ARTIFICIAL SOIL PROFILE FOR VEGETABLE PRODUCTION: A POTENTIAL CASE OF URBAN AGRICULTURE

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

~~*ATModi*~~

Signed: Professor Albert T. Modi (Supervisor)

Date: 21 October, 2020

DECLARATION

I, Nosipho Precious Phungula, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

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a) their words have been re-written but the general information attributed to them has been referenced;

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(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

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GENERAL ABSTRACT

A significantly large population of South Africa migrates from rural to urban areas, leaving opportunities for small-scale subsistence agriculture for a perceived better livelihood. Food insecurity and poverty seem to increase in the peri-urban areas because of poor opportunities for food production and the inescapable need for money to survive. The advantages of urban farming have been published in the literature for many years, but there are still opportunities to introduce innovative methods that are confirmed by scientific findings. This study aimed to determine the efficiency of portable bags and artificial soil profiles on year-round production of common vegetables in South Africa, namely, Swiss chard, lettuce, onion, beetroot, and green pepper. Artificial soil profiles were created in the bags using commonly found urban homestead common organic garden refuse (grass and wood) garden soil and collected rock, respectively. One vegetable, lettuce was used to represent fertilizer requirements and three recommendations (0, 50, and 100%) were applied. Measured crop growth parameters included plant height, leaf number, stomatal conductance, chlorophyll content index, leaf area index, and photosynthetically active radiation. Soil moisture content, soil water potential, and soil temperature were also determined. Crop biomass yield and mineral content at harvest were also determined. The artificial environment was compared with soil plot environment (sandy loam soil with 110 mm depth) under rainfed conditions, with limited supplemental irrigation during dry periods. Results showed that vegetable production is possible all year round in both artificial and real profile conditions. The vegetable yield was reduced in non-soil artificial profiles, but the fertilizer application supported it all year round. Vegetable nutritional value, in terms of selected minerals, differed significantly between seasons and less between normal and artificial profiles, where even no fertilizer application produced yield all year round. The study concludes that disposable bags have a potential role for vegetable production in urban areas, where land area is limited. Potential food security benefits are linked more to nutrient access than quantity access. There is a need to test the findings of the study a different environmental and socio-economic conditions, to influence government policy.

Keywords: artificial soil profile, fertilizer, season, temperature, vegetable nutrient content

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LIST OF ABBREVIATIONS

Abbreviation	Definition
A	Soil with grass, rocks, and wood sticks
CCI	Chlorophyll Content Index
DAP	Days After Planting
L	Soil with grass
LAI	Leaf Area Index
PAR	Photosynthetically Active Radiation
R	Soil with rocks
S	Soil only
SC	Stomatal Conductance
UA	Urban agriculture
W	Soil with wood sticks

1. GENERAL INTRODUCTION

Projections state that 50% of the Africa population will be urbanized by 2034 and the total population of Africa will reach 2 billion by the year 2050, whereas 60% will be urbanized (Collinson et al., 2007). About 77% of the South African population will be urbanized by 2050 (Llewellyn, 2017). An exponentially increasing population requires infrastructure such as new schools, clinics, roads, new water pipes, sewage treatment plants, electricity networks, waste-disposal facilities, and more food, which in turn require large spaces of land as part of resource investments (Turok and Borel-Saladin, 2014). Urbanization, rapid natural disasters, and climate change can, singularly or in combination, trigger high demand for land and food-derived more from external sources than from self-subsistence (Sharma et al., 2019; Pascual et al., 2018). The unavailability of land represents the highest limiting factor to food production in urban areas (Peprah, 2014). Urban land is used mainly for the construction of houses leaving no space for gardening; buildings have exhausted the available farming land (Peprah, 2014).

Urbanization has brought challenges and opportunities for developing countries, also the growing capacity of the world's population in cities is bound by a lack of employment and weak institutional capabilities (Turok and Borel-Saladin, 2014). Resulting risks include increasing poverty, food insecurity, instability, and environmental degradation. This rapid demographic growth puts extreme pressure on natural watercourses, air quality, green spaces, landfill sites, and biodiversity; overall the ecosystem is in danger, thereby expanding environmental risks and threatening resource scarcity (Turok and Borel-Saladin, 2014).

Urbanization is well defined as the "concentration of a population in relatively permanent locations, within geographical boundaries and characterized by, among other things, crowding, a cash economy, a low level of physical activity in occupations," (Mwangi, 1995). The growth of cities is due to the natural growth of migration from the rural areas to the cities and urban areas, leaving the government with a challenge on how to feed the growing population whilst fighting the impacts of urbanization (Veenhuizen, 2006; Llewellyn, 2017). The power of a city to produce enough and affordable food depends on numerous factors including space, availability of resources, and climate (Llewellyn, 2017). The current living conditions there suggest that urbanization is an unbeatable phenomenon in the Sub-Sahara African (SSA) countries, where the speedy rate of urbanization changes household income, education, and employment opportunities, which directly define the peri-urban food insecurity phenomenon (Akerele et al., 2016).

Generally, the focus of literature and government policy, regarding food insecurity and malnutrition has been on rural areas, but there is an evident shift towards urban areas, where population increases occur rapidly (Akerele et al., 2016). In South Africa, the apartheid era resulted in relatively slow urbanization, however after apartheid cities have grown by more than 50% (Collinson et al., 2007). Furthermore, the 2011 census results showed evidence of urban growth, reporting that the country had a total population of 51.8 million people with an annual growth rate of 1.5% and an urbanization rate was 61.7% (Ruhiiga, 2014). According to statistics in 2001, the level of urbanization reached 56%, having an increment of 4.3% between 1996 and 2001 as shown in Table 1.1 (Posel, 2017). As for the 2001-2011 period, a relative decline in growth rates was observed for Pretoria, Ekurhuleni, Durban, and Johannesburg (Ruhiiga, 2014). Of the largest cities, only Cape Town showed a higher rate relative to the 1996-2001 period (Ruhiiga, 2014). Internal movements within individual cities and rural-to-urban migrations resulted in the variation in population changes as indicated in Table 1.1 (Ruhiiga, 2014). Big cities are deemed as opportunistic area.

Table 1.1: Population and population growth rates of major urban areas in South Africa, 1996-2011 (Ruhiiga, 2014).

