done more for demonstration purposes than with any expectation of differences. The storage tank was used to irrigate four of the eight soil structures and four of the eight compost structures. A municipal tap was used to water the remaining structures. Municipal water was used to fill the storage tank, ensuring that the water quality was the same.

3.2.7 Growth media

Two growth media were tested for suitability in this trial (soil and compost). Red Hutton soil was collected from the University of Pretoria's Experimental farm and the compost was purchased from Qualicon Resources (Pty) Ltd in Pretoria East. In preparation for potting, the growth media was sieved and wetted. During potting the growth media was weighed using a measuring scale, making sure that all same-sized bags were of the same weight to ensure that the bags were balanced on the structures. For soil potting, 1.4 kg and 5.5 kg of soil were filled into small and medium-sized planter bags, respectively. In the 2019/2020 summer trial, germination and plant growth were badly affected by soil crusting and poor drainage thus for the two winter crop trials, the soil was mixed with vermiculite at a ratio of 5:1 (40 kg of soil was mixed with 8 kg vermiculite) to improve aeration (Figure 3.6 A and B). After thorough mixing, the mixture was used to fill the planter bags in readiness for planting. Soil analysis was done before trial establishment which was before addition of vermiculite. For compost potting, a plant based compost was used, 750 g and 3.5 kg were weighed to fill the small and medium bags respectively. After potting, the growth media was irrigated for a week to moisten it and to leach the compost since fresh compost was used and there was a concern that it will burn the crops. Before potting, both growth media were analyzed for pH and nutrient content, the soil was low in most plant nutrients as compared to compost (table 3.2).

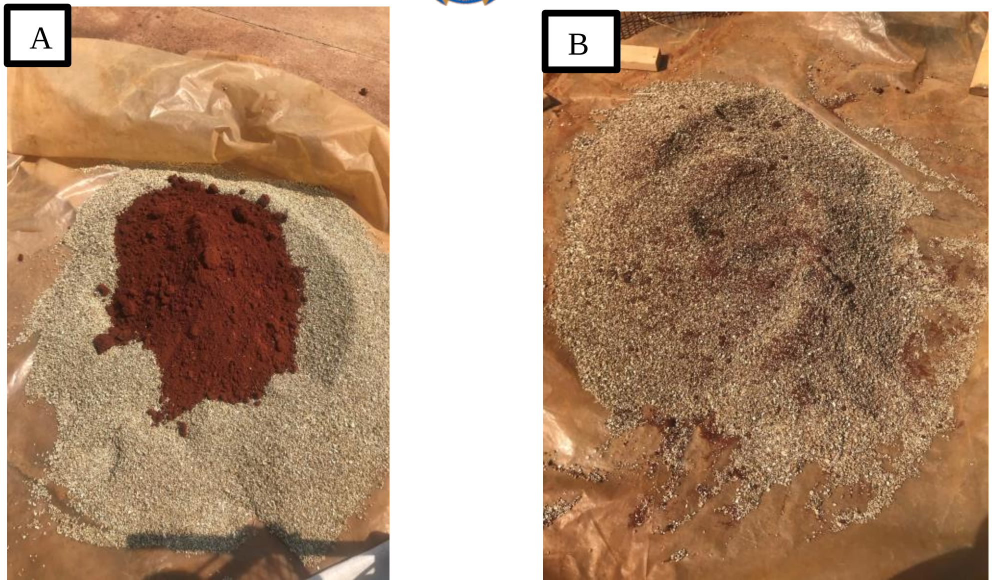


Figure 3. 6 A before mixing and B after mixing the soil and vermiculite at a ratio of 5:1

Table 3. 2 Soil and compost analysis results before planting

	pH	**NO_3^-**	**NH_4^+**	**P**	**K**	**Zn**	**Fe**
	(KCl)	**mg kg^{-1}**					
Soil	4.58	13.02	5.79	0.7	39	0.49	20.79
Compost	7.26	1 277.37	406.19	40.6	8 283	77.642	342.67

3.2.8 Irrigation system

A permanent drip irrigation system was installed with two water supply methods (tank (Figure 3.7 A) and municipal tap water (Figure 3.7 B)) was used. A mother line was connected to either a tank or tap and at each structure, daughter lines delivered water to each of the three levels on a structure. An arrow dripper connected to a four-way manifold (Figure 3.7 C) with the capacity to deliver 2 l of water hr^{-1} was then inserted into each of the planter bags. A control valve (Figure 3.7 D) was installed on the daughter lines (Figure 3.7 F) to control water flow and to avoid wasting water through over irrigation especially when irrigating the small planter bags, they will reach field capacity quicker than the medium size bags. During the first winter cropping cycle (2020/2021) the municipal water supply to the site was interrupted for almost three weeks. Due to this, both the mother lines were connected to the water tank for 2020 as well as the 2021/2022 growing seasons.

A simple handheld water sensor (Figure 3.7 E) was used to keep the moisture content in check and the growth media was always kept at field capacity. Irrigation was done after one to three days, depending on how much rainfall was received in the previous 12 hours. The total amount of irrigation water used per vegetable is recorded on table 3.3. The water received per vegetable is dependent on the growth cycle of the vegetable and the size of the planter bag. Swiss chard received more water because it’s cycle was long and it was grown on the medium bag size. It was also harvested multiple times. Even though the beetroot cycle was ten days longer than Swiss chard, the bag size was smaller hence it used less water.

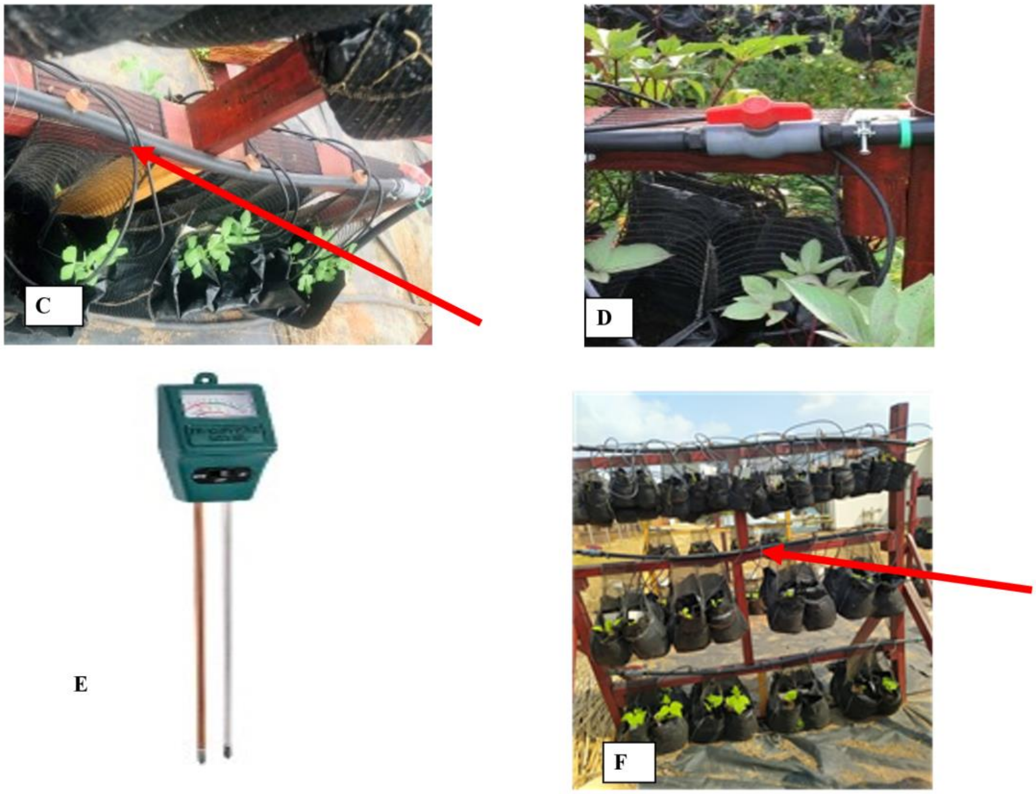


Figure 3. 7 The two water sources A— Storage tank, B— Municipal tap water. C—Dripper lines connected to a four-way manifold, D— control valve, E— portable moisture sensor, F— Sublines (each level has 1 subline)

Table 3. 3 Amount of water applied for a single growing cycle (2020/2021)

Crop	**Compost**		**Soil**	
	Total ℓ per plant	**Total ℓ per crop per structure**	**Total ℓ per plant**	**Total ℓ per crop per structure**
Beetroot	41.3	661.3	61.3	980
Swiss chard	108.7	869.3	131.5	1052
Garden peas	98.7	789.3	119.5	956
Total ℓ per structure	-	4633.3	-	6088

3.2.9 Fertilizer application

Due to a delay in the growth media analysis data, fertilizer needs were based on the amounts of N, P and K extracted from the field per ton of produce (table 3.4). These extraction amounts were based on information obtained from Hygrotech (2019). The amount of fertilizer required for each crop was calculated using a good yield under irrigation. The amount of Limestone ammonium nitrate (LAN 28%), superphosphate (8.3%), and potassium chloride (KCl 50%) applied are presented in table 3.5. The amount was split and applied twice during the growing season: the first application was done a week before planting with the last application four weeks after planting. After germination, an equal number of plants from both cardinal orientations were selected to receive Trelmix as a weekly foliar spray (at a ratio of 1 ml:1 l of water) and the rest served as control plants. The Trelmix contains Fe and Zn which have been identified as part of the main nutrient deficiencies in human diets. The aim of adding the Trelmix was to biofortify the crops with these two nutrients. The Trelmix nutrient content is listed in table 3.6.

Table 3. 4 N, P and K requirements of beetroot, Swiss chard, and garden peas. Expressed amount of N, P and K removed per ton of produce

Crop	**Yield (t ha^{-1})**	**N (kg t^{-1})**	**P (kg t^{-1})**	**K (kg t^{-1})**
Beetroot	25	2.9	0.5	6.9
Swiss chard	15	5.0	0.6	5.0
Peas	3	10.0	1.5	7.1

Table 3. 5 Amount (g per bag) LAN, Superphosphate and KCl applied to each crop in both seasons

Crop	**LAN (28%)**	**Supers (8.3%)**	**KCl (50%)**
Beetroot	0.2	0.1	0.3
Swiss chard	1.0	0.2	0.6
Peas	0.4	0.1	0.2

Table 3. 6 Trelmix formulation

kg	***l***
22.6 g Fe/kg	21.3 g Fe/*l*
3.2 g Cu/kg	3.0 g Cu/*l*
3.3 g Mn/kg	3.1 g Mn/*l*
2.4 g Zn/kg	2.3 g Zn/*l*
1.1 g B/kg	1.0 g B/*l*
0.3 g Mo/kg	0.3 g Mo/*l*
0.3g Mg/kg	0.3 g Mg/*l*

Figure 3. 8 Container of Trelmix

3.2.10 Weed, Pest, and disease control

Vegetables were constantly monitored for any signs of weeds, pests and diseases. Because planting was done late in the season, there was an outbreak of aphids and pea moths (Figure 3.9 A). Cypermethrin mixed at a ratio of *5 ml/10 l* of water was used for spraying to prevent the further spread of these pests. After germination, there were small animals that were feeding on the garden pea leaves, affecting the growth of the plants (Figure 3.9 B). These can be small farm herbivores such as rabbits, rock hyrax and duiker buck. Some garden pea plants died due to damping off. Powdery mildew was a problem in the second growing season (Figure 3.9 C). Weeds when spotted, when removed manually by pulling them out by hand.

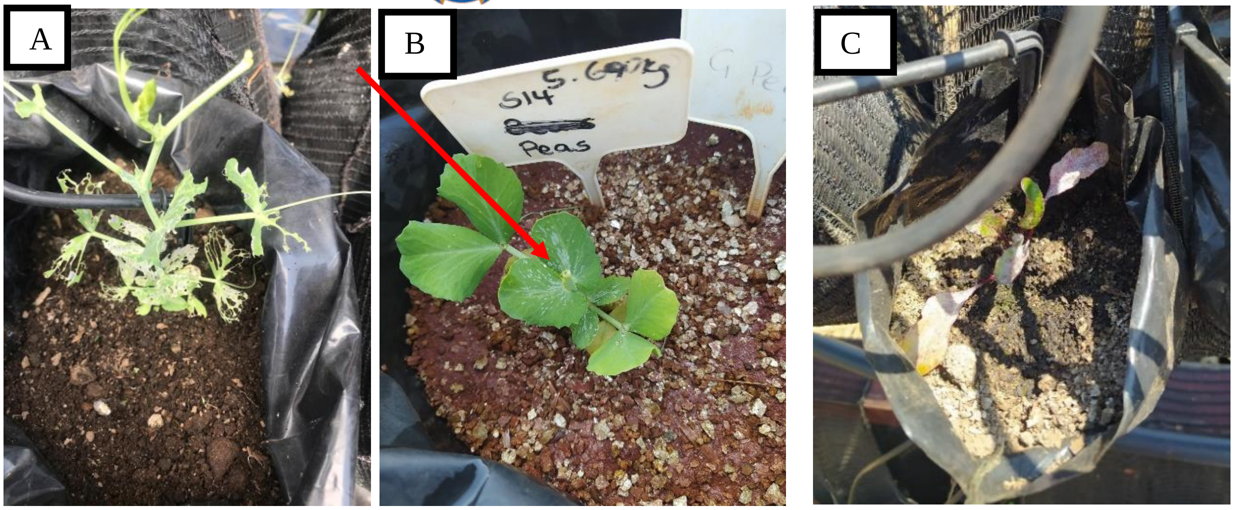


Figure 3. 9 A— a pea plant affected by pea moths, and B— a 2-week-old pea plant affected by small herbivores by feeding on the aerial part of the plant C— effected by powdery mildew on a beetroot plant

3.2.11 Harvesting and Parameters Measured

During the growing season, weekly plant height measurements were taken for all three vegetable crops. The beetroot was only harvested once while garden pea and Swiss chard were harvested more than once. Data collected during the continuous harvesting of Swiss chard were the number of leaves, leaf area, and leaf fresh mass and leaf length (Fig 3.10 A). For garden pea, the parameters were the number of pods per plant, seeds per pod, pod length (Fig 3.10 B), and pod fresh mass. At final harvest of the garden peas, the pods were picked from the plant, and the rest of the plant was cut at ground level Parameters recorded were the plant fresh mass, pod fresh mass, number of pods, length of pod and seeds per pod. For Swiss chard, the whole plant was cut closer to the ground surface and parameters measured were leaf length, number of leaves, leaf area and leaf mass. Data collected during beetroot harvest were root fresh mass, leaf fresh mass, leaf area, number of leaves, root length (Fig 3.10 C), and root diameter. All plant material was put in brown paper bags and then taken to a ventilated drying oven at 68°C in preparation for plant tissue analysis.