	Population			Population growth rate (%)	
City	1996	2001	2011	1996-2001	2001-2011
Bloemfontein	603704	645400	747437	1.4	1.6
Cape Town	2563612	289243	3740026	2.6	2.9
Durban	2751193	3090122	3442361	2.5	1.1
East London	682287	695278	755200	0.4	0.9
Ekurhuleni	2026807	2478651	3178471	4.5	2.8
Johannesburg	2639110	3225309	4434827	4.4	3.8
Port Elizabeth	969771	1005779	1152115	0.7	1.5
Pretoria	1682701	2144505	2921488	5.5	3.6

The livelihood in the urban areas is very challenging in such a way that money is required for every activity. Many urban dwellers do not earn enough salary to cover all the costs, and they may sacrifice their diet needs (Ruhiiga, 2014). Consequently, malnutrition and food insecurity become the issue of concern for urban dwellers, they turn to consume less nutritious food (Satterthwaite et al., 2010). Backyards for urban houses are very small for the cultivation of crops unlike in rural areas. Also, most of the soils are contaminated and adding remedy and any amendments in the soil require money that they do not have (Satterthwaite et al., 2010). Urban agriculture seemed to be a complementary strategy for addressing poverty and food insecurity because it plays a vital role in enhancing environmental management in urban areas (Akerele et al., 2016). Based on this worldwide issue, urban agriculture response to major challenges for urban dwellers including urban poverty, food insecurity/malnutrition, little direct access to fresh food markets (Veenhuizen, 2006).

Urban agriculture (UA) has been promoted as a tool that will improve a sustainable environment and improve the status and diets of households, addressing poverty in the urban areas for the poorest and improve well-being (Mwangi, 1995). The study of (Satterthwaite et al., 2010) reported that millions of urban dwellers suffer under-nutrition today, perhaps due to their low income. Thus, the lack of capacity to produce food resulted in poor health and nutritional status. Meanwhile, the general trend in food production has to keep up with the increasing population, which creates competition that does not favor the poor (Deng et al., 2015). As much as urbanization has a positive impact on technology innovation and improving economic growth, it also harms the agricultural sector, for example, cultivated land is degraded (Deng et al., 2015).

The practice of UA in South Africa is very new and started to grow after decades of apartheid when the city's population growth increased exponentially, urban areas were receiving large amount migrants from the rural homelands to the extent that the municipalities could not keep up with the influx (Crush et al., 2011). Food production to meet household requirements escalated following continued evolution from apartheid to a democratic country in 1994 (Crush et al., 2011). Whereas the level of food inflation and high unemployment rate within the formal economy was the issue of concern (Crush et al., 2011), many of the migrants often live in informal settlement facing poverty and malnutrition, while spending little income on groceries (Crush et al., 2011). It has been reported that in the SSA countries food insecurity is mainly dominant in the urban areas because of great reliance on obtaining food from the market compared to rural people who can cultivate their food or generate income by selling extra produce (Baiphethi and Jacobs, 2009).

The overall aim of this study was to assess the value of containerized vegetable production using disposable bags, combined with artificial soil profile based on selected vegetable crop physiological response, growth, and harvestable yield under irrigation, all year round. Vegetable plant tissue mineral content was used as an indicator of food security.

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2. LITERATURE REVIEW

2.1. Introduction

According to Zezza and Tasciotti (2010), urban agriculture is “the production of crops and livestock goods within cities and towns”. Urban agriculture (UA) has different systems such as horticulture, floriculture, forestry, aquaculture, and livestock production (Hallett et al., 2016). Urban agriculture is identified by high competition for land, limited space, use of organic solid wastes and wastewater, hence, it plays a role in managing urban natural resources (Van der Merwe, 2003). Urban agriculture started with many different forms having the same objective as rural farming (Rich et al., 2018). The mandate was to respond to food shortage, unemployment, and producing perishable products such as vegetables which are high-value crops that can bring income and generating opportunities for small farmers, also provide a diverse diet (Rich et al., 2018). Utilizing UA in limited space can improve food security for the urban dwellers, supplementing daily food. The link between urban agriculture and food security has been studied intensively in the past years, for example, UA is one of the tools that is used to combat urban hunger and malnutrition by providing nutritious food cheaper than market purchases and more consistent access to freshness (Crush et al., 2011).

To improve the situation for urban residents, it was found crucial to use any available space to cultivate more food, including rooftops, window boxes, on roadsides, riverbanks, and vacant lots (Crush et al., 2011). Furthermore, they can even sell the surplus, thus providing much more needed income (Crush et al., 2011). For some, especially those who live just outside the city, this kind of farming becomes their main job and supports the entire family or group of families (Crush et al., 2011). Increased UA production has the potential to improve the food security of poor households in both rural and urban areas by increasing food supply, and by reducing dependence on purchasing food in a context of high food price inflation (Baiphethi and Jacobs, 2009).

The widespread poverty and shortage of food remain the main challenge in South Africa. Many underprivileged citizens are surrounded by increasing unemployment rates and struggle to combat poverty eradication and food insecurity (Khumalo and Sibanda, 2019). Now, UA is recognized as an essential livelihood strategy to control or reduce food insecurity within the urban areas, and thus, poverty alleviation (Khumalo and Sibanda, 2019). Considering a steady increase in the economic growth of South Africa, poverty levels and food insecurity have not decreased significantly. Hence, this innovation tool presents an opportunity as a livelihood strategy to alleviate poverty and ensure household food security within the urban spheres (Khumalo and Sibanda, 2019). Thus, it is important to review the development of urban agriculture, different soilless innovative systems used to produce vegetables in urban areas, and their potential contribution to urban food security.

2.2 Contribution of urban agriculture to South African peri-urban areas

According to current information (FAO, 2019), Africa is a leading continent (Figure 2.1) when it comes to food insecurity and hunger compared to other continents, with the number of people that suffer from hunger slowly increasing from 2015 to 2018. This can be related to the kind of food that is consumed in terms of nutrition value. Income and education determine the type of dietary practices. African diet is more on grain foods with less consumption of fruits and vegetables (Oniang'o et al., 2003). African staple crops include cereal, cassava, yam, sweet potato on a daily consumption (Oniang'o et al., 2003). Therefore, an innovative strategy such as UA can be vital to meet up the production of food for those that are needed. Recent statistics show that only about 45.6% of South Africans are not below the food security line, while 28.3% are at risk of food shortage and 26% are actually food insecure and experience hunger (Visser and Tibesigwa, 2016).