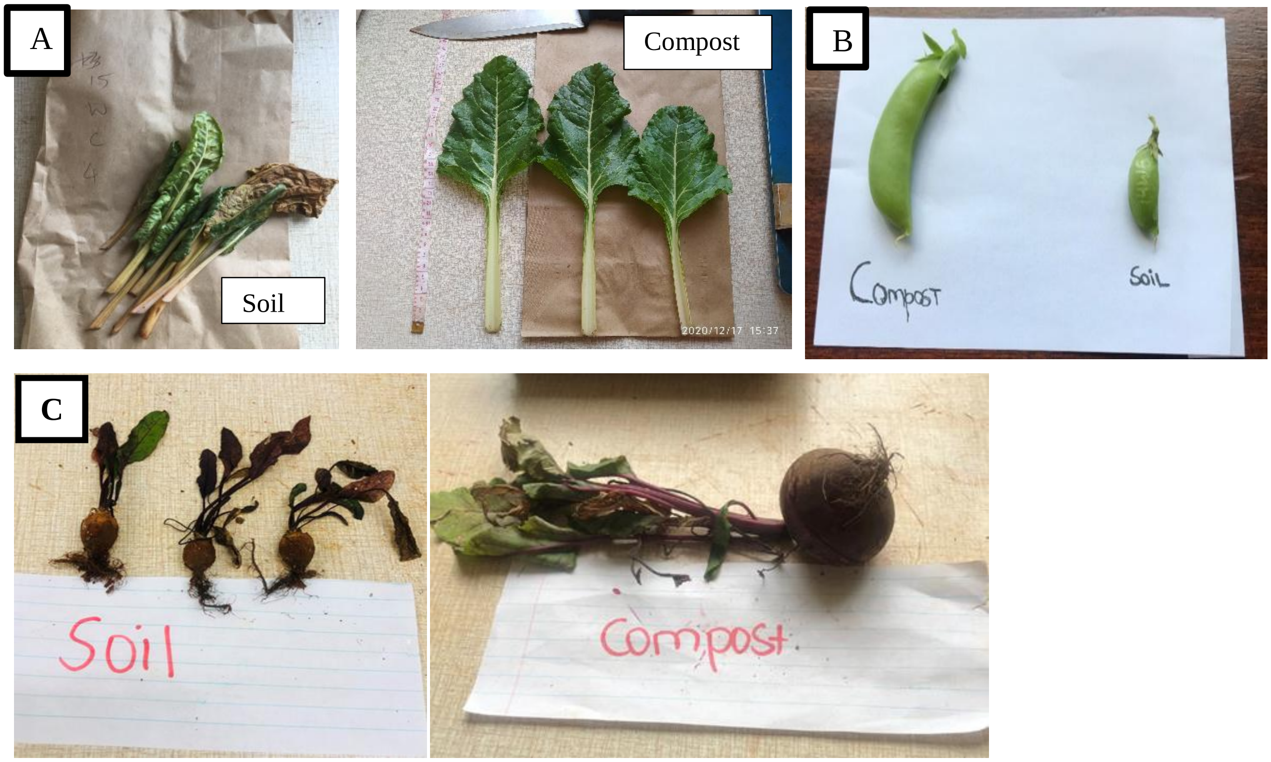


Figure 3. 10 Pictures that were taken during Swiss chard (A) garden pea (B) beetroot (C) harvesting

3.2.12 Chemical analysis

Chemical analysis was done at the Soil Science laboratory in the University of Pretoria, Hatfield campus. In preparation for planting, soil chemical analysis was done using a pH meter and spectrophotometer. Elements tested were pH, EC, Nitrate (NO_3), Ammonium (NH_4), Magnesium (Mg), phosphorus (P), Calcium (Ca), Potassium (K), Iron (Fe), Copper (Cu), Zinc (Zn) Aluminium (Al), Sodium (Na), and Manganese (Mn). Similar elements were also analyzed at the end of the trial in both the growth media and plant tissues. Analysis procedures were adopted from the AgriLASA soil handbook.

a) Growth media analysis- soil and compost samples were first dried, grinded using mortar and pestle, then sieved in preparation for analysis.

b) Plant tissue analysis- The above ground parts of the plant were oven dried, grinded and sieved then digested for analysis.

3.2.13 Statistical Analysis

Data obtained from the trial was further processed using Microsoft Excel and statistically analyzed using the Statistical analysis Software programme (SAS) (Webb et al. 2014). ANOVA tables are presented in the Appendix. To determine if treatment means were significantly affected by the applied treatments, Duncan's LSD at the 5% level of probability were used.

CHAPTER 4

4.0 Results and discussion

The results of growth media analysis before planting and after harvesting are presented in this chapter along with effect of the growth media, direction and foliar Trelmix treatment on the yield and yield parameters of three vegetables (beetroot, garden pea and Swiss chard). The yields of the vegetables were significantly influenced by the growth media, with some parameters being influenced by cardinal orientation and Trelmix treatment. Growing season also had a significant effect on the yield and yield characteristics.

4.1 Growth media nutrient content before planting and after harvesting

The pH of the soil and compost used in this study was suitable for the growth of the three vegetables crops even though the pH was higher than the recommended range which 5.5-6.5 (Crohn 2016) and was also higher after each harvest (Table 4.1). The increase in pH may be more of an irrigation and drainage issue. The growth media's electrical conductivity (EC) was low enough and did not cause problems. It was within the optimal EC range for crop growth which ranges from 0.8-1.8 dS m^{-1} and should not exceed 2.5 dS m^{-1} (Tibebe et al. 2022). A huge drop in EC for compost in the second season was observed and this may be due to leaching that was done before planting.

These findings are in line with Heath (2016) who reported an increase in leachate EC collected from pots of soil on vertical structures and in his study over irrigation was pointed the problem by Derrow (2017) who conducted the same study but in his study, irrigation was being monitored.

Although the soil may require additional nutrient treatment because it is not as nutrient rich as the compost, the soil's macro and micronutrient levels (P, K, Fe, and Zn) made it ideal for growing vegetables.

Table 4. 1 Minerals in growth media before planting (2020) and after harvesting in first season 2021

Growth media		Acidity and Minerals								
			dS m^{-1}	mg kg^{-1}						
		pH	EC	P	K	Fe	Zn	NH_4	NO_2	NO_2+NO_3
Soil	Before	7.18	0.18173	5.6	67.9	20.9	1.4	19.29	0.47	3.863
	After	7.47	0.16089	28.4	126.95	30.5	1.416	4. 647	0.199	8.424
Compost	Before	6.91	0.84533	10078	6218.7	3308.1	895.1	65.365	0.111	60.872
	After	7.23	0.89075	9046.1	3792.9	2677.3	843.3	44.675	0.083	94.328

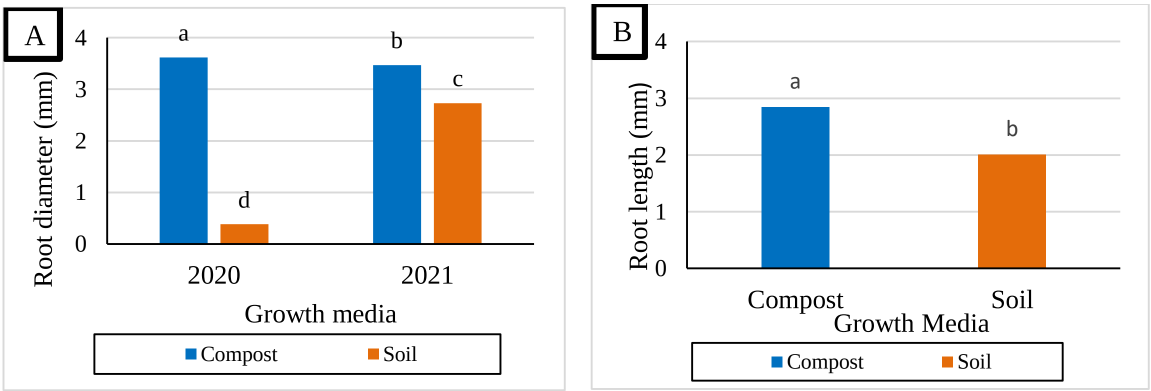
Table 4. 2 Minerals in growth media after harvesting in second season (2021)

Growth media	Acidity and Minerals								
		dS m^{-1}	mg kg^{-1}						
	pH	EC	P	K	Fe	Zn	NH_4	NO_2	NO_2+NO_3
Soil	7.7	0.17833	159.27	109.1	60.46	12.54	39.37	7.45	46.91
Compost	7.4	0.55581	6837.2	2243.8	1433.3	98.57	39.37	6.69	225.69

4.2 The effect of growth media on yield and yield components

4.2.1 The effect of growth media on the root size of beetroot

The edible root length and diameter of beetroot (Figure 4.1 A and B) differ significantly between the different growth media and seasons ($P<0.05$). Beetroot grown in compost had a bigger root diameter and were longer (Figure 4.2 A and B) than those grown in soil (Fig 4.2 C). While root diameter varies from cultivar to cultivar, growing conditions can affect the growth and expansion of root crops. According to AgroTexGlobal (2020), an average diameter of a medium sized beetroot ranges from 5-7 cm, smaller beetroot varieties are harvested after 90 days with a diameter of 4-5 cm. The beetroot variety used in this study was Crimson globe which has a potential to yield a root diameter of 5 cm for early cropping. Results obtained from this study were below the normal average beetroot diameter ranges. We can attribute the smaller root diameter and length to a lack of root respiration. After irrigation and on rainy days, the soil was taking longer to dry out. Sapkota et al. (2021) tested the effects of organic and inorganic nitrogen sources on the growth, yield, and quality of beetroot varieties in Nepal. The researchers found that poultry manure and farm manure treatment increased plant height, leaf number, leaf length, leaf width, and beetroot diameter. This might collaborate with the results obtained in the compost grown crop. Even though the beetroot did perform better in the compost, this growth media was not without problems as some beetroots harvested from the compost was rotten (Figure 4.2 D and E).



Means denoted by the same letter indicate there is no significant difference at P< 0.05.

Figure 4. 1 The effect of growth media on beetroot growth and expansion. A=Root diameter for seasons 1 and 2, B= Root length for seasons 2

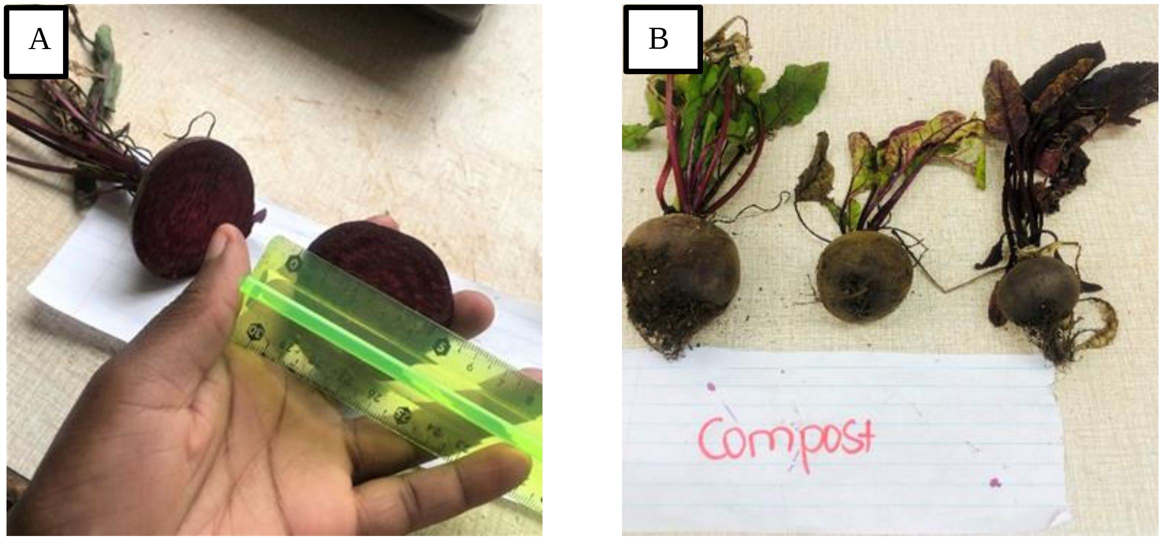
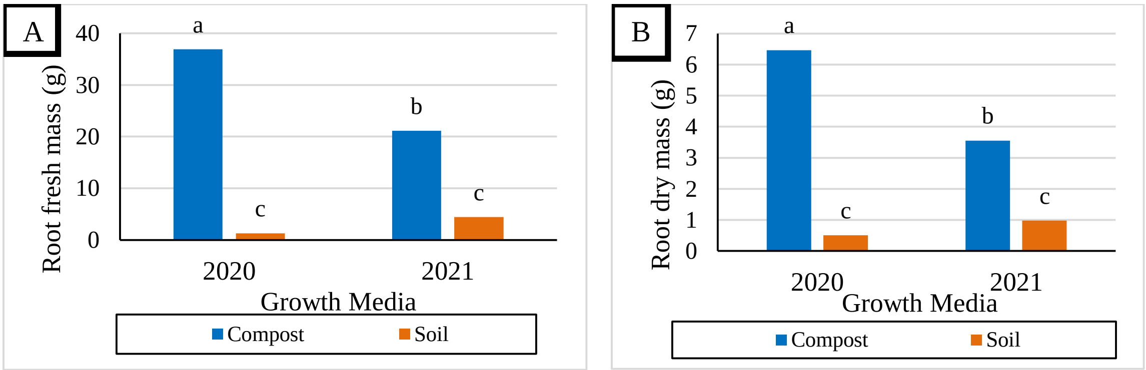


Figure 4. 2 The effect of growth media on beetroot bulb growth and expansion. A, B and C= pictures that were taken during the harvesting of beetroot. D and E= Rotting on some beetroot bulb harvested in compost

4.2.2 Yield of beetroot as affected by growth media

Beetroot yield was significantly influenced by growth media and season ($P<0.05$). Both fresh and dry mass in both seasons were significantly higher in the compost as growth media than in the soil (Fig 4.3 A and B). This finding is in agreement with Hlisnikovský et al. (2021) and Shafeek et al. (2019) who reported an increase in yield and yield parameters of beetroot when treated with compost and potassium. Similar findings were reported by Heydarzadeh et al. (2021) with application of 50 t ha^{-1} of animal manure resulted in an increase in root yield of field grown sugar beet (69.71 t ha^{-1}) as compared to the control plants (47.98 t ha^{-1}). Compost is a rich source of plant nutrients, and its decomposition releases nitrogen slowly into the environment. This is necessary for leaf development as well as for chlorophyll production. It is the leaves that manufacture plant food (sugars), which are then stored as sugar in the roots. The growth cycle was 138 days and 126 days for season one and two respectively. Both seasons were longer than the normal growth cycle for Crimson globe which is 90-110 days (Sakata 2018). Under normal growing conditions, an average beetroot bulb yield is 110 grams and for this trial, lower bulb yields were recorded. This might be because the bags used had a diameter of only 11 cm when pot plants require pots with a minimum diameter of 20 cm and quality deep (Candide 2022). Poor drainage, crusting, and compaction were observed in the soil, which resulted in poor growth and root development. Bolting was also a problem in soil grown beetroot (Fig 4.4 C). The first season's beetroot yield (2020/2021 (Fig 4.3 A)) was higher than that of the second season (2021/2022 (Fig 4.3 B)), possibly because the plants were affected by powdery mildew in the second season.



Means for seasons denoted by same letter indicate there is no significant difference at $P< 0.05$.