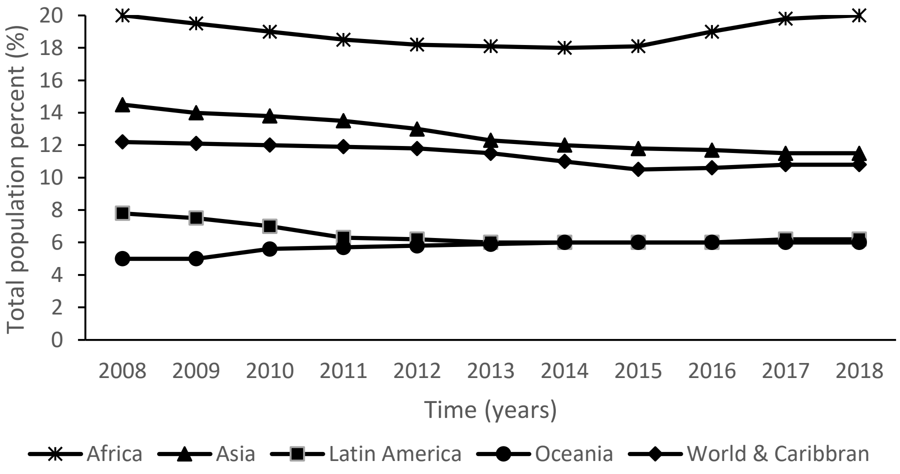

Figure 2.1: Prevalence of undernourishment continents from 2008 to 2018 (FAO, 2019)

According to South African Statistics, the urban population has increased. In 2011, the Gauteng Province took first place having the highest population of 12.2 million people followed by Kwa-Zulu Natal with 10.3 million people (Khumalo and Sibanda, 2019). This population increase is due to the movement of job seekers and opportunities from rural to the larger metropolis (Khumalo and Sibanda, 2019). Urbanization was delayed in South Africa specifically Kwa-Zulu Natal, due to apartheid past influence and laws which were existing, hence even today the main factor of rising urban population is rural to urban migration (Khumalo and Sibanda, 2019). For the past several years' poverty has been linked with rural communities and now that phenomenon has shifted to urban areas. This suggests that there is increased pressure for increased food supply on urban agriculture and conventional agriculture cannot guarantee food security for the rapidly increasing population (Khumalo and Sibanda, 2019). Therefore, it has become a huge challenge to secure food provision for poor urban citizens (Khumalo and Sibanda, 2019).

The study that was conducted in Rhini, Eastern Cape, examining the importance of AU. Households practiced UA and claimed that with their gardening products they can save less than R100 per month (p/m) in food costs (Thornton, 2008). For example, households earning between R740 and R1,480 p/m would experience a monthly increase of less than R100 to 150 in food expenditures without their garden (Thornton, 2008). Their gardens were small plots from 1 to 2 m^2 and do not use all the space for growing food. Intercropping techniques are not widely practiced, therefore there is a lack of crop diversity (Thornton, 2008). Hence, it is very unusual that such small garden plots can produce sufficiently for a household to save about R300 or even R150 p/m (Thornton, 2008). Despite lack of job opportunities and poverty, urban residents are encouraged to use available resources such as small land, household labor, and social grant income, to generate more food from their gardening (Thornton, 2008). Additionally, urban dwellers do receive social grants but remain below the poverty income line due to maintaining high monthly food expenditures, hence, UA comes as a tool that will help to supplement food (Thornton, 2008).

Khumalo and Sibanda (2019) conducted a study in eThekwini Municipality, Tongaat peri-urban area, to analyze the contribution of urban-peri agriculture (UPA) towards the food security status of households practicing UPA activities and that do not practice UPA activities (Khumalo and

Sibanda, 2019). Two hundred and eight (208) households were selected 109 were UPA practicing and 99 non-UPA practicing households using a stratified random sampling procedure. The Household Dietary Diversity Score (HDDS) and Household Food Insecurity Access Score (HFIAS) measures were used to estimate a household's food security condition (Khumalo and Sibanda, 2019). A Pearson Chi-Square test showed that the employment status, access to arable land, land ownership and household monthly income variables were statistically significantly related with the food security status (in terms of HDDS) of households (Khumalo and Sibanda, 2019). The results from the HDDS tool, showed that 54% of the UPA practicing households consumed more than six food groups. These seemed to be food secure in terms of dietary access compared with the non-UPA practicing households (40%) in the same food group (Khumalo and Sibanda, 2019). The HFIAS showed that about 72% of the UPA practicing households are food secure in terms of food access, whereas the non-UPA practicing households (61%) are less worried about food shortages (Khumalo and Sibanda, 2019). Overall, the results showed that UPA practicing households are better off in terms of food insecurity as compared to non-UPA households (Khumalo and Sibanda, 2019).

2.3 Environmental constraints limiting vegetable production

The decline in crop productivity worldwide is primarily caused by environmental stresses, reducing yield for crops by more than 50% in addition to urbanization contribution (La Pena and Hughes, 2007). The occurrence of climate change on a global scale, accompanied by urbanization, has a significant negative impact on agriculture, food supply, and crop productivity as affected by unexpected rainfall and unpredicted high and low temperatures (La Pena and Hughes, 2007). Consequently, this causes land degradation, extreme geophysical events, reduced water availability, and sea-level rise leading to the postulation of salinity (La Pena and Hughes, 2007). In hot and dry situations, high evapotranspiration leads to water loss, leaving salt around the plant roots which disturbs the plant's capacity to take-up water (La Pena and Hughes, 2007). Physiologically, salinity causes high solute concentration in the soil, causes ion-specific stresses because of adjusted K^+/Na^+ proportions and prompts a development in Na^+ and Cl^- concentrations that are harmful to plants (Abou-Hussein, 2012). The United States Department of Agriculture (USDA) observed that onions are more sensitive to saline soils, whereas cucumbers, eggplants, peppers, and tomatoes are moderately sensitive (La Pena and Hughes, 2007).

The climate change variable's contribution has resulted in a huge impact on water resources, food security, hydropower, and human health and changes in crop production (Kang et al., 2009). Ocean levels are ascending and salinization is hypothesized to lessen crop productivity and impact food security negatively (Abou-Hussein, 2012). Heavy rains cause excessive soil moisture and most vegetables are sensitive to flooding or too much water because oxygen is reduced in the root zone which inhibits aerobic processes (La Pena and Hughes, 2007). High temperatures cause significant loss in productivity due to reduced fruit set, lack of opening of the stomata, and poor pollen formation (La Pena and Hughes, 2007).

South Africa is one of the 30 arid countries in the world, receiving annual rainfall of 450 mm whereas the global average is 860 mm per year (Bwapwa, 2018). Therefore, the country can be considered as a water-scarce one (Bwapwa, 2018). In South Africa, water scarcity is a mixture of various factors, including limited and highly polluted water due to low rainfall, a fast-growing population, and high evaporation rates (Bwapwa, 2018). Several studies have been done about water shortage and all of them have shown a decline in quality due to the occurrence of pollution primarily caused by urbanization, mining, industry, power generation, afforestation, and agriculture (Bwapwa, 2018). The agricultural sector uses about 60% - 70% of the water in many places in the world. Regarding this issue, there is a need to find appropriate strategies to minimize the use of freshwater for irrigation purposes such as farming that will use less water, e.g., containerized production where the soil is protected, there is no runoff and soil remains humid in most cases and hydroponics (Bwapwa, 2018).

Besides climate change contributing to water scarcity, water in the urban areas is used in many ways resulting in competition between water user sectors. Urban water use can be broadly classified into domestic, industrial, agricultural, and sometimes ecological uses (Zhou and Tol, 2005). The level and purpose of water use differ intrinsically across the sectors, for example, industrial and agricultural sectors use water mainly as production input as opposed to the residential sector which uses water as a direct consumption good (Zhou and Tol, 2005). Meeting the water demands of growing cities requires not only large quantities of high-quality water for domestic use but also large volumes of water for industrial production (Zhou and Tol, 2005).

Therefore, urban dwellers do not receive enough water for watering their gardens. For example, Lagos and Abidjan have average municipal water supplies of only 40-45 liters/capita/day for their entire populations, whereas Nairobi has a mere 17.7 liters/capita/ day, while Lome and Accra supply less than 10 liters (Zhou and Tol, 2005). Even in cities with high average domestic water consumption, many people, especially those living in slums and peri-urban areas, do not receive an adequate share of the municipal supplies (Appasamy and Meinzen-Dick, 2002). Many urban dwellers use wastewater from the kitchen and bathroom for example after washing vegetables, utensils, and clothes or taking baths, for irrigating home gardens due to the scarcity of water (Shrestha, 2016).

The production of vegetables has increased worldwide; has doubled over the past century and now exceeded the production of cereals. Furthermore, in China, they have increased the area under the cultivation of vegetables from 12 to 16 million hectares (La Pena and Hughes, 2007). Vegetables are sensitive to environmental extremes; they prefer cooler temperatures hence in hot and humid lowlands the productivity is minimal whereas extremely high temperatures and limited soil moisture cause low yields in the tropic regions (La Pena and Hughes, 2007). Vegetables are essential for well-balanced diets as they supply phytonutriceuticals. Each vegetable has its combination of phytonutriceuticals and that is used to differentiate vegetable types (Dias, 2012). These vegetable phytonutriceuticals can protect the human body from a wide range of chronic diseases, such as diabetes, and also improve good vision, reduce the risk of heart disease, and stroke (Dias, 2012).

2.4 The use of soilless culture systems to produce vegetables

Traditionally, the land is the key to production and agriculture has been a soil-based activity since the beginning (Van Tuijl et al., 2018). However, technological developments and modern life result in increasing scarcity of suitable agricultural land, hence it is even possible to produce food in the air and water (Van Tuijl et al., 2018). Agricultural systems have transformed into various innovative cultivations to address the challenges of poor food production in urban areas. These include environmental protection such as allotments for self-consumption, large-scale commercial farms, community gardens, and even edible landscapes, vacant spaces such as rooftops, fallow land, and smaller areas like roadsides or private balconies, using bags, mats, and containers

(Eigenbrod and Gruda, 2015). Additionally, nutrient solutions as well as efficient lighting systems, and automatic control have been developed (Hallett et al., 2016). These cultivation methods include systems without a solid medium, as well as aggregate systems that are inorganic or organic substrates, are used. Furthermore, it has been reported by many authors that locally produced food is much fresher and more nutritious than imported food and therefore urban farming has the potential to increase the overall food intake and improve nutrition (Eigenbrod and Gruda, 2015). Vegetables in urban areas are produced using different farming methods as discussed in the following sections.

2.4.1. Home gardening

Home gardening (Figure 2.2) is very popular worldwide the most common form of urban agriculture. This farming system is the cultivation of various vegetables in the backyard and uses low-cost amendment inputs (Eigenbrod and Gruda, 2015). The fresh produce is more of adding vegetables in households or act as the main source for consumption. Utilization of home gardening will help with food expenses and people are not dependent on the market and gain extra income if a surplus of vegetables is sold. Lastly, it supports daily meals for the family members year-round (Eigenbrod and Gruda, 2015; (Shrestha, 2016). Again this will be very beneficial for developing countries because they spend too much on purchasing food, for example, the urban poorest spend about 60–80 % of their income on food, through urban horticulture such expenditure can be reduced. Additionally, this plays a huge role in the family's survival, and producing their food would allow them to save a great amount of money and use it for other needs (Eigenbrod and Gruda, 2015).

2.4.2. Community gardening

Community gardening is the cultivation of various crops by different people in a shared space. In some cases, it utilizes urban open space and the gardens range from small plots to larger areas (Eigenbrod and Gruda, 2015). In developing nations community gardens are often established to alleviate poverty, contribute to food security, and suppress malnutrition for urban dwellers, through community gardens urban dwellers can use shared land to improve their nutrition intake (Eigenbrod and Gruda, 2015). Third world countries like Sri Lanka, Argentina, and Madagascar utilize school garden programs to provide fresh and healthy food for young students as well as education about agriculture and this has an important role in terms of nutrition and food security (Eigenbrod and Gruda, 2015).

Figure 2.2: Typical example of a home garden (Shrestha, 2016).

2.4.3 Rooftop

To overcome the cost of leasing vacant spaces and necessary resources for farming in the urban areas using roofs of urban buildings and other urban infrastructures ease the cost of farming (Hui, 2011). Normally, high-rise buildings roof in cities is occupied by equipment such as chiller plant, water tanks, lift motor room, TV antennae, and water distribution pipes (Figure 2.3) (Hui, 2011). It is found necessary to use available space for farming to solve food security for urban dwellers. Many large vacant rooftops are underutilized such as school, industrial, community, shopping malls, or gymnasiums buildings, and can be used for an urban farm (Hui, 2011). The installation of green roofs with urban farming comes with numerous benefits including environmental, social, and economic sustainability (Hui, 2011). Also benefiting in visual, aesthetic, and local human climatic amelioration, reducing food transportation, recycle organic wastes by converting to composts, mitigate urban heat island, increase biodiversity, improve air quality, improve urban stormwater management and sound insulation and noise absorption (Hui, 2011). Additionally, the strategy of rooftop vegetable improves nutrition and food security.

Figure 2.3: Rooftop (Hui, 2011)

Rooftop gardens are most productive when installed on the flat roof styles hence, the weight of a green roof system is of vital importance and it is necessary to select extremely light-weight systems (Hui, 2011). However, climatic factors can have negatively affect rooftop cultivation including strong wind that might blow away the crops and soil. Roofs must be able to drain rainwater without creating pools of water during heavy rainfalls and cause waterlogging. The high temperature might affect some plant species, strong solar and UV radiation might cause problems to the green roof materials and components (Hui, 2011).