Figure 4. 3 The yield of beetroot as affected by growth media A= Root fresh mass, B= Root dry mass

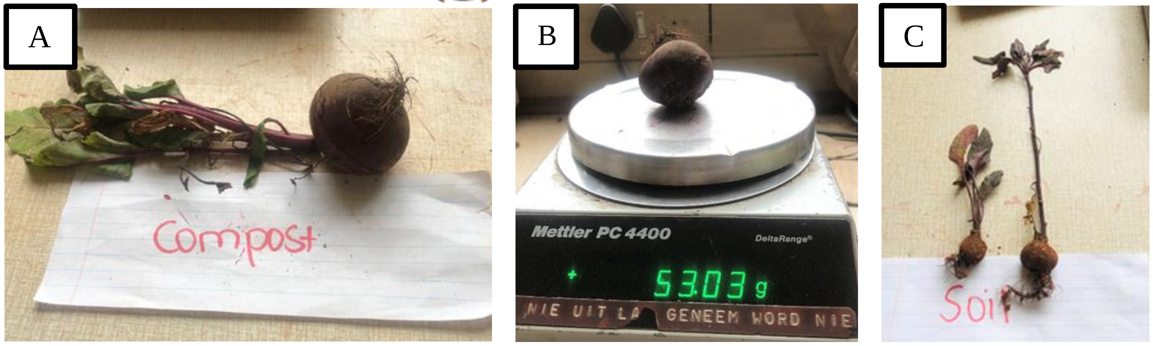
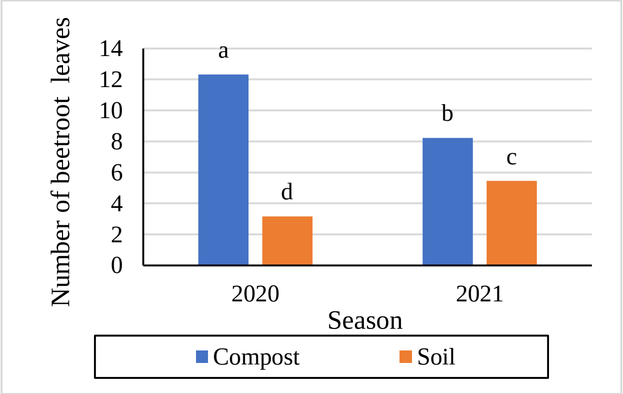


Figure 4. 4 Growth media effect on the root mass of beetroot A= Beetroot bulb harvested from compost, B= mass of a beetroot bulb harvested from compost and C= beetroot bulbs harvested from soil, one showing signs of bolting

4.2.3 Number of leaves per beetroot plant as affected by growth media

The type of growth medium and growing season significantly affected the number of beetroot leaves per plant (P<0.05). There were significantly more leaves in the compost (Fig 4.5). The results of this study agree with Dlamini et al. (2020) who observed a slight increase in plant height, the number of leaves, and fresh mass in beetroot after the application of cattle manure. Findings from Marajan et al. (2017) are also in compliance. In their study application of compost significantly increase the growth parameters (number of leaves, root fresh and root dry mass) of sugar beet plants as compared to that of the control plants.

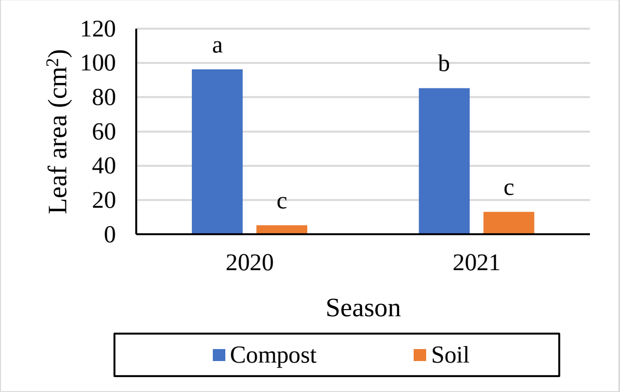


The same letter means indicate no significant difference at P< 0.05.

Figure 4. 5 The average number of beetroot leaves per plant as influenced by growth media and growing season

4.2.4 Beetroot leaf area as influenced by growth media

Beetroot leaf area was significantly affected by the growth media and growing season ($P<0.05$). Compost-grown plant leaves were bigger and greener than soil-grown plants (Fig 4.6). Soil grown beetroot leaves were having a purplish to reddish colour which could be a sign of P deficiency. Compost contains nitrogen and carbon, which are integral to leaf growth. In the first season, compost had a greater leaf area compared to the second season. This might be the result of a severe powdery mildew attack of the compost grown beetroot plants. Powdery mildew causes yellowing and withering of leaves by producing white spots on the leaves, thus reducing photosynthesis capacity (Cowger et al. 2012) .

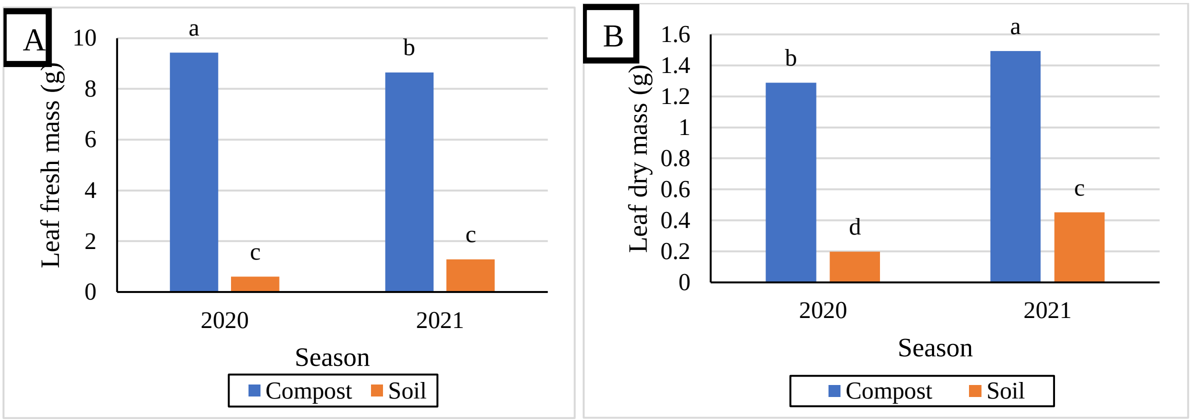


Means denoted by the same letter indicate there is no significant difference at $P< 0.05$.

Figure 4. 6 The beetroot leaf area as influenced by the growth media and growing season

4.2.5 Leaf mass of beetroot as affected by growth media

The mass of beetroot leaves varies significantly between the two-growth media. Leaf mass was higher in compost plants (Fig 4.7 A and B). The higher leaf mass can be attributed to the slow release of nitrogen by the compost, which is essential for leaf growth. The current study's findings agree with Marajan et al. (2017) who reported an increase in sugar beet leaf dry weight as a result of organic manure application. Since compost can be used as an organic fertilizer, it produces a higher leaf fresh mass when used as a growth media. Plant roots can easily penetrate through it since it is well aerated, and rich in plant nutrients. The compost used in this trial was first used to produce summer crops, and then re-used for the winter crop trial season one, whereas for the second season, fresh compost was mixed with reused compost from the previous seasons. Compared to the root yield, the leaf yield was less. This maybe a result of the below ground being cooler than the above ground. This study's findings echoed the findings by Kenter et al. (2006) who reported a difference in leaf and root dry mass of sugar beet as affected by temperature. The sugar beet tap root dry matter yield accumulated exponentially and leaf dry matter accumulated linearly.



Means denoted by the same letter indicate no significant difference at P< 0.05.

Figure 4. 7 (A and B). Leaf fresh and dry mass of beetroot as influenced by growth media

A two-way ANOVA showed no significant difference on the yield and yield parameters of beetroot based on cardinal orientation except in beetroot root dry mass (Appendix 2A). The current study's results are in compliance with findings from Jahan et al. (2016) and Islam et al. (2019) who reported no significant difference on Radish morphological characteristics because of cardinal orientation. From their studies, better yields were obtained from the control condition and least yields from the east orientation. In the first season, the east side recorded a better root dry mass while in the second season root dry mass was slightly higher on the west side compared to east (Table 4.3). Compared to the east side, the leaf dry mass was higher on the west side.

Table 4. 3 Beetroot yield and parameters as affected by cardinal orientation

Year	Direction	Root diameter	Root fresh mass	Root dry mass	Number of leaves	Leaf area	Leaf fresh mass	Leaf dry mass
2020	East	2.012	21.084	3.863a	7.800	51.879	5.076	0.747
	West	1.969	17.772	3.121b	7.705	49.657	4.956	0.800
2021	East	2.589	9.845	1.841d	6.595	47.427	4.983	0.951
	West	2.784	9.224	1.859c	7.082	51.085	4.956	0.994
	LSD	NS	NS	S	NS	NS	NS	NS

ANOVA results revealed a significant interaction between direction and foliar Trelmix treatment on the root yield of beetroot (Table 4.4). Beetroot control plants growing on the east side of the vertical structure had a better root yield compared to Trelmix treated plants. Beetroot grown on the west side had better root yields when treated with Trelmix compared to untreated plants. Better root diameter was recorded on micronutrient treated beetroot grown on the west side of the vertical structure and the lowest was recorded on east grown Trelmix treated beetroot plants. A higher beetroot yield (fresh and dry mass) was recorded on east grown control plants with the lowest recorded on west grown control plants. The increase in yield of treated plants support findings by Rahimi et al. (2019) who reported an increase in qualitative and quantitative parameters of sugar beet cv. Sonja as a result of foliar application of boron, iron, zinc and manganese. From their study, micronutrients effect was significant in all studied parameters.

Table 4. 4 Beetroot yield and yield parameters as influenced by Trelmix treatment and cardinal orientation

Direction	Micronutrient	Total fresh mass	Root diameter	Root fresh mass	Root dry mass	Number of leaves	Leaf area	Leaf fresh mass	Leaf dry mass
East	Control	22.587	2.426b	17.181a	3.077a	7.247	51.025	5.422	0.859
	Treated	18.337	2.175d	13.748c	2.626c	7.127	48.281	4.637	0.838
West	Control	17.288	2.200c	12.300d	2.282d	7.085	49.871	5.102	0.870
	Treated	19.580	2.552a	14.786b	2.699b	7.702	50.871	4.811	0.863
LSD		NS	S	S	S	NS	NS	NS	NS

4.3 Effect of growth media on Swiss chard yield and yield parameters

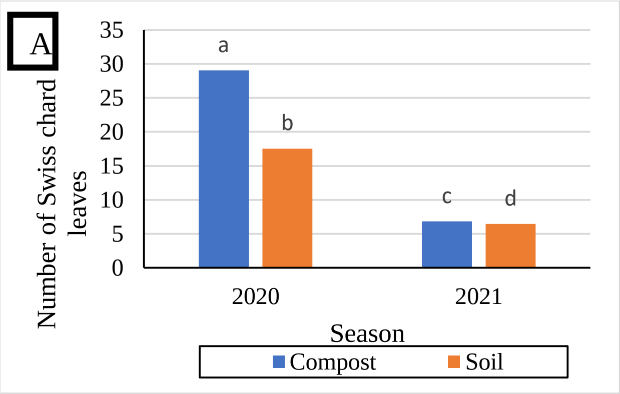
4.3. Swiss chard leaves harvested as influenced by growth media, cardinal orientation and foliar micronutrient treatment

Results from the two-way ANOVA showed a significant difference in the number of Swiss chard leaves harvested as affected by growth media and growing season ($P<0.05$). More leaves were harvested in the first season than in the second season (Figure 4.8 A). A total of three harvests were done during the second season, in contrast to seven weekly harvests in the first season. Soil yielded substantially fewer Swiss chard leaves than compost.

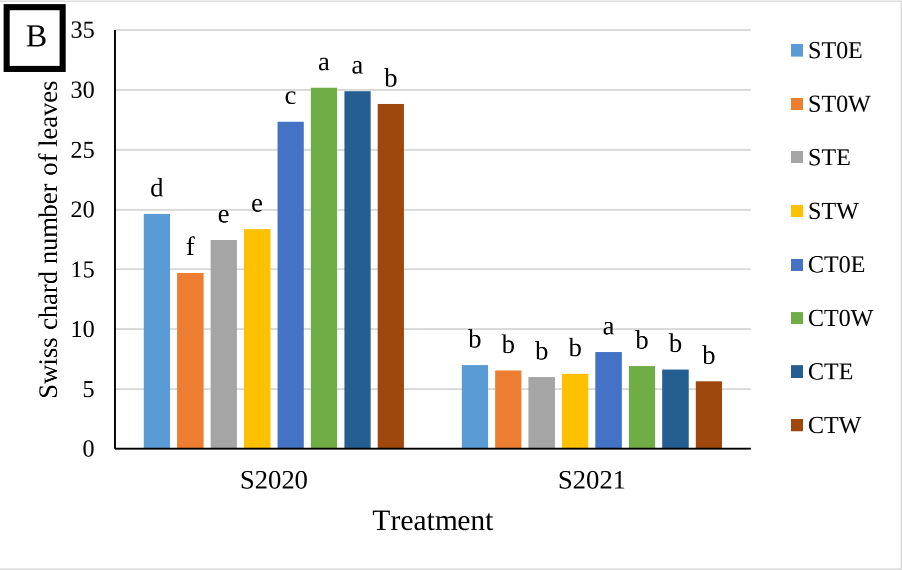
A positive three-way interaction was observed between growth media, cardinal orientation and Trelmix treatment for the number of Swiss chard leaves harvested (Fig 4.8 B). In season 1 (S2020) a higher number of leaves were harvested from CT_0W even though there was no significant difference on the mass recorded from it and CTE. Foliar micronutrient treatment in west grown compost plants in 2020 reduced the number of leaves harvested (CT_0W and CTW) and an opposite was observed in east grown compost plants (CT_0E and CTE). In soil growing plants different results were noted whereby Trelmix treatment in east growing (ST_0E and STE) plants resulted in a reduction in harvested leaves with an increase in west treated plants (ST_0W and STW).

In season 2021 (S2021) Trelmix treatment resulted in a reduction in the number of leaves regardless of the growth media used. East-grown non Trelmix treated compost plants (CT_0E) had recorded a highest number of leaves and it differ significantly from all other treatment combinations. The other treatment combinations did not differ significantly.

This study'sfindings are similar to the results of Eksi et al. (2015) who conducted a green roof farming trial evaluating varied compost rates with cucumbers and peppers. They found that higher amounts of compost led to higher plant yields. Perhaps this is because compost acts as a reservoir for plant nutrients while its cation exchange properties aid in nutrient retention. The second season's harvest didn't vary based on growth media. There were fewer leaves harvested in the second season than in the first season, which could be attributed to the use of pesticides which disrupted the growth of new leaves.



Means denoted by the same letter indicate there is no significant difference at $P< 0.05$.

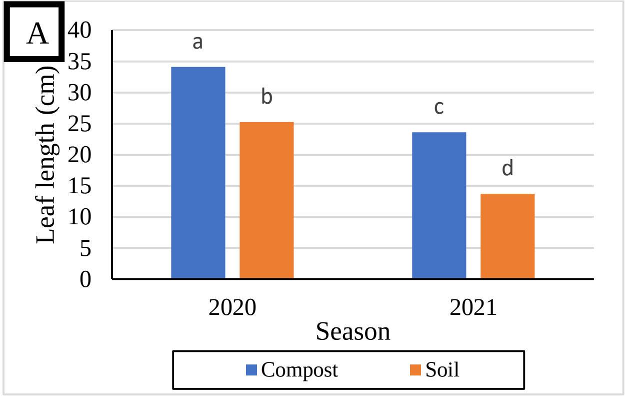


S= soil, C= compost, T_0 = control plants, T= Trelmix treated, E= east, W= west, S2020= growing season 2020, S2021= growing season 2021. Bars having same letters within a column group denote no significant difference LSD= 1.975

Figure 4. 8 A Influence of growth media on Swiss chard harvest B effect of interaction of growth media, direction and micronutrients treatment on the number of Swiss chard leaves in two seasons.

4.3.2 Influence of growth media on Swiss chard leaf length

Swiss chard leaf length was significantly affected by the growth media and growing season ($P<0.05$) (Figures 4.9 and 4.10). Compost-grown Swiss chard grew taller than soil-grown Swiss chard. Findings from the current study are in line with Rivelli and Libutti (2022) who reported an increase in Swiss chard leaf length due to soil application of organic fertilizer (Vermicompost). Drainage problems in the soil may have contributed to poor root respiration. It would take longer for the soil to dry out after rain and a dense crust would form. Compared to the second season, Swiss chard plants performed well in the first season (Figure 4.9 A). The cooler temperatures of the second growing season may have affected the drainage speed of the growth media.



Means denoted by the same letter indicate there is no significant difference at P< 0.05.