2.4.4. Vertical farming

This system allows for the cultivation of various crops in a relatively small area, thereby reducing the necessity of large cultivable land (Al-Kodmany, 2018). The vertical farming system is soil and climate effect independent to an extent that cultivation can take place all year round even in the presence of weather extremes (Al-Kodmany, 2018). The idea behind vertical farming is simply to produce more food on less land used, thus vertical farming could promote food production efficient and sustainable extremes (Al-Kodmany, 2018). It is also useful to enhance the economy, reduce pollution, provide new employment opportunities, restore ecosystems, and provide access to healthy food (Al-Kodmany, 2018). Vertical farming is advantageous over other methods because it is not reliant on favourable climatic conditions, hence, even cities with contaminated soil that are more close to the industries or areas experiencing severe weather conditions could grow healthy food sustainably and independently from others (Eigenbrod and Gruda, 2015). Lastly, consumers are being near to the fresh produce and the controlled environment throughout the building producing higher yields (Al-Kodmany, 2018).

2.4.5. New technologies for indoor farming

Cultivating vegetables vertically has many advantages as mentioned above. Moreover, vertical farming plants are hidden in a building; hence the amount of sunlight received by plants is inefficient and not at the same level as in conventional cultivation (Al-Kodmany, 2018). Light is essential for photosynthesis, therefore, it is important to supplement light sources to ensure sufficient and high-quality yields (Al-Kodmany, 2018). This leads to the development of highly efficient artificial light sources such as light-emitting diode (LED) which gives plants radiant energy to encourage plant growth, plant development, and product quality (Eigenbrod and Gruda, 2015); (Al-Kodmany, 2018). This lamp has various unique advantages over existing horticultural lighting, for example, size being small and having increased longevity and low heat emission even at very high light intensity levels (Eigenbrod and Gruda, 2015). Also, LED lamps can control spectral composition, giving people a choice to select a favorable light spectrum for photosynthesis (Eigenbrod and Gruda, 2015). Indoor farming uses LED and it offers multiple benefits such as crops will be less subjected to climate, infestation, the nutrient cycle, crop rotation, polluted water runoff, pesticides, and dust (Eigenbrod and Gruda, 2015). Indoor farming offers a healthier and conducive environment to grow crops; also it operates year-round providing higher yields and not affected by severe weather conditions (Al-Kodmany, 2018). Despite the resource efficiency of indoor farming systems, they are very expensive (Eigenbrod and Gruda, 2015).

2.4.6 Hydroponics

Hydroponics is the growing of plants in nutrient solutions with or without the use of media such as gravel, vermiculite, Rockwool, peat moss, sawdust, coir dust, coconut fiber, and many more that are used primarily to provide mechanical support (Sharma et al., 2019). Hydroponics differ in terms of farming methods. The system can use water as the growing medium, beneficial for fast plant growth with no soil-related cultivation problems, and decreases the use of fertilizers or pesticides (Al-Kodmany, 2018). Aeroponics involves spraying plant roots with mist made up of nutrient solutions (Al-Kodmany, 2018). Aquaponics mixes aquaculture, for example, fish farming with hydroponics (Al-Kodmany, 2018). Organoponics cultivation system is mostly used where soil fertility quality is low. This system is suitable for developing countries or areas without proper infrastructure or access to fertilizers and other inputs amendments. This farming system is similar to a home or community garden. The difference is that organic input is used here. This system operates in the absence of fertilizer, therefore using readily available organic materials is linked to ecologically friendly practices (Eigenbrod and Gruda, 2015). Since it is environmentally friendly, it is highly suitable for urban horticulture (Eigenbrod and Gruda, 2015). It was reported (Agriculture et al., 2016) that the yield of organoponics can be greater by 17 % compared to other systems.

The greatest part of the hydroponic system is that it is built for the recycling of nutrient solution, e.g., wick, drip, ebb-flow, deep water, and nutrient film technique (NFT) and is customized automatically operated, therefore, labor is reduced for weeding, spraying, watering and tilling (Sharma et al., 2019). Additionally, utilizing this system saves large amounts of water for irrigation, pest and diseases are limited, and it has been reported that with this kind of technique higher yields are obtained compared to conventional agriculture (Sharma et al., 2019). However, there are some constraints with hydroponics, including costs, especially for small-scale farmers, because it requires the technical skills of people to operate. Water diseases are very common since many plants are sharing nutrients solutions, imbalanced electrical conductivity (EC) and pH of the nutrient solution can be problematic to the growth and development of a plant (Sharma et al., 2019).

2.4.7 Sack gardening

Kenya has developed a new form of urban agriculture called sack gardening, which was developed and spread during the last decade from 2007-2008 during post-election violence (Gallaher et al., 2013). Sack gardening is the planting of vegetables into both top and sides of a sack by puncturing holes across the entire sack and insert seedlings into it (Peprah, 2014). The sack is filled with soil plus manure and stones to facilitate water movement as indicated in Figure 2.5 a pole is inserted in the middle of the sack to support the sack posture. This type of cultivation allows households to plant different crops such as kale, Swiss chard or spinach, green onions, and coriander as shown in Figures 2.4 and 2.6 (Peprah, 2014; Gallaher et al., 2013). This method of farming is found cheap for small-scale urban agriculture and provides a viable livelihood strategy to the urban poor in other regions of the world, and even in highly space-constrained urban environments (Gallaher et al., 2013). Various studies (Gallaher et al., 2013; Coleman, 2014; Peprah, 2014; Hallet et al., 2016) have demonstrated that sack gardening can have a positive impact on household food security, either by providing an additional income source, increasing dietary diversity, or helping to protect against seasonal unavailability in the food supply, supplement household food consumption rather than as a business venture also (Gallaher et al., 2013). This kind of planting uses materials that are readily available and cheap compared to other systems that have been mentioned above and the sack is portable and can be placed anywhere. Sacks are normal household items usually used for storing farm produce such as maize meal which may also be bought from the market (Peprah, 2014). The center of the sack is covered, therefore evaporation is reduced, hence soil is kept humid, thereby increasing water efficiency to enable roots to penetrate deeper into the sack to access water (Coleman, 2014).

Figure 2.4: Sack gardening (Peprah, 2014).

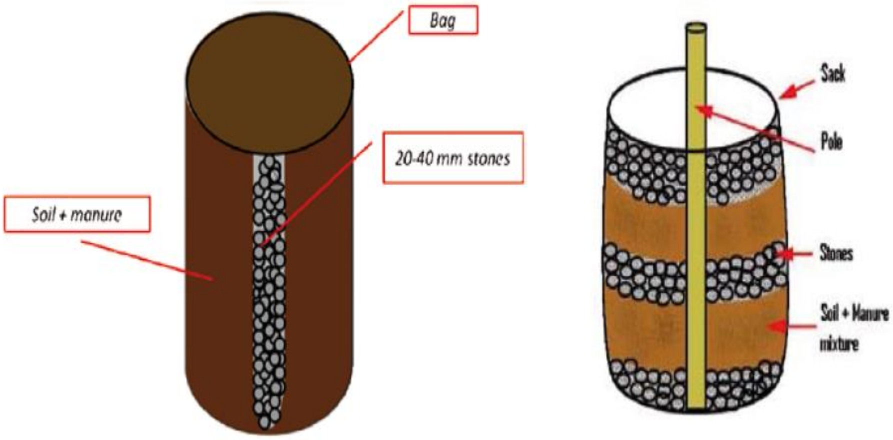

Figure 2.5: Illustration of a sack filled with soil and stone used for cultivation (Pascal and Mwende, 2008).