Figure 4. 9 The leaf length of Swiss chard as influenced by growth media

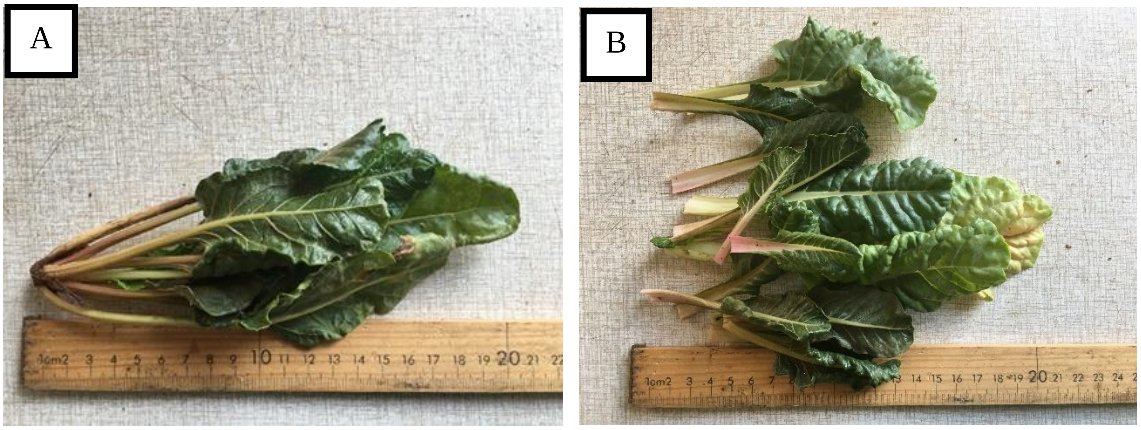
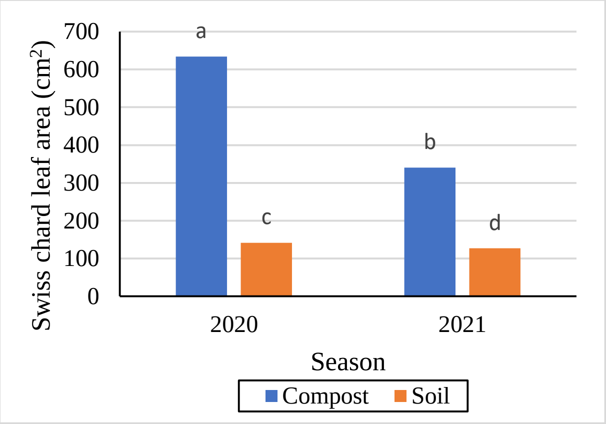


Figure 4. 10 Swiss chard length measured during harvesting. A= Compost harvested Swiss chard B= soil harvested Swiss chard

4.3.3 Swiss chard leaf area as affected by growth media

Swiss chard plants' leaf area was significantly affected by growth media (Figures 4.11). Compost-grown plants have broader leaves than soil-grown plants. Results from the current study are in compliance with Riaz et al. (2015) who reported a significant increase in the leaf mass of gerbera plants with use of different growing substrates and maximum leaf area was recorded from a mixture of silt, farmyard manure and topsoil. A higher leaf area was observed for compost plants in the first season. Despite these findings, the difference in soil between the first and second growing season was minimal. Smaller leaf areas may be caused by powdery mildew infestation. Powdery mildew affects leaf growth, which in turn affects the total harvest and its severity is related to the age of the leaf (Marçais and Desprez-Loustau 2014). Powdery mildew causes necrosis and deformation that reduces leaf area.

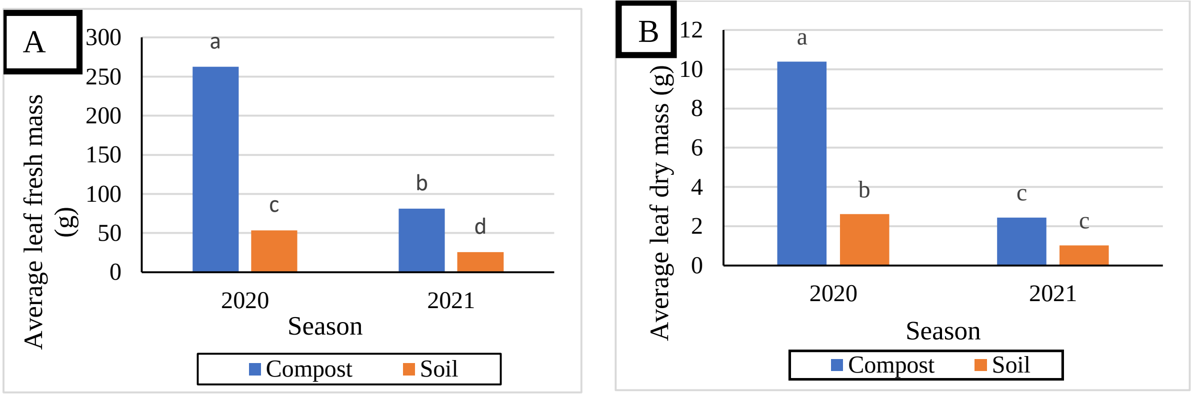


Means denoted by the same letter indicate there is no significant difference at $P< 0.05$.

Figure 4. 11 Effect of growth media on the Swiss chard leaf area

4.3.4 Effect of growth media on Swiss chard yield

A significant difference exists in the number of Swiss chard leaves harvested on compost versus the soil (Figure 4.12 A and B). The compost yielded bigger and more leaves (Figure 4.13 A). Comparatively, soil harvested Swiss chard leaves were short and small. Soil harvested Swiss chard was also light green to yellow in colour. This study confirms the findings of Abbey and Appah (2016), who examined the effect of variable compost manure rates on the growth of kale and Swiss chard. Swiss chard yields were higher when compost manure was added at a higher rate. As compared to the second season, higher Swiss chard yields were recorded in the first season. A powdery mildew outbreak (Fig 4.13 B) may be to blame for the decrease in the number of harvestable leaves. Also, some plants were scorched (Fig 4.13 C) and some died (Fig 4.13 D) due to the spraying of chemicals against powdery mildew, which resulted in fewer harvests.



Means denoted by the same letter indicate there is no significant difference at P< 0.05 with a different letter statistically significant.

Figure 4. 12 Influence of growth medium on Swiss chard leaf mass. A= leaf fresh mass B= Leaf dry mass

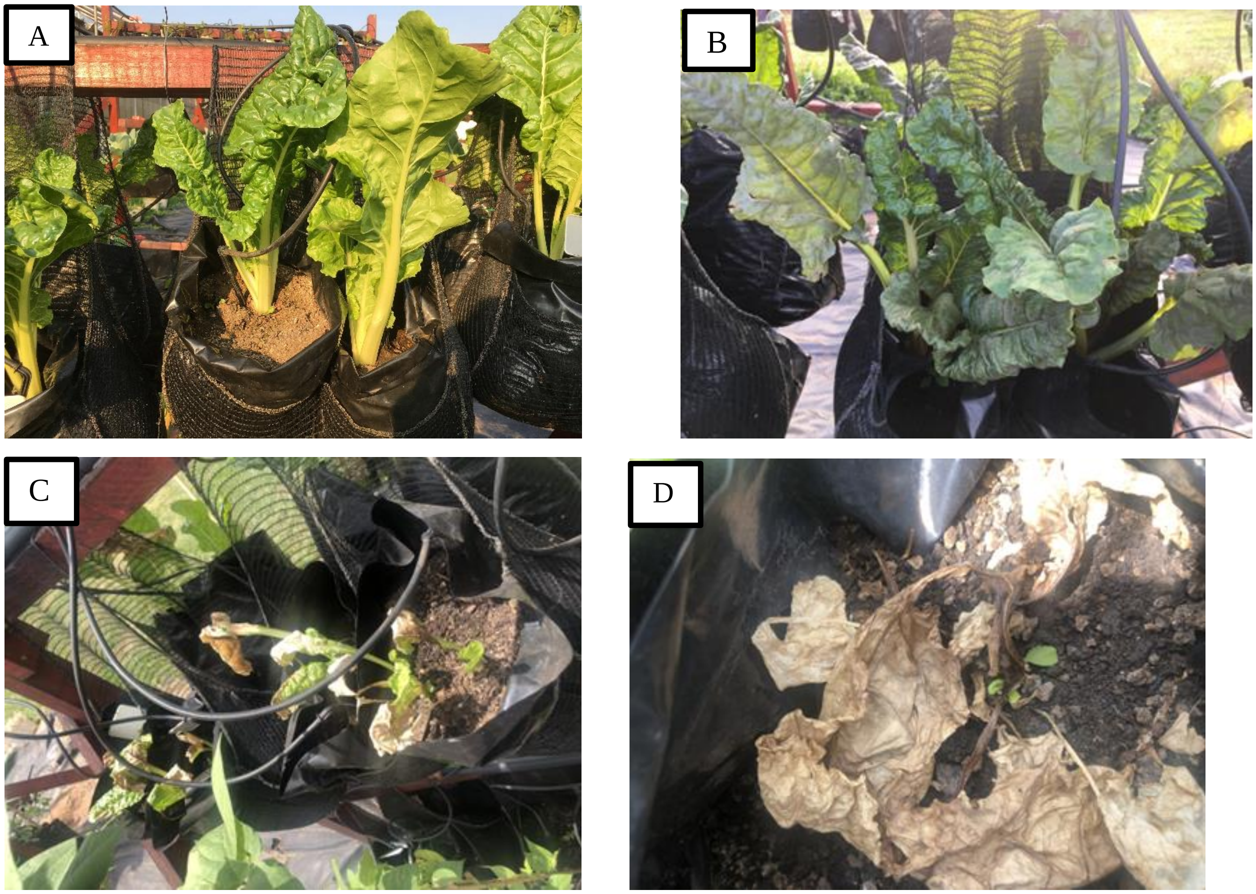


Figure 4. 13 Influence of growth medium and pesticide treatment on Swiss chard leaf mass A= Health growing Swiss chard B= powdery mildew infested plants C= Plants after spraying for powdery mildew D= The leaves were scorched, and some plants did not recover

Cardinal orientation had no significant effect on the Swiss chard yield and yield characteristics. A slightly higher number of Swiss chard leaves were harvested on the east direction compared to west (Table 4.5). The leaves on the west side were longer compared to east. In both growing seasons, yield parameters varied less between cardinal and orthogonal orientations. The results of the current study are in line with Derrow (2017) who found no significant difference on the yield and yield traits of Cardinal basil (*Ocimum basilicum* 'Cardinal' L) when grown on an A frame east-west oriented vertical structures but a variation was observed when comparing the south and north side. Dragićević (2011), on his study on the best cardinal orientation for greenhouse to absorb maximum solar radiation, he concluded that E-W direction is the perfect orientation for crop growth because in Winter more solar radiation is absorbed and in Summer the absorbed radiation is reduced. Similar results were also reported by Jahan et al. (2016) with spinach that was grown under a mahagoni tree, plants varied significantly due to the tree while the orientation effect was not significant.

Table 4. 5 Swiss chard yield and yield parameters as a function of cardinal orientation

Year	Direction	Number of leaves	Leaf length	Lea area	Leaf fresh mass	Leaf dry mass
2020	East	23.591	29.451	381.574	153.516	6.629
	West	23.023	29.889	394.181	162.600	6.400
2021	East	6.932	18.640	240.406	55.804	1.700
	West	6.341	18.684	227.471	51.095	1.775
	LSD	NS	NS	NS	NS	NS

Trelmix treatment had a significant influence on Swiss chard leaf dry mass. Micronutrient-treated plants had a better leaf dry mass compared to non-treated plants (Table 4.6). The reason may be that micronutrients promote plant growth and increase yields. A better leaf dry mass was recorded in S2021. Control plant's dry mass did not differ significantly across the two growing seasons. Results from the current study are in line with Ballabh et al. (2013) who reported a substantial increase in yield and yield parameters of onion due foliar micronutrient treatment but contradicts findings by Ozdener and Aydin (2010);Rugeles-Reyes et al. (2019);Zhi et al. (2015). In their studies they were evaluating the effect of foliar zinc spraying on the growth and yields of arugula plants and no significant effects were found.

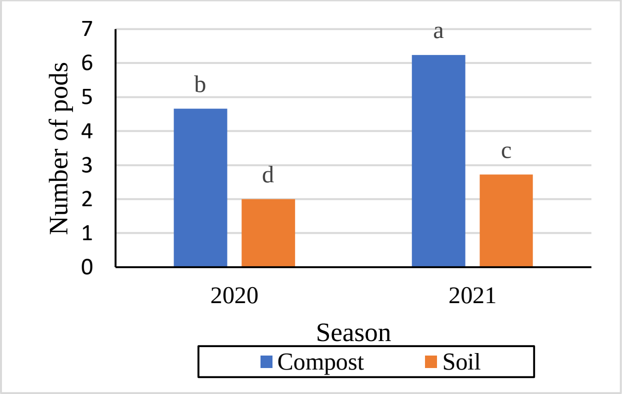
Table 4. 6 Effect of micronutrient treatment on the yield and yield parameters of Swiss chard

Year	Micronutrient	Number of leaves	Leaf length	Leaf area	Leaf fresh mass	Leaf dry mass
2020	Non-treated	6.136	28.293	238.439	55.878	1.762c
	Treated	23.636	31.047	394.681	167.614	5.403b
2021	Non-treated	7.136	17.950	229.438	51.022	1.713c
	Treated	22.977	18.595	381.074	148.412	7.596a
	LSD	NS	NS	NS	NS	S

4.4 Garden pea yield and yield parameters as affected by growth media

4.4.1 The effect of growth media on the number of pods produced by garden pea plants

Growing media and growing season significantly influenced pea pod development ($P>0.05$). More pods were harvested from compost grown plants than soil (Fig 4.14). The findings of this study are in line with Gopinath and Mina (2011) who reported an increase in number of garden pea pods per plant when treated with organic manures over control plants. The second growing season saw more harvest than the first season. In the first season, seed germination may have been poor, resulting in fewer plants and poorer pod yields. Garden peas are drought-resistant plants with very low water requirements. Plant growth can be stimulated by irrigation but standing or poorly drained media hinder germination and cause excessive vegetative growth (Deshpande and Adsule 1998).

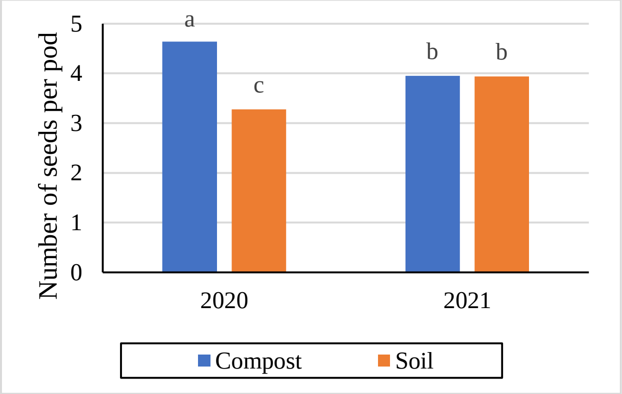


Means with the same letters do not differ significantly.

Figure 4. 14 The number of pods yielded per plant as affected by the growth medium

4.4.2 Seed production per pod of garden peas as affected by growth medium

Analysis of variance results revealed a significant effect on the number of seeds per pod due to the type of growth media used and the season (P>0.05). Similar results were reported by Gopinath and Mina (2011) whereby different organic manures were used in production of garden pea plants. All manure treatments significantly influenced the grain yield/pod. Compared to soil, compost produced more seeds per pod (Fig 4.15). An equal number of seeds per pod were recorded in the second season regardless of the growth media used. Pods harvested from compost contained fully formed seeds, whereas soil-grown seeds were still forming or malformed. This maybe because plant growth was poor in soil.



Means with the same letter show that there is no significant difference, P<0.05.

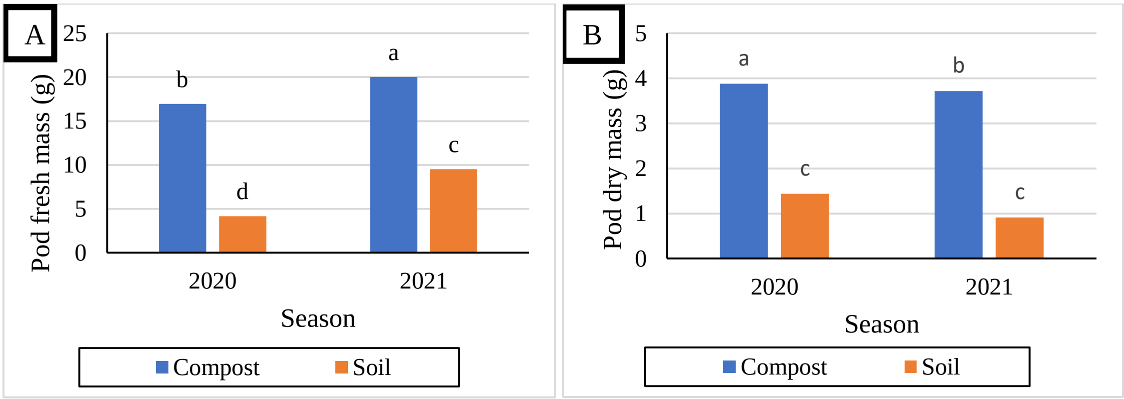
Figure 4. 15 Garden pea seed production as influenced by growth media

4.4.3 Influence of growth media on garden pea pod yield

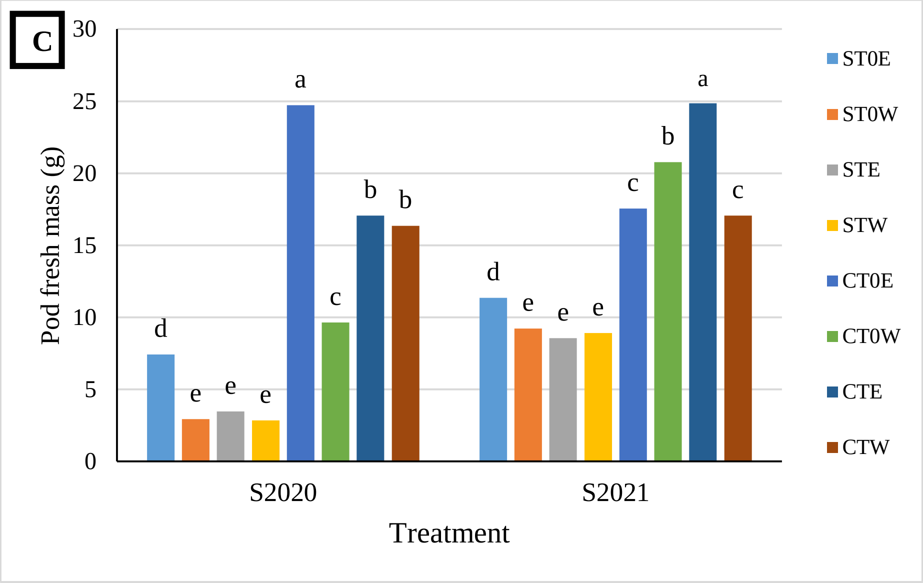
Growing media had a significant impact on garden pea pod yield. The soil produced lower yields than compost (Fig 4.16 A and B). The use of compost in pea production enhances plant growth and yield. Results obtained in this study are in line with Pandey et al. (2006), who reported an increase in garden pea pod yield after organic manure treatment. In their studies they used varied rates and sources organic manure. Rapid plant senescence in soil reduced yields. Soil grown garden pea plants produced smaller pods compared to compost (Fig 4.17 A). Cooler temperatures during the second season may have played a part in this. Garden pea plants grow well in cooler climates, with a germination temperature of around 22° (Behera et al. 2022). The second planting of garden peas took place in August, and the maximum temperature averaged 23.6° with a minimum of 8°. Planting for Season 1 took place in September when temperatures were higher. The average maximum temperature was 27.1° and the minimum was 11.5°.

The ANOVA results revealed a significant interaction between growth media, direction and micronutrient treatment on pod fresh mass (Fig 4.16 C). In season 2020, micronutrient treatment resulted in a reduction on pod mass of all east grown plants regardless of the growth media used. On the west growing plants, foliar Trelmix spraying resulted in a significant increase in pod mass of compost grown plants and in soil the increase was insignificant. Highest pod fresh mass was recorded in CT$_0$E. Pod fresh mass recorded in treatments CTE and CTW did not differ significantly. ST$_0$E recorded a pod fresh higher than all the soil treatments combination. There was no significant difference in fresh pod mass recorded in treatments STE, ST$_0$W and STW.

In the second growing season (S2021), foliar Trelmix spraying resulted in a significant increase in pod fresh mass of east grown compost plants (CTE) and a decrease in mass of west grown compost plants (CTW). There is a significant difference between control treatments (CT$_0$E and CT$_0$W) when compared to Trelmix treatments (CTE and CTW). Highest pod fresh mass was recorded in CTE. Like in season 2020, ST0E recorded higher garden pod fresh mass than all soil treatments combination. There was no significant difference between STE, ST$_0$W and STW.



Means denoted by the same letter indicate there is no significant difference at P< 0.05.



S= soil, C= compost, T_0 = control plants, T= Trelmix treated, E= east, W= west, S2020= growing season 2020, S2021= growing season 2021. Bars having same letters within a column group denote no significant difference LSD=

Figure 4. 16 Pod yield of garden peas in response to growth media. A = Pod fresh mass B= Pod dry mass C= Interaction between growth media, direction and micronutrients on pod fresh mass

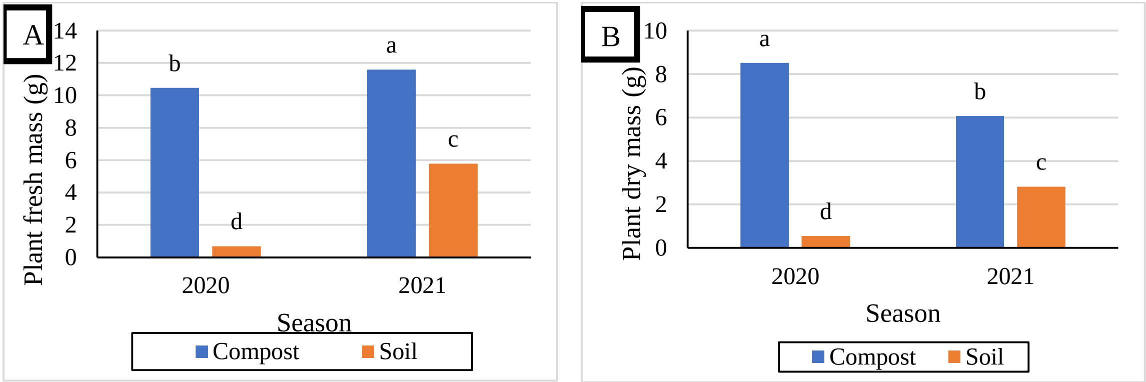
Figure 4. 17 Size difference between garden pea pods harvested from compost and soil in the first season

4.4.4 Effects of growth media on the mass of garden pea plants

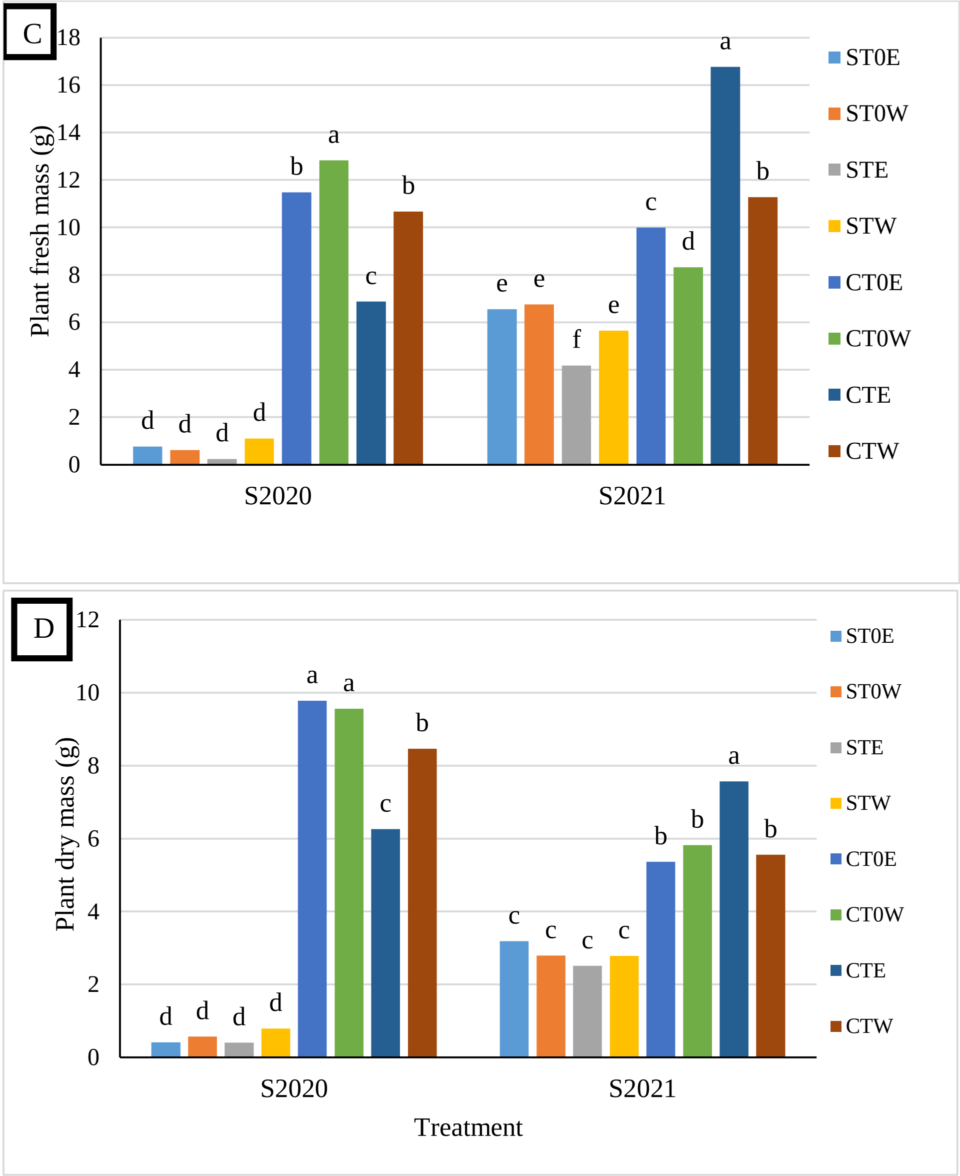
The results of the two-way ANOVA table revealed a significant interaction on the growth media type and growing season on the vegetative yields of garden peas ($P<0.05$) (Fig 4.18 A and B. Compost harvested garden pea plants had a higher vegetative yield compared to soil-grown plants (Fig 4.19). Organic compost promotes the vegetative growth of pea plants. Compost-grown pea plants were bushy (Fig 4.19 A and C), while soil-grown plants were tall and thin (Fig 4.19 B and C). The results of this study agree with those of Chaudhary et al. (2022), who used different compost sources to grow peas. In their study animal manure compost improved the growth of garden pea plants. Plant fresh mass was higher in the second season compared to the first season (Fig 4.18 A). Perhaps this is due to the increased rainfall a few weeks before harvest.

The interaction effect of growth media, direction and micronutrient treatment significantly influenced the garden pea plant fresh and dry mass (Fig 4.18 C and D). In season S2020, compost control plants (CT$_0$E and CT$_0$W) recorded a higher plant fresh and dry mass as compared to treated plants (CTE and CTW). CT$_0$W had the highest plant fresh mass and STE recorded the lowest fresh and dry mass. There is a significant reduction in plant fresh and dry mass between CT$_0$W and CTW also between CT$_0$E and CTE. The plant mass (fresh and dry) of soil grown garden pea plants revealed no significant difference resulting from the interaction of growth media, cardinal orientation and foliar Trelmix spraying (ST$_0$E, ST$_0$W, STE AND STW did not differ significantly).

In the second season (S2021), CTE resulted in plant mass (fresh and dry mass) significantly higher than all the treatments followed by CTW, CT$_0$E and CT$_0$W. Plant dry mass of CT$_0$W, CTW, CT$_0$E did not differ significantly and similarly all soil treatment combinations (ST$_0$E, STE, ST$_0$W, STW) did not differ. STE recorded a lower fresh and dry mass than all treatment combinations. ST$_0$E, ST$_0$W and STW did not significantly differ from each other.



Means denoted by the same letter indicate there is no significant difference at $P< 0.05$.



S= soil, C= compost, T_0 = control plants, T= Trelmix treated, E= east, W= west, S2020= growing season 2020, S2021= growing season 2021. Bars having same letters within a column group denote no significant difference LSD=

Figure 4. 18 Mass of garden pea plants as influenced by growth media. A= garden pea fresh yield, B= garden pea plant dry mass C=fresh mass as influenced by third order interaction D= interaction on dry mass

Figure 4. 19 A= Garden pea plant in compost B= Garden pea plants growing in soil C= effect of growth media on pea plants

The interaction between cardinal orientation and growing season had significantly influenced the yield and yield attributes of garden peas (Table 4.7). Better garden pea pod yield and plant mass were recorded on the east side of the vertical structure in the 2021 growing season. This maybe due to that more rainfall was received in the 2021 growing season and it may be assumed that the east orientation allows for better light penetration and interception enhancing photosynthesis thus giving higher yields with the help of precipitation. The current study's findings are in line with Karanja et al. (2017) who reported a significant difference on yield and yield attributes of cowpeas due to row orientation. In their study they were comparing the east-west against the north-south orientation on the grain yield of cowpeas. The east-west produced a higher number of pods/plants ranging from 3.5-7.5. Findings from Tsubo et al. (2003) are also in agreement with the latter finding.

Table 4. 7 Effect of cardinal orientation and growing season interaction on the yield and yield parameters of garden peas

Year	Direction	Number of pods	Number of seeds/pods	Pods fresh mass	Pods dry mass	Plant fresh mass	Plant dry mass
2020	East	3.498	4.642	13.183	2.738	4.839	4.213
	West	3.156	3.274	7.945	2.573	6.305	4.846
2021	East	4.581	3.950	15.521	2.617	9.374	4.656
	West	4.375	3.938	13.993	2.100	7.999	4.235
	LSD	NS	NS	S	NS	S	S

Foliar micronutrients treatment had a significant influence on the growth and yield of garden peas (Table 4.8). Pod and vegetative yields were higher in S2021 versus S2020. Planting time may have contributed to this. Planting was done when temperatures were cooler in 2021, and a constant amount of rainfall was received throughout the growing season. Number of pods and plant dry mass were slightly higher in control plants than in treated plant. The findings of the current study contradict (Borah and Saikia 2021, Pandey et al. 2010), who reported an increase in plant fresh mass after foliar zinc treatment. An increase in plant dry mass due to foliar zinc treatment was also reported by Stoyanova and Doncheva (2002), and Hamouda et al. (2018) . This may be due to that zinc influences auxin synthesis a growth promoting hormone (El-Tohamy 2007).

Table 4. 8 Effect of micronutrient treatment on the yield and yield parameters of garden peas

Year	Micronutrient	Number of pods	Number of seeds/pods	Pods Fresh mass	Pods dry mass	Plant fresh mass	Plant dry mass
2020	Control	3.748	3.804	11.194	2.857	6.421	5.081
	Treated	2.906	4.112	9.934	2.454	4.723	3.979
2021	Control	4.750	4.031	14.729	2.263	7.906	4.604
	Treated	4.206	3.900	14.786	2.364	9.468	4.288
	LSD	NS	NS	NS	NS	S	S

Results from the ANOVA showed a significant interaction effect between growth media and cardinal orientation on the garden pea pod yields. A higher garden pea pod mass was recorded from east grown compost plants. This maybe be due to that compost is rich in plant nutrients and the east side on the vertical structure maybe assumed to allow for better light penetration and interception enhancing photosynthesis thus giving higher yields. Soil grown west plants recorded lower pod fresh mass with the lowest recorded on soil west grown plants.