Figure 2.6: Sack planted spinach (Pascal and Mwende, 2008).

Most studies of the containerized production of vegetables have been conducted under a controlled environment utilizing expensive white or black plastic and unaffordable growing medium. The current study differs from previous ones such that it advocates the use of readily available materials such as biodegradable sack and growing medium is easily accessible, under the limited area.

2.4.8 Growing pillar and growing wall

This type of cultivation was inspired by sack gardening; the notion behind this farming method was to increase the soil depth in the sack and allowing cultivation of many crops such as deep rooting crops and solidity of the structure to grow more crops as shown in Figure 2.6 (Coleman, 2014). Both growing pillar (GP) and growing wall (GW) use welded-wire fencing for the structure Figure 2.6, fabric for the inner lining, and compost as a medium for growing (Coleman, 2014). The entire surface is used including the sides and top, same as sack gardening, whereas GP is a huge cylinder about half a square meter of ground space having a height of about two meters, enlarging growing surface ten times greater than the occupied ground area (Coleman, 2014).

Figure 2.7: The vertical growing systems with a solidity structure (Coleman, 2014)

2.4.9 Grow bag technique

This technique utilizes a white polythene bag having black color inside with a depth of 1–1.5 m long and 18 cm wide, which is UV resistant, bags are filled with sterilized growing media (Hussain et al., 2014). Small holes are punctured on the upper bag and inserted 2-3 seedlings, per bag (Hussain et al., 2014). Also, two small holes at the bottom of the bag on each side for drainage purposes (Hussain et al., 2014). This white colour will reflect sunlight to the plants; it also minimizes relative humidity in between plants and the development of fungal diseases (Hussain et al., 2014). Containerized plant production presents many advantages such as the loss of water and nutrients are limited, evaporation is minimized and the growing medium is kept humid. Previous studies showed that growing media (Table 2.3) that have been studied have been a vital innovation, allowing growers to control water and nutrient supply to the plant roots whilst soil-borne pathogens are reduced (Putra and Yuliando, 2015). Furthermore, growing media must provide appropriate physical structure, suitable biological and chemical environment in which plant roots can effectively access nutrients. It also needs to meet the practical and economic requirements of the grower, also must be affordable, easy to obtain, and manageable for everyone (Putra and Yuliando, 2015). In many cases, vegetables are cultivated using soilless culture systems or hydroponics systems. The lesser medium the system requires the easier and less expensive to operate. A good medium can hold a nearly equal concentration of air and water. The various crops grown in different soilless culture media (Table 2.3) can grow different vegetable types (Hussain et al., 2014).

Table 2.2: Growing media used in soilless culture (Hussain et al., 2014).

Media/system	Major crop grown
Rockwood	Tomato, lettuce, cucumber muskmelons, cauliflower, chrysanthemum, Berbera, camation, and strawberry
Perlite, sand and rockwool	Tomato, lettuce, cucumber, and capsicum
Perlite and Rockwool	Tomato, cucumber, and capsicum
NFT, DFT	Tomato, cucumber, and lettuce
Rockwool	Roses, chrysanthemum, camation, tomato, cucumber, capsicum, and cut flowers

There are many advantages of growing plants under soilless culture compared with soil-based culture. Soilless culture offers various opportunities to provide optimal conditions for plant growth and higher yields. They also control soil-borne diseases and pests, minimizing costs and time taken for various tasks such as seedbed preparation which are avoided in the soilless culture of cultivation hence this is more convenient for a large urban population. (Hussain et al., 2014). It also offers a clean healthy working environment, thereby avoiding contaminations, and thus labour is reduced. However, despite many advantages, soilless culture has some limitations, for example, application on a commercial-scale requires technical knowledge and higher initial capital (Hussain et al., 2014).

2.5. Conclusion

Several researchers strongly suggest that the pressure of urbanization and climate change will continue to be important factors in agricultural activities. It is noteworthy that urban agriculture gardens can suppress poverty and malnutrition in urban areas. Therefore, food insecurity can be minimized, hence the diversity of diet is facilitated with these gardens. Home, community, rooftop, sack, growing pillar, and growing wall gardens were found to be inexpensive compared to other gardens and they are very simple in terms of application. Hydroponics, vertical farming, LED and growing bags require skills and use expensive materials that are not readily available. Therefore, sack gardening was chosen to be used for the present study due to its simplicity and minimal requirement of skills. Sack production has tremendous advantages over other cultivation systems, including the ease of location. It can be placed on many different surfaces, including cemented ground. The design suits people with disabilities and the elderly, maintenance is reduced compared to a conventional garden, no-tillage and weeding are involved and weeding is only done on the top surface of the sack. Additionally, the material is inexpensive and readily available in most parts of the world.

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3. EFFECTS OF CONTAINERIZED PRODUCTION WITH DIFFERENT ARTIFICIAL SOIL PROFILES ON GROWTH PARAMETERS

Abstract

Currently, most of the land is urbanized consequently harms the environment and small cultivable land is left for agricultural activities, the land is being colonized by buildings, and most of the surfaces are paved. Huge space has been lost in the occurrence of evolution resulting in depletion of soil fertility, thereby soil productivity is reduced causing a decrease in crop production. A study was conducted in Kwazulu-Natal, South Africa to validate containerized vegetable production for urban agriculture using biodegradable bags, also evaluate plant growth parameters, and monitoring production year-round. Beetroot, lettuce, green pepper, onion, and spinach grew in sacks filled with five different artificial soil profiles growing media namely, soil only (S), rocks with soil (R), soil with wood sticks (W), soil with grass (L) lastly soil with grass, rocks and wood sticks (A) under irrigated field with three fertilizer level (0, 50 and 100%). %). These vegetables were selected randomly based on their daily consumption by people and nutritious value. The five plots were done with minimal addition of fertilizer. Data of the following parameters were collected: plant height, leaf number, stomatal conductance (SC), soil water potential, chlorophyll content index (CCI), leaf area index (LAI), soil moisture, soil temperature and intercepted photosynthetically active radiation (PAR). There was a significant difference ($P<0.05$) between crops and sacks, 100% level of fertilizer, and S100 had the notable optimal growth of selected vegetables for both seasons summer and winter, however, all soil profiles showed significant growth. Overall onion showed significant growth in summer whereas beetroot, green pepper, lettuce, and spinach had optimal growth during winter. The findings suggest that degradable sacks are efficient for containerized production of vegetables for cultivating contrasting vegetables throughout the year. Also, the cultivation of vegetables is efficient with minimal application of fertilizer.

Keywords: Containerized, urbanization, artificial soil profile, beetroot, lettuce, onion, spinach, and green pepper.

3.1 Introduction

The occurrence of climate change on a global scale and urbanization has a significant negative impact on agriculture, food supply, and crop productivity (La Pena and Hughes, 2007). Climate change affects land degradation in quality and soil profile size (quantity) due to extreme geophysical events such as drought and floods (La Pena and Hughes, 2007). Urbanization has an effect of competition for land in favour of physical developments while cultivated land is reduced (La Pena and Hughes, 2007). Urban populations are generally consumers and not producers of food, this puts pressure on the remaining agricultural land to provide food security. South Africa is undergoing rapid urbanization accompanied by climate change, arable land is diminishing, hence innovative strategies to produce vegetables under less water and nutrient demand are required to meet food demand (Khumalo and Sibanda, 2019). Effective crop productivity with less usage of water and fertilizer is vital for sustainable agriculture practices (Peprah, 2014). There is a pressing need for the development of innovative cultivation systems in this modern life because additional planting space will be not available in the upcoming decades (Peprah, 2014). Adopting strategies such as urban agriculture seems to be an innovative boost for the livelihood and minimize food insecurity for the urban dwellers (Peprah, 2014). The modern life production of food is shifting from soil-based towards containerized production due to lack of arable land mostly in peri-urban areas.

Agriculture is faced with three major challenges firstly, meeting food demand, secondly developing environmentally friendly production methods and sustainability, lastly improving nutritional food security (Nyathi et al., 2019). Over the past decades, some initiations have been done to address matters of food insecurity, nutrition security, and underwater scarcity (Nyathi et al., 2019). However, most of the attention has been given to cereals and legumes such as maize, rice, wheat, groundnut, and beans (Nyathi et al., 2019). Focusing on cereal production solely as a tool to combat hunger will not abate the occurrence of micronutrient deficiency-related diseases (Nyathi et al., 2019). There is a need to increase the consumption of vegetables as a strategic intervention for addressing micronutrients and vitamin deficiency (Nyathi et al., 2019). This can be done by conducting sustainable food systems that are conducive for both rich and poor people, highly nutritious, climate-smart, and health sufficient (Nyathi et al., 2019).

This study aimed to evaluate the agronomic potential of containerized vegetable production under field conditions. Crop performance for growth, development, and economic yield was determined using an intercropping system, compared with land production at the same site.

3.2 Material and methods

3.2.1 Plant material – five vegetables

Five different vegetable seedlings namely beetroot (B), Swiss chard - Spinach (S), lettuce (L), onion (O), and green pepper (G) were acquired from an accredited nursery Sunshine Seedlings (https://www.sunshineseedlings.co.za/), in Wartburg (29°25'S; 30°34'E), KwaZulu-Natal, South Africa. Seedlings were six weeks old and reached the full seedling stage before they were transplanted.

Green pepper: Capsicum *annuum (L.*) figure 3.1 comes from Solanaceae family originating from Central and South America Mexico, after the 1500s cultivation of peppers was spread all the Europe and Asia, here in South Africa sweet pepper is well grown in Gauteng, Northern Cape, Eastern Cape, Limpopo, Western Cape and Kwazulu-Natal (DAFF, 2013). Sweet peppers are recognized as the second most important vegetable after tomato grown extensively and cultivated in almost every country in the world, China takes the first rank for the production of peppers (Go et al., 2017). Peppers vary in shape (bell; some have round to oblong to tapered with smooth and shiny skin) and colour (yellow, red, and green) (DAFF, 2013). It is mainly used for salads, garnishing can be consumed raw as well (DAFF, 2013). This crop is perennial, however, it is treated as an annual crop in temperate climates, peppers are a warm-season crop, sensitive to frost and grow poorly under low temperature 5 and 15˚C, whereas very high temperatures above 30˚C result in flower abscission and reduced yields (DAFF, 2013). The optimum temperature for a well-developed pepper is between 20 to 25˚C (DAFF, 2013). Optimum soil pH is 6-7. Sweet peppers take 60-90 days after planting to reach maturity. For this study Jupiter pepper cultivar was used: it turns red at maturity.

Figure 3.1: Green pepper plant

Beetroot: *Beta vulgaris* (L.) figure 3.2 is a member of Chenopodiaceae family originating from Asia and Europe, considered as medicine that cures bad smell, coughs, headache and aphrodisiac now are used for salads or commercially as a dye to colour processed food (DAFF, 2013; Mampa et al., 2017). Beetroot grows in well-drained sandy loam soil with a neutral range of pH 5.8-7.6, prefers cool weather with optimal growth in spring and autumn season, and also tolerates freezing, but optimum temperature for growth is 18 to 20^{o}C (DAFF, 2013). Crimson Globe cultivar was used for this study; a high-yielding variety growing best in warm and cool-season; roots are uniform, round to flat-round shaped with a slender attractive taproot. It takes about 55-60 days to reach maturity, has smooth skin, internal color is deep red, medium sugar level, leaves height can reach 35-40 cm having medium green with some purple color (DAFF, 2013).

Figure 3.2: Beetroot plant

Onion: *Allium cepa* belongs to the Amaryllidaceae (figure 3.3) family originating from arid western Asia. This crop is cultivated in different climate conditions in South Africa (DAFF, 2013). It prefers deep well-drained loamy soil with a pH between 5.5 to 6.5; thrives best on highly fertile, slightly acid, well-drained sandy loams and organic soils; optimum temperature for plant growth is 18-22°C (DAFF, 2013). South Africa uses two types of cultivar, short-day and intermediate day, both are sensitive to photoperiodism, where a short day requires 10-12 hours and intermediates require 12-14 hours to initiate bulb formation (DAFF, 2013). Leaves consist of two parts, one develops from a short-flattened stem at the base of the bulb called a sheath, fleshy surrounds the younger, secondly, the green blade (Tesfay et al., 2011). All parts of the onion produce a strong odor when crushed releasing alliinase enzymes (Tesfaye et al., 2018). Onion is a very good source of vitamin C, B_6, biotin, chromium, calcium, and dietary fiber (Tesfaye et al., 2018). This biennial monocot crop has different bulb colours (red, yellow, and white) and shape, however, it is treated as an annual crop (DAFF, 2013**)**. Harvest season begins when the onion plant leaves have senesced, the neck has sealed, and bulbs have matured and reached normal size (DAFF, 2013**)**.