Growth media	Direction	No of pods	Pods fresh mass	Pods dry mass	No of seeds/pod	Plant fresh mass	Plant dry mass
Soil	East	2.310	7.711c	1.299	3.473	2.937	1.626
	West	2.406	5.981d	1.048	3.739	3.532	1.732
Compost	East	5.768	20.993a	4.057	4.500	11.276	7.244
	West	5.125	15.957b	3.534	4.142	10.772	7.400
LSD		NS	S	NS	NS	NS	NS

4.5 Plant tissue content of macro and micronutrients after Trelmix application

This study's focus was on increasing the content of iron and zinc in vegetables to address the issue of hidden hunger. For analysis, a whole plant except for the roots was analysed for the content of macro and micronutrients but only these four will be discussed in detail Phosphorus (P), Potassium(K) Iron (Fe) and Zinc (Zn).

4.5 Effect of Trelmix on the micronutrient plant tissue content

4.5.1 Effect of micronutrient application on the iron content in plant tissues

Using Trelmix as a foliar spray increased the tissue iron content of all three vegetables studied (Fig 4.20 A and B). Trelmix is a micronutrient-rich fertilizer that can be applied to both soil and leaves. This treatment increases the bioavailability of nutrients in vegetables. Foliar applications are more effective than soil applications as observed in previous studies. When applied to soil, chemical reactions occur that reduce its effectiveness. Foliar feeding is the most effective method of nutrient management (Krishnasree et al. 2021). Although tissue iron concentration is species dependant, most leaf iron concentration ranges from 50 and 150 mg kg^{-1} and with a concentration above 500 mg kg^{-1} being toxic (Buturi et al. 2021). It was observed that Trelmix-foliar treated plants have a higher iron content over no spray. Soil grown Trelmix treated beetroot plants have a higher iron content compared to compost plants. Foliar spray of iron increased iron concentration in chickpea grain to 46.3 mg kg^{-1} when sprayed with a mixture of iron urea and zinc and non-iron spray recorded 36.2 mg kg^{-1} (Singh et al. 2015a). Soil control plants have a higher iron content compared to compost control. In the second season, garden pea compost-grown plants sprayed with Trelmix had a higher iron content than the other two vegetables. Trelmix-treated soil-grown beetroot contained more iron in all seasons. It is reasonable to assume that beetroot responds better to foliar fertilizer treatment. The beetroot results are in line with Petek et al. (2019) who reported increased micronutrient content in compost-grown foliar-sprayed beetroot.

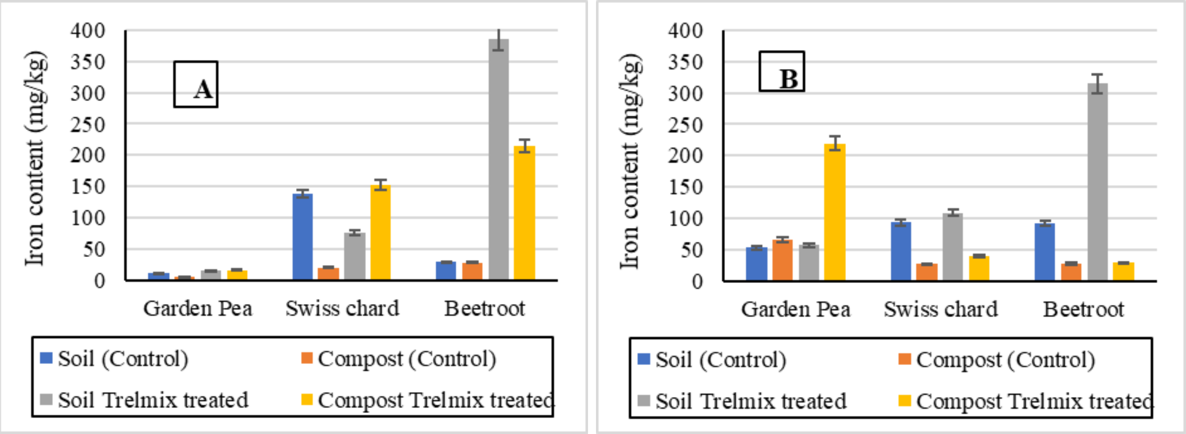


Figure 4. 20 Effects of Trelmix treatment on the iron content of garden pea, Swiss chard, and beetroot plants per growth media in season one (A) and season two (B)

4.5.2 Trelmix application effect on zinc content

Foliar Trelmix treatment increased the zinc tissue content of all three vegetables in both trials (Fig 4. 21 A and B). The Trelmix treated plants recorded a higher zinc content than control plants. All compost-grown beetroot plants in the first season (A) contained more zinc than Swiss chard and garden peas. Compost-grown garden pea micronutrient-treated plants contain the highest level of zinc (10.162 mg kg^{-1}), followed by Swiss chard soil-treated plants with 8.40 mg kg^{-1}. According to Broadley et al. (2007), a zinc foliar concentration more than 100 mg kg^{-1} reduce growth of most crops and for leafy vegetables such as lettuce, zinc concentration more than 218 mg kg^{-1} affect root dry mass and aerial parts. Zinc sufficiency for most species' ranges from 15- 20 ppm in dry matter of mature plants (Hafeez et al. 2013). The zinc content of garden pea compost control plants was higher than that of soil control plants in season 2. In both seasons, soil-grown Swiss chard-treated plants contained more zinc than beetroot or garden peas. Compared with Salih (2013), who observed a zinc increase in cowpea plants following foliar treatments with iron, boron, and zinc, the current study's results are in agreement. The findings also concerted the work done by Shivay et al. (2016) and Singh et al. (2015b) who reported an increase in chickpea protein, iron, and zinc concentration after foliar spraying with urea or zinc (0.5%$ZNSO_4$) or iron (0.3%$FESO_4$) grain zinc concentration recorded 27.1 mg kg^{-1} without Zn spray and 32.5 mg kg^{-1} with Zn spray.

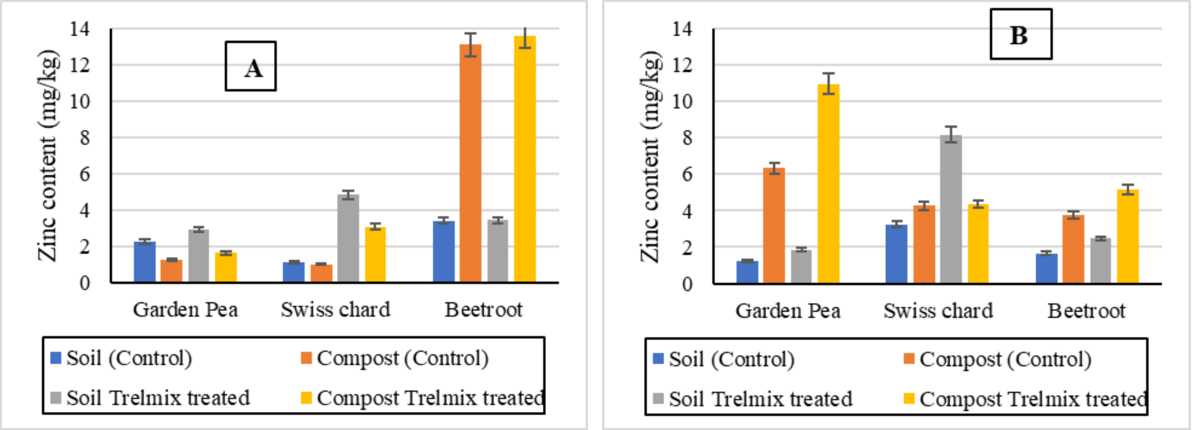


Figure 4. 21 Foliar micronutrient application effect on the zinc content of beetroot, garden pea, and Swiss chard in season one (A) and season two (B)

4.5.3 Effect of micronutrient application on the Phosphorus content in plant tissues

The trend revealed a decrease in the plant tissue phosphorus content due to foliar micronutrient treatment (Fig 4.22 A and B). The phosphorus content of control plants was higher than that of treated plants. Findings by Borah et al. (2021) are in compliance, a decrease of phosphorus in garden pea leaves after foliar zinc treatment was reported. Similar results were reported by Stoyanova and Doncheva (2002) and Ladumor et al. (2020). This may be due to that inorganic phosphorus in the soil decreases with zinc application (Ghoneim 2016, Menser and Sidle 1985) and phosphorus-zinc antagonism effect. The pH of the growth media, available oxides of iron and aluminium, organic matter, and the amount and type of clay are all factors that influence phosphorus adsorption (Alovisi et al. 2020). A straight fertilizer (superphosphate) was soil-applied in this study using a split application method. Phosphorus adsorption can be affected in acidic soils; it is absorbed into surfaces of iron and aluminium and forms complexes (Asomaning 2020).

A study by Singh and Bhatt (2013) also reported a reduction in *Lens culinaris* leaf phosphorus content due to foliar zinc spraying but Lu et al. (1998) study findings on *Brassica napus* were contradictory concluding that the interaction between the two nutrients is species dependant (Fageria et al. 2002).

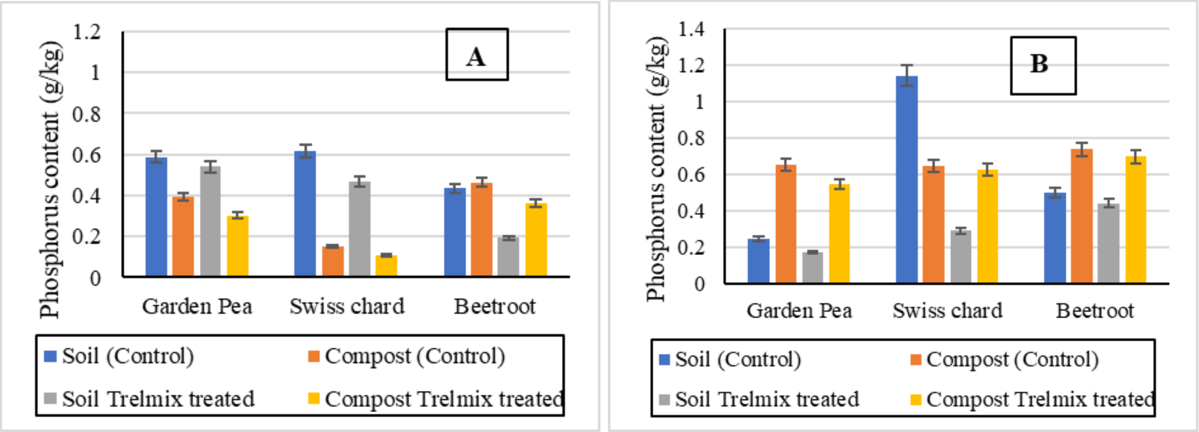


Figure 4. 22 Phosphorus content in plant tissues of beetroot, garden pea, and Swiss chard after Trelmix foliar application in season one (A) and season two (B)

4.5.4 Trelmix effect on Potassium content

There is an increase in potassium tissue content of the three vegetables due to foliar micronutrient treatment. Results from Heydarzadeh et al. (2021) are in compliance, sugar beet root potassium content increased from 3.42 meq per 100 g in control plants to 4.47 meq per 100 g in manganese foliar sprayed plants. The use of micronutrients influenced potassium adsorption. Potassium levels were higher in treated plants than in the control (Fig 4.23 A and B). The second season soil-grown Swiss chard-treated plants had the highest potassium content. The weather and the nutrient holding capacity of the growth media can both influence mineral adsorption (Petek et al. 2019). The potassium content of compost control and treated plants differed. Foliar Trelmix feeding increased the tissue potassium content. The current study's findings contradicts Rahimi et al. (2019), in their study they used iron, zinc, boron and manganese as a foliar spray to improve the nutrient content of soil-grown sugar beet Cv. Sonja. Potassium content was higher in control plants (4.26 mg kg^{-1}) and Boron treatment recorded the lower K content of 3.64 mg kg^{-1} .

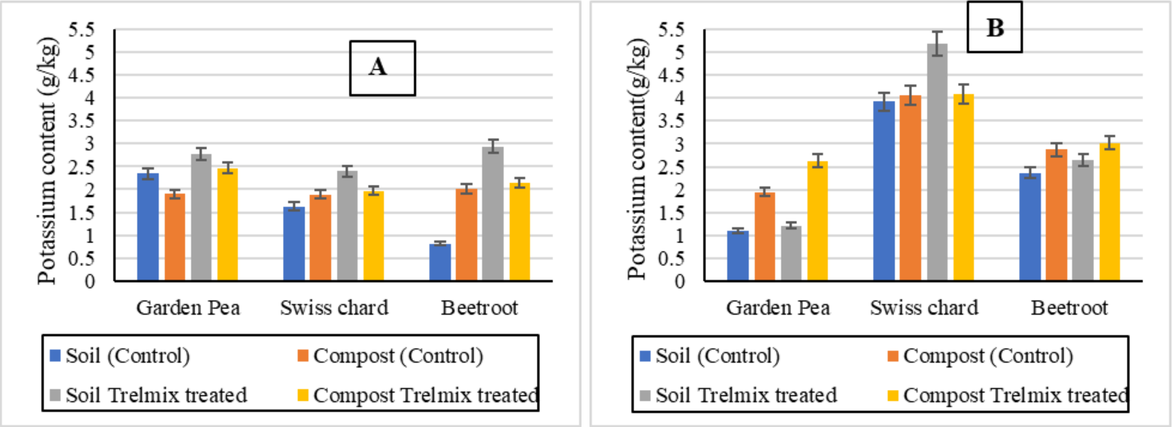


Figure 4. 23 Effect of foliar micronutrient treatment on the potassium content of beetroot, garden pea, and Swiss chard in season one (A) and season two (B)

CHAPTER 5

5.0 GENERAL CONCLUSION AND RECOMMENDATIONS

Urban food insecurity is widely noticed as a major developmental challenge in Sub Saharan countries such as South Africa. Most of South Africa's population is living in urban areas. Urbanization and rural to urban migration results in a decrease in the availability of arable agriculture land in urban areas. Urban farming which is the production of food (plants and animals) within a town or city is an umbrella for a variety of farming systems with varied intentions and it has been a common practice for ages. It has the potential to address urban food security and alleviate poverty by subsidizing food expenditure, generating income through the sale of products and working on urban farms, and influencing prices by supplying lower-cost products to the market. When one thinks of Agriculture and specifically vegetable production, the issue of limited horizontal space is often why urban dwellers cannot product their own vegetables. The use of vertical hydroponic systems can be explored. It takes less space, and it yields higher than traditional horizontal planting. However, the installation and running costs of this system are too steep for an ordinary farmer.

In addition, the technology used in horizontal hydroponic farming system requires technical expertise making it challenging to be used by all farmers especially small-scale farmers, left alone a resource poor family. Furthermore, the variety of crops produced in such system is most often leafy vegetables and herbs. To address nutritional needs of a person, one needs a diverse diet made up of not only leafy vegetables but also fruiting and or rooting vegetables. Using locally available and less expensive material such as stacking old tyres, water bottles, sacks, old clothes and growth media based vertical farming systems, vegetables can be produced at a lower cost. This will make farming cheaper and easy for all farmers/households including the landless.

Using two different growth media, this study attempted to incorporate a mixture of vegetable into a vertical farming system. This system yielded positive results for all three vegetables, fruiting and rooting vegetables grew successfully on the vertical structures but if one is to grow beetroot, it is necessary to establish beetroot from seedlings because direct seeding causes germination problems. Pests and diseases spread quickly in this system especially if crops are grown out of season, so plants must be closely monitored, and a regular pest control program must be in place. This trial was plagued by aphids and powdery mildew, resulting in death of some plants. Pest resistant and temperature tolerant varieties should be considered.

Growth media was evaluated for suitability. Crops were grown in compost or in soil. The soil grown plants performed badly with a few missing plants. It is suspected that due to the weight of the soil and gravity it compacted over time causing waterlogging. Also soil crusting resulted due to poor drainage. Due to the weight of the soil, especially when wet, it caused some structures to collapse. This just compounded the issues with using soil to fill the growing bags. Compost, on the other hand is a lighter growth media, is well drained, has a good water holding capacity and is rich in plant nutrients and therefore proved to be the best medium for growing crops in a multi-layer vertical bag farming system used in this research. But the compost needs to be well leached and supplemented with some fertilizer.

This study assessed the feasibility of the use of vertical bag farming structure by poor landless household by calculating the expense of installing and maintaining one structure for one growing season. The start-up costs is rather high (± R3 650.00 per structure) with especially the irrigation system contributing to almost 50% of the cost. The amount of irrigation water and fertilizer used per structure was also measured. The water used for a structure with compost over the growing period was ranging from 4633 to 4726 litres and for soil it was between 5836 and 6088 litres. The start-up and running cost might be too expensive for a household making it a major drawback of the system. The total amount of granular fertilizer applied to a single structure was less than 1.25 kg and for foliar feeding, less than 100 ml of fertilizer was used. This does not add up to a huge expense. For research purposes we used new material, but by making use of reclaimed materials (wooden pallets), irrigation the bags by hand with a bucket and using old bags etc. for the saddle and growing bags, the cost could be reduced significantly. In the case where this vertical bag system worked better using compost to fill the growing bags, food waste and other plant materials around the home can be used to produce one’s own compost. This will prevent adding to running costs.

Vegetables were produced with the aim to contribute to the nutritional need of a family of four, two adults and two children. Results from this type of system prove that a diversity of vegetable types can be grown in this system but careful planning is necessary to prevent under or over production at any given time. Production of multiple harvested vegetables such a Swiss chard and staggering crops that are harvested once can also help.

Results from growth media and plant tissue analysis revealed that foliar micronutrient feeding increased the macro and micronutrient content of beetroot, garden pea, and Swiss chard. It supports previous reports that foliar micronutrient treatment increases plant tissue nutrient content. The nutrient content of the three vegetables varied according to the growth media. Phosphorus content was higher in compost control plants. Iron content of soil-grown beetroot was higher in both seasons than all compost-treated plants. Plant yield and yield parameters were influenced by foliar micronutrient treatment, but the impact was not significant. To compare the effects of foliar spraying on plant tissue and root nutrient content, root analysis should be conducted in the future.

Cardinal orientation has been reported to impact vegetables' growth and yield in previous studies, contrary to the findings of this study. Vegetable growth and yield were not significantly affected by direction in either season. Although the variation was insignificant, the east side yielded more than the west side. It is recommended that a similar study be conducted using data loggers to measure environmental factors such as temperature and humidity because plant growth is influenced by these factors.

Vertical vegetable garden can be practiced by resource poor farmers/households with limited horizontal space or who are landless. The major drawback can be that of installation and operation costs which may be too steep.

In summary, the recommendations are as follows:

- Use nutrient rich organic growth media which is light and have a good water holding capacity
- Establish a mixture of vegetable crops. Preferably vegetable crops that can be harvested over a period of time (such as Swiss chard) in combination of single harvestable crops (such as beetroot). In both cases one should carefully plan the planting and harvesting schedule to prevent under or over supply at any given time during the year.
- Due to the size of the bags that can be used and the limited water holding capacity of the growing media used, one will need a storage drum/tank to prevent crops from dying when water supply from a municipal tap (water shortage and infrastructure problems) or borehole

(loadshedding) is interrupted. Something that has been experienced a lot in South Africa in the last couple of years.

- The application of nutrients is important to ensure good crop growth and yields. Nutrients can be bought or cheaper alternatives such as compost and compost tea can be used. If Zn and Fe supplements are needed in the diet, biofortification of the vegetables can be considered as an alternative, by adding Zn and Fe rich micronutrient fertilizers directly to the crops.
- Cardinal orientation have an effect on the growth and yield of the vegetable crops. Therefore, we recommend installation of data loggers to evaluate which side is warmer and which other environmental factor is causing the difference and how it can be manipulated in order for both sides of the vertical structure to be used without negatively affecting crop growth and yield.

Limitations of the study

The vegetables used in this study were cool season vegetables but due to some delays, planting was done late in the season when temperatures were a bit higher which might have contributed to the poor crop performance and pests infestation. Also different planting dates were used for the two seasons making it hard to draw a concrete conclusion.

The trial was conducted outside with no control over the environmental factors and adverse weather condition. A storm happened in the first season blowing away whole structures and some broke, taking too long to repair and set up the trial again. More precipitation was received in the second season affecting the growth of soil grown vegetables due to poor drainage and it is suggested that the trail is conducted under enclosed environment and a lighter, well drained soil is used .

Season one vegetables were badly affected by a watercut in the municipal water which resulted in a change in the irrigation water source and all plants were then irrigated with water from the storage tank.

Due to limited funding, a small water pump was used and the crops on the upper level were not getting enough water hence it was recommended that irrigation be done per level which was time consuming.

Things to consider in future works

It would be of great importance to measure environmental factors from both cardinal orientation of the vertical structures. Each side can be measured separately by installing data loggers on either side of the structure to assess if the differences in growth and yield is an environmental effect or not since previous studies done reported no difference on the yield and yield parameters of vegetables grown on the E-W orientation but variation is reported when comparing E-W to N-W orientation.

Test the perfomance of a lighter soil, including soil with decomposed plant remains to improve infiltration and drainage

Implementing these system under enclosed environmental conditions maybe even the soil based system might perfom better and also develop appropriate irrigation scheduling strategies for these systems.

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APPENDICES

APPENDIX A: An illustration of the vertical system setup

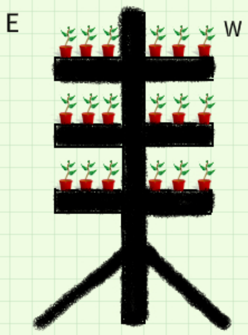

Fig 1. The side view of the vertical structures

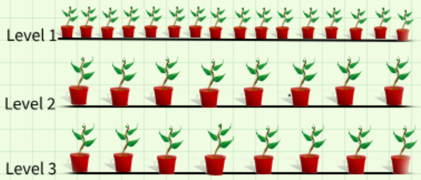

Fig 2. The front view of the vertical structure showing the three different levels

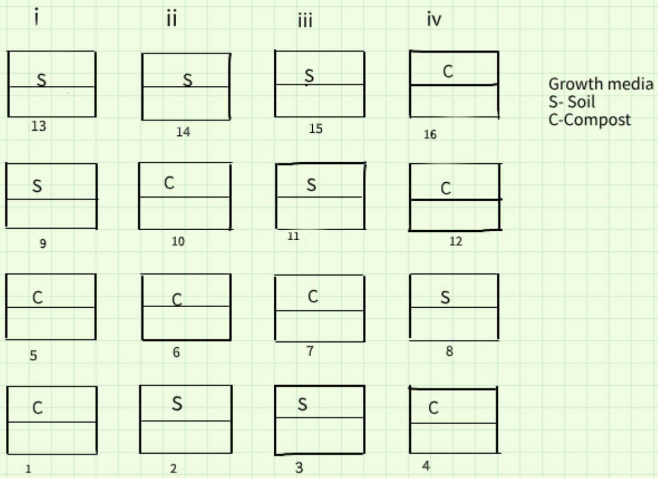

Fig 3. Random distribution of growth media on the vertical structures

Appendix B: Plant tissue soil analysis ANOVA tables.

Table 1. ANOVA for Beetroot root diameter

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	627.0775002	9.7980859	7.05	<.0001
Error	255	354.2326970	1.3891478		
Corrected Total	319	981.3101972			
R-Square	**CV**	**Root mean square error**		**Root fresh mass mean**	
0.639021	47.5808162	1.178621		2.477094	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media (GM)	1	344.9640070	344.9640070	248.33	<.0001
Direction	1	0.4481820	0.4481820	0.32	0.5705
Micronutrient	1	0.1156633	0.1156633	0.08	0.7732
Season	1	19.5058528	19.5058528	14.04	0.0002
GM*Direction	1	4.2611279	4.2611279	3.07	0.0811
GM*Micronutrient	1	0.0524839	0.0524839	0.04	0.8460
GM*Season	1	141.9674839	141.9674839	102.20	<.0001
Direction*Micronutrient	1	6.7727973	6.7727973	4.88	0.0281
Direction*Season	1	1.0932458	1.0932458	0.79	0.3758
Micronutrient*Season	1	0.3264275	0.3264275	0.23	0.6283
GM*Dire*Micro*Season	5	4.1248880	0.8249776	0.59	0.7047

ANOVA for beetroot yield

Table 2 a. ANOVA for Beetroot root fresh mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	77177.27463	1205.89492	15.47	<.0001
Error	255	19873.96296	77.93711		
Corrected Total	319	97051.23758			
R-Square	**CV**	**Root mean square error**		**Root fresh mean**	
0.795222	53.07418	8.828200		16.63370	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	56681.87383	56681.87383	727.28	<.0001
Direction	1	298.63694	298.63694	3.83	0.0514
Micronutrient	1	8.41591	8.41591	0.11	0.7427
Season	1	3942.88351	3942.88351	50.59	<.0001
GM*Direction	1	193.98630	193.98630	2.49	0.1159
GM*Micronutrient	1	6.69958	6.69958	0.09	0.7696
GM*Season	1	8438.24879	8438.24879	108.27	<.0001
Direction*Micronutrient	1	673.48058	673.48058	8.64	0.0036
Direction*Season	1	139.85764	139.85764	1.79	0.1816
Micronutrient*Season	1	52.66998	52.66998	0.68	0.4118
GM*Dire*Micro*Season	5	366.26032	73.25206	0.94	0.4557

Table 2b. ANOVA for Beetroot root dry mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	2169.504286	33.898504	14.06	<.0001
Error	255	614.627015	2.410302		
Corrected Total	319	2784.131301			
R-Square	**CV**	**Root Mean Square error**		**Root dry mass Mean**	
0.779239	53.80208	1.552515		2.885604	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	1424.120069	1424.120069	590.85	<.0001
Direction	1	10.089994	10.089994	4.19	0.0418
Micronutrient	1	0.014189	0.014189	0.01	0.9389
Season	1	108.584880	108.584880	45.05	<.0001
GM*Direction	1	7.642914	7.642914	3.17	0.0761
GM*Micronutrient	1	0.206614	0.206614	0.09	0.7699
GM*Season	1	307.638670	307.638670	127.63	<.0001
Direction*Micronutrient	1	14.044632	14.044632	5.83	0.0165
Direction*Season	1	11.164138	11.164138	4.63	0.0323
Micronutrient*Season	1	0.485539	0.485539	0.20	0.6539
GM*Dire*Micro*Season	5	10.376546	2.075309	0.86	0.5079
GM*Direction*Micronutrient	1	33.03131	33.03131	1.05	0.3066

ANOVA for beetroot leaves

Table 3. ANOVA for number of beetroot leaves

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	3877.503814	60.585997	14.32	<.0001
Error	255	1078.883686	4.230916		
Corrected Total	319	4956.387500			
R-Square	**CV**	**Root mean square error**		**Leaf fresh mass mean**	
0.782325	26.69157	2.056919		7.706250	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	2769.979647	2769.979647	654.70	<.0001
Direction	1	3.285872	3.285872	0.78	0.3790
Micronutrient	1	2.848447	2.848447	0.67	0.4127
Season	1	32.895360	32.895360	7.77	0.0057
GM*Direction	1	6.252760	6.252760	1.48	0.2252
GM*Micronutrient	1	8.299343	8.299343	1.96	0.1626
GM*Season	1	789.665070	789.665070	186.64	<.0001
Direction*Micronutri	1	10.135082	10.135082	2.40	0.1229
Direction*Season	1	6.111652	6.111652	1.44	0.2305
Micronutrient*Season	1	6.861737	6.861737	1.62	0.2040
GM*Dire*Micro*Season	5	10.898176	2.179635	0.52	0.7647

Table 4. ANOVA for beetroot leaf area

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	572847.5381	8950.7428	18.08	<.0001
Error	255	126248.7931	495.0933		
Corrected Total	319	699096.3312			
R-Square	**CV**	**Root mean square error**		**Leaf Dry Mean**	
0.819411	44.26919	22.25069		50.26225	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	516046.1009	516046.1009	1042.32	<.0001
Direction	1	39.8450	39.8450	0.08	0.7769
Micronutrient	1	34.9155	34.9155	0.07	0.7908
Season	1	92.0963	92.0963	0.19	0.6666
GM*Direction	1	51.8665	51.8665	0.10	0.7465
GM*Micronutrient	1	367.1400	367.1400	0.74	0.3900
GM*Season	1	6860.9465	6860.9465	13.86	0.0002
Direction*Micronutri	1	261.3821	261.3821	0.53	0.4681
Direction*Season	1	667.4600	667.4600	1.35	0.2467
Micronutrient*Season	1	26.6117	26.6117	0.05	0.8168
GM*Dire*Micro*Season	5	1859.6027	371.9205	0.75	0.5859

Table 5a. ANOVA for beetroot leaf fresh mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	5472.264949	85.504140	22.74	<.0001
Error	255	958.853331	3.760209		
Corrected Total	319	6431.118280			
R-Square	**CV**	**Root mean square error**		**Leaf FM Mean**	
0.850904	36.11708	1.939126		5.369000	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	5078.056625	5078.056625	1350.47	<.0001
Direction	1	0.415710	0.415710	0.11	0.7398
Micronutrient	1	13.305422	13.305422	3.54	0.0611
Season	1	0.087444	0.087444	0.02	0.8789
GM*Direction	1	0.846635	0.846635	0.23	0.6355
GM*Micronutrient	1	11.949900	11.949900	3.18	0.0758
GM*Season	1	41.880286	41.880286	11.14	0.0010
Direction*Micronutri	1	4.537598	4.537598	1.21	0.2730
Direction*Season	1	0.167803	0.167803	0.04	0.8329
Micronutrient*Season	1	4.710639	4.710639	1.25	0.2641
GM*Dire*Micro*Season	5	18.771982	3.754396	1.00	0.4192

Table 5b. ANOVA for beetroot leaf dry mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	64	102.6525302	1.6039458	9.46	<.0001
Error	255	43.2311985	0.1695341		
Corrected Total	319	145.8837286			
R-Square	**CV**	**Root mean square error**		**Leaf dry mass mean**	
0.703660	46.09200	0.411745		0.893312	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	87.86631435	87.86631435	518.28	<.0001
Direction	1	0.02554681	0.02554681	0.15	0.6982
Micronutrient	1	0.00875906	0.00875906	0.05	0.8204
Season	1	2.11715578	2.11715578	12.49	0.0005
GM*Direction	1	0.00043311	0.00043311	0.00	0.9597
GM*Micronutrient	1	0.04676462	0.04676462	0.28	0.5999
GM*Season	1	0.04353346	0.04353346	0.26	0.6128
Direction*Micronutri	1	0.00360203	0.00360203	0.02	0.8842
Direction*Season	1	0.04853714	0.04853714	0.29	0.5931
Micronutrient*Season	1	0.29250077	0.29250077	1.73	0.1902
GM*Dire*Micro*Season	5	0.92168358	0.18433672	1.09	0.3678

ANOVA for Swiss chard yield

Table 6. ANOVA for number of Swiss chard leaves

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	25	15616.85795	624.67432	42.13	<.0001
Error	150	2224.00000	14.82667		
Corrected Total	175	17840.85795			
R-Square	**CV**	**Root mean square error**		**Leaf fresh mass mean**	
0.875342	25.71898	3.850541		14.97159	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	1554.14205	1554.14205	104.82	<.0001
Direction	1	14.77841	14.77841	1.00	0.3197
Micronutrient	1	1.27841	1.27841	0.09	0.7694
Season	1	12227.77841	12227.77841	824.72	<.0001
GM*Direction	1	9.55114	9.55114	0.64	0.4235
GM*Micronutrient	1	2.05114	2.05114	0.14	0.7105
GM*Season	1	1369.77841	1369.77841	92.39	<.0001
Direction*Micronutri	1	5.46023	5.46023	0.37	0.5449
Direction*Season	1	0.00568	0.00568	0.00	0.9844
Micronutrient*Season	1	30.27841	30.27841	2.04	0.1551
GM*Dire*Micro*Season	5	173.21023	34.64205	2.34	0.0447

Table 7. ANOVA for Swiss chard leaf length

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	25	9674.21586	386.96863	14.07	<.0001
Error	150	4125.20644	27.50138		
Corrected Total	175	13799.42229			
R-Square	**CV**	**Root mean square error**		**Total fresh mass mean**	
0.701059	21.70063	5.244175		24.16601	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	3858.284505	3858.284505	140.29	<.0001
Direction	1	2.549687	2.549687	0.09	0.7612
Micronutrient	1	114.326587	114.326587	4.16	0.0432
Season	1	5331.515651	5331.515651	193.86	<.0001
GM*Direction	1	0.904453	0.904453	0.03	0.8563
GM*Micronutrient	1	0.451778	0.451778	0.02	0.8982
GM*Season	1	11.276618	11.276618	0.41	0.5229
Direction*Micronutrient	1	4.157401	4.157401	0.15	0.6980
Direction*Season	1	1.703737	1.703737	0.06	0.8038
Micronutrient*Season	1	57.330468	57.330468	2.08	0.1509
GM*Dire*Micro*Season	5	24.268476	4.853695	0.18	0.9710

Table 8. ANOVA for Swiss chard leaf area

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	25	7515866.855	300634.674	29.57	<.0001
Error	150	1525080.579	10167.204		
Corrected Total	175	9040947.434			
R-Square	**CV**	**Root mean square error**		**Total fresh mass mean**	
0.831314	32.43160	100.8326		310.9083	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	5479381.257	5479381.257	538.93	<.0001
Direction	1	1.185	1.185	0.00	0.9914
Micronutrient	1	5622.146	5622.146	0.55	0.4583
Season	1	1042680.109	1042680.109	102.55	<.0001
GM*Direction	1	9887.779	9887.779	0.97	0.3256
GM*Micronutrient	1	10488.377	10488.377	1.03	0.3114
GM*Season	1	851422.895	851422.895	83.74	<.0001
Direction*Micronutrient	1	2500.196	2500.196	0.25	0.6207
Direction*Season	1	7176.446	7176.446	0.71	0.4022
Micronutrient*Season	1	233.421	233.421	0.02	0.8798
GM*Dire*Micro*Season	5	25640.735	5128.147	0.50	0.7726

ANOVA for leaf mass

Table 9a. ANOVA for leaf fresh mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	25	1532590.559	61303.622	38.99	<.0001
Error	150	235815.972	1572.106		
Corrected Total	175	1768406.530			
R-Square	**CV**	**Root mean square error**		**Total dry mass mean**	
0.866651	37.50058	39.64980		105.7312	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	768849.4266	768849.4266	489.06	<.0001
Direction	1	202.0485	202.0485	0.13	0.7205
Micronutrient	1	6366.4565	6366.4565	4.05	0.0460
Season	1	481072.7185	481072.7185	306.01	<.0001
GM*Direction	1	350.5122	350.5122	0.22	0.6375
GM*Micronutrient	1	1307.4278	1307.4278	0.83	0.3633
GM*Season	1	260128.4813	260128.4813	165.46	<.0001
Direction*Micronutrient	1	84.2289	84.2289	0.05	0.8173
Direction*Season	1	2065.2408	2065.2408	1.31	0.2536
Micronutrient*Season	1	2263.8203	2263.8203	1.44	0.2320
GM*Dire*Micro*Season	5	3900.0449	780.0090	0.50	0.7788

Table 9b. ANOVA for Swiss chard leaf dry

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	25	2633.161329	105.326453	9.98	<.0001
Error	148	1562.131679	10.554944		
Corrected Total	173	4195.293007			
R-Square	**CV**	**Root mean square error**		**Leaf length Mean**	
0.627647	78.53571	3.248837		4.136764	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	915.8501577	915.8501577	86.77	<.0001
Direction	1	0.3682807	0.3682807	0.03	0.8521
Micronutrient	1	49.9184709	49.9184709	4.73	0.0312
Season	1	984.7748154	984.7748154	93.30	<.0001
GM*Direction	1	0.9579195	0.9579195	0.09	0.7636
GM*Micronutrient	1	39.0667429	39.0667429	3.70	0.0563
GM*Season	1	435.2013840	435.2013840	41.23	<.0001
Direction*Micronutrient	1	0.7792565	0.7792565	0.07	0.7862
Direction*Season	1	1.2173347	1.2173347	0.12	0.7346
Micronutrient*Season	1	54.5081250	54.5081250	5.16	0.0245
GM*Dire*Micro*Season	5	34.4818182	6.8963636	0.65	0.6594

ANOVA for garden pod mass

Table 10 a. ANOVA for number of garden pea pods

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	22	419.6692743	19.0758761	9.21	<.0001
Error	102	211.1787257	2.0703797		
Corrected Total	124	630.8480000			
R-Square	**CV**	**Root mean square error**		**Pods fresh mass mean**	
0.665246	36.85659	1.438881		3.904000	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	295.7192081	295.7192081	142.83	<.0001
Direction	1	2.3204585	2.3204585	1.12	0.2922
Micronutrient	1	14.8799700	14.8799700	7.19	0.0086
Season	1	41.0690850	41.0690850	19.84	<.0001
GM*Direction	1	4.2375377	4.2375377	2.05	0.1556
GM*Micronutrient	1	1.5922154	1.5922154	0.77	0.3826
GM*Season	1	5.7296077	5.7296077	2.77	0.0993
Direction*Micronutrient	1	2.5455001	2.5455001	1.23	0.2701
Direction*Season	1	0.1424803	0.1424803	0.07	0.7936
Micronutrient*Season	1	0.6839642	0.6839642	0.33	0.5667
GM*Dire*Micro*Season	5	16.1746131	3.2349226	1.56	0.1774

Table 10 b. ANOVA for garden pea seeds per pod

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	22	40.8506444	1.8568475	1.37	0.1500
Error	96	130.1409523	1.3556349		
Corrected Total	118	170.9915966			
R-Square	**CV**	**Root square mean error**		**Pod dry mass mean**	
0.238904	29.16921	1.164317		3.991597	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	13.73433321	13.73433321	10.13	0.0020
Direction	1	0.01238390	0.01238390	0.01	0.9241
Micronutrient	1	0.12677722	0.12677722	0.09	0.7604
Season	1	0.00603934	0.00603934	0.00	0.9469
Direction	1	0.62670179	0.62670179	0.50	0.4810
GM*Direction	1	2.39987546	2.39987546	1.77	0.1865
GM*Micronutrient	1	1.69658301	1.69658301	1.25	0.2661
GM*Season	1	13.24981105	13.24981105	9.77	0.0023
Direction*Micronutri	1	4.30545374	4.30545374	3.18	0.0779
Direction*Season	1	0.08517220	0.08517220	0.06	0.8026
Micronutrient*Season	1	1.69190738	1.69190738	1.25	0.2667
GM*Dire*Micro*Season	5	0.74669359	0.14933872	0.11	0.9899

ANOVA for pod mass

Table 11 a. ANOVA for pod fresh mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	22	6283.700551	285.622752	22.28	<.0001
Error	102	6075.29628	61.99282		
Corrected Total	124	7591.018243			
R-Square	**CV**	**Root mean square error**		**Pod Fresh mass mean**	
0.827781	28.28223	3.580061		12.65834	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	4193.091497	4193.091497	327.15	<.0001
Direction	1	355.172779	355.172779	27.71	<.0001
Micronutrient	1	11.228546	11.228546	0.88	0.3515
Season	1	545.061099	545.061099	42.53	<.0001
GM*Direction	1	84.720663	84.720663	6.61	0.0116
GM*Micronutrient	1	44.855730	44.855730	3.50	0.0642
GM*Season	1	40.281097	40.281097	3.14	0.0792
Direction*Micronutrient	1	48.130632	48.130632	3.76	0.0554
Direction*Season	1	106.709393	106.709393	8.33	0.0048
Micronutrient*Season	1	13.465067	13.465067	1.05	0.3078
GM*Dire*Micro*Season	5	667.145518	133.429104	10.41	<.0001

Table 11 b. ANOVA for pods dry mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	22	281.0327132	12.7742142	6.87	<.0001
Error	102	189.7010640	1.8598144		
Corrected Total	124	470.7337772			
R-Square	**CV**	**Root mean square error**		**Pod dry mass mean**	
0.597010	54.97893	1.363750		2.480496	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	222.3827117	222.3827117	119.57	<.0001
Direction	1	4.1853836	4.1853836	2.25	0.1367
Micronutrient	1	0.3867181	0.3867181	0.21	0.6494
Season	1	2.9950414	2.9950414	1.61	0.2073
GM*Direction	1	0.6579707	0.6579707	0.35	0.5533
GM*Micronutrient	1	2.8172728	2.8172728	1.51	0.2212
GM*Season	1	0.8543069	0.8543069	0.46	0.4995
Direction*Micronutri	1	3.2955825	3.2955825	1.77	0.1861
Direction*Season	1	1.6278685	1.6278685	0.88	0.3517
Micronutrient*Season	1	1.8702028	1.8702028	1.01	0.3183
GM*Dire*Micro*Season	5	8.4450250	1.6890050	0.91	0.4789

ANOVA for number of peas plant mass

Table 12a. ANOVA for garden pea plant fresh mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	22	2426.489928	110.294997	13.59	<.0001
Error	91	738.661053	8.117154		
Corrected Total	113	3165.150982			
R-Square	**CV**	**Root mean square error**		**Number of pods Mean**	
0.766627	38.23146	2.849062		7.452140	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Growth media	1	1653.443646	1653.443646	203.70	<.0001
Direction	1	0.056251	0.056251	0.01	0.9338
Micronutrient	1	0.124835	0.124835	0.02	0.9016
Season	1	263.546817	263.546817	32.47	<.0001
GM*Direction	1	8.039543	8.039543	0.99	0.3223
GM*Direction	1	8.251828	8.251828	1.02	0.3160
GM*Micronutrient	1	17.884236	17.884236	2.20	0.1412
GM*Season	1	107.688390	107.688390	13.27	0.0004
Direction*Micronutrient	1	0.355301	0.355301	0.04	0.8347
Direction*Season	1	54.793268	54.793268	6.75	0.0109
Micronutrient*Season	1	71.566344	71.566344	8.82	0.0038
GM*Dire*Micro*Season	5	270.937467	54.187493	6.68	<.0001

Table 12b. ANOVA for garden pea plant dry mass

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	22	1090.952763	49.588762	32.04	<.000
Error	91	140.828610	1.547567		
Corrected Total	113	1231.781373			
R-Square	**CV**	**Root mean square error**		**Number of Pods mean**	
0.885671	26.95611	1.244013		4.614956	
Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
GM	1	859.9190997	859.9190997	555.66	<.0001
Direction	1	0.3068201	0.3068201	0.20	0.6572
Micronutrient	1	4.1768505	4.1768505	2.70	0.1039
Season	1	0.1913084	0.1913084	0.12	0.7260
GM*Direction	1	0.0000014	0.0000014	0.00	0.9992
GM*Micronutrient	1	2.0648468	2.0648468	1.33	0.2511
GM*Season	1	151.6515377	151.6515377	97.99	<.0001
Direction*Micronutrient	1	0.3158089	0.3158089	0.20	0.6525
Direction*Season	1	7.5498108	7.5498108	4.88	0.0297
Micronutrient*Season	1	13.5253539	13.5253539	8.74	0.0040
GM*Dire*Micro*Season	5	45.8351772	9.1670354	5.92	<.0001

APPENDIX C: Season one growth media and plant tissue nutrient content

Table 14 a. Growth media nutrient content before and after first season trial termination (2020/21)

Growth Media	Trelmix Treatment	Nutrient content (mg/kg)					
		Mg	Ca	Al	Mn	Na	Cu
Soil	Before	154.4	327.08	308.9	24.8	27.0	0.219
	After	309.6	423	375.5	37.1	26.1	3.6
Compost	Before	10098	9333.7	592.4	660.5	631.3	31.5
	After	9253.5	9520.3	552.2	510.4	778.2	28.3

Table 14 b. Plant tissue nutrient content first season (2020/21)

Vegetable	Micronutrient	Minerals (mg/kg)						
		Mg	Ca	Al	Mn	Na	Cu	S
Garden pea	Soil (Control)	380.8	1764.31	2.530	3.861	93.851	0	858.020
	Compost (Control)	602.5	1207.31	7.656	15.13	19.291	0.442	854.520
	Soil-treated	412.5	2300.31	12.087	4.559	48.001	0	918.720
	Compost- Treated	1038	1370.31	12.647	17.95	114.101	0.639	825.920
Swiss chard	Soil (Control)	284.6	99.414	106.757	2.723	158.501	1.119	1054.31
	Compost (Control)	371.1	45.144	141.057	5.389	112.901	0.405	511.614
	Soil-treated	351.1	45.134	22.847	5.644	271.201	0.229	887.214
	Compost-treated	245.3	82.704	154.557	3.903	90.911	0.185	511.514
Beetroot	Soil (Control)	927.4	121.214	179.357	84.67	79.091	0.893	2044.31
	Compost (Control)	418.5	198.414	179.357	5.253	71.991	0.194	1272.31
	Soil-treated	881	69.084	270.257	93.75	38.361	1.337	751.014
	Compost-treated	395.2	222.114	21.257	5.512	53.101	0.2	2281.31

APPENDIX D. Season two growth media and plant tissue nutrient content

Table 15 a. Growth media nutrient content before and after second season trial termination (2021/22)

Growth Media	Nutrient content (mg/kg)						
	Mg	Ca	Al	Mn	Na	Cu	S
Soil	473.84	1650.7	452.26	39.52	100.04	6.43	38.07
Compost	6910.3	10695	131.4	292.6	759.1	22.6	975.625

Table 15 b. **Plant tissue nutrient content season two (2021/22)**

Vegetable	Micronutrient	Nutrient content (mg/kg)						
		Mg	Ca	Al	Mn	Na	Cu	S
Garden pea	Soil (Control)	619.9	1008	43.167	4.692	30.57	0.974	254.047
	Compost (Control)	354	1959	39.247	1.519	38.26	1.345	834.247
	Soil-treated	739.1	862	51.457	3.5	78.86	0.361	469.947
	Compost-treated	655.6	3087	41.487	1.979	96.83	2.137	1174.147
Swiss chard	Soil (Control)	1069	817.3	113.547	35.21	363.8	3.301	605.347
	Compost (Control)	1041	1412	14.857	1.609	1062	0.502	349.747
	Soil-treated	1196	976.5	85.667	8.865	368.4	1.568	805.847
	Compost-treated	919.4	1713	24.567	1.85	1002	0.499	330.347
Beetroot	Soil (Control)	909.0	814	311.247	12.25	162.9	1.534	292.047
	Compost (Control)	628	573.0	24.387	0.589	350.6	0.731	256.247
	Soil-treated	958.70	922.80	102.947	10.83	169	0.922	332.347
	Compost-treated	841.10	1121.0	27.237	0.347	316.3	0.501	275.347