Figure 3.3: Onion plants

Lettuce*: Lactuca sativa* figure 3.4 belongs to the Asteraceae family originating from the Mediterranean area, and cultivation started as early as 4500 BC. In the beginning, lettuce crops were used to extract oil now is popular as a salad ingredient (DAFF, 2013). Cultivars of lettuce include crisphead, butterhead, Cos or Romaine, loose-leaf or bunching, and stem lettuce (celtuce), commercial colors vary from yellow-green to dark red (DAFF, 2013). This annual crop prefers cool weather but can tolerate winter cold or heat and it grows well under short-day conditions having an optimum temperature between 15-18°C (DAFF, 2013). Lettuce prefers soil with good drainage and high organic matter content with a pH of 5.5-6 while soil moisture must be not more than 50% in the root zone (DAFF, 2013). Crisphead or Iceberg cultivar was used for this study having tight, dense heads that resemble cabbage and has crunchy, thin to very thick and tough leaves, no clear midrib but with flabellate venation; predominantly green leaf margin hardly to rather strongly incised; it takes 40-55 days to reach maturity (DAFF, 2013).

Figure 3.4: Lettuce plant

Spinach: Swiss chard (*Beta vulgaris* subsp. *vulgaris*) figure 3.5 is a member of Chenopodiaceae family originating from Iran, prefers cool climate having an optimum temperature between 7 to 24 ^{o}C young plants can tolerate -9 ^{o}C, and grows best in well-drained sandy loams with 6.5-6.8 soil pH (DAFF, 2013). This annual crop has a deep taproot and shallow secondary root and can survive during cold winter temperatures. However, spinach can grow successfully under partial shade in summer provided there is enough water in the root zone (DAFF, 2013). Spinach is rich in iron content and other essential minerals (DAFF, 2013). Ford hook giant cultivar was used for this study. It grows erect, with thick, very crinkly, glossy dark green leaves green leaf with the white stem; uniform plants; high yielding, having 40-60 days duration to reach maturity.

Figure 3.5: Spinach plants

3.2.2 Description of experimental site and design

A field trial experiment was conducted at the University of KwaZulu-Natal, Pietermaritzburg, South Africa (29°37'12"S; 30°23'49"E) during autumn/winter (winter crop) and spring/summer (summer crop) in 2019 under supplementary irrigation (5mm/week) using Solid set sprinkler (70-85% potential application efficiency (Griffiths, 2006). The first trial was conducted from 13 April to 31 July (15 weeks) and the second trial was conducted from 24 August to 16 December (16 weeks). The altitude of Pietermaritzburg is 850 – 950 m, winters are mild for vegetables, frost-free. Crops were planted on the ground on a natural soil profile (sandy loam; 110 mm deep) and in the sacks with five different artificial soil profiles. Treatments are shown in Table 3.1.

The experimental design was a factorial experiment, replicated three times (Figure 3.6). Soil artificial profile components (Table 3.1) were {soil only (S), soil/rock/soil (R), soil/grass/soil (L), soil/wood sticks/soil (W) and soil / rock/wood stick/grass/soil (A)}. This formed the main factor, with fertilizer level, and the type of crop (lettuce, beetroot, spinach, green pepper, and onion) as sub-factors arranged in a randomized complete block design. Therefore, the treatment structure was (3*3), each sack bag had a size of 50 kg (total number of the sack was 45) (Table 3.2). The five plots were replicated three times with no fertilizer application, vegetables were planted on the natural soil profile for comparison with no fertilizer access conditions. Plant spacing was 30 cm between rows and 25 cm within rows. Sacks were filled with the soil that was taken where land plots we created. The field-sack intercropping layout is shown in Figure 3.6. Each sack had a total of 20 seedlings (five seedlings per crop). On the top surface ($0.25m^2$), there was one seedling of each crop randomly located equidistantly, using rooting depth. On the sides of a sack, the five seedlings were planted (rooting depth) in rows, 20 cm apart, and 20 cm above ground for the lowest row. Figures 3. 6 to 3.9 show plants planted in different positions of the sack design at different stages of growth. Before planting, soil samples were taken for analysis (Go and Martey, 2017). This was repeated post-harvest, at the end of the experiment (after one year). A composite sample was made by collecting soil from several spots of the field at a depth of 0-15 cm before the initiation of the experiment, post-harvest soil samples were collected from each sack at a 0-15 cm depth. The properties included pH, organic carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and clay percentage. Fertilizer application was based on recommendations for lettuce (DAFF, 2013)

Figure 3.6: The arrangement of the field trial intercropping on land and in sacks.

Figure 3.7: Sack with 100% fertilizer level (W100)

Figure 3.8: Sack with 50% fertilizer application at harvest (A50).

Figure 3.9: Sack with 0% fertilizer application at harvest (W0)

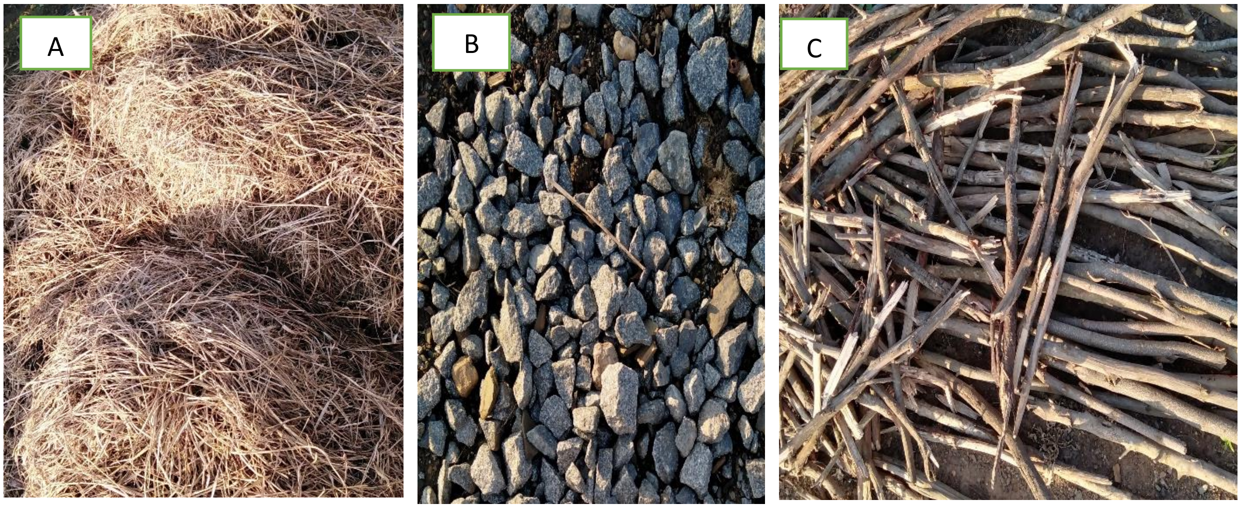


Figure 3.10: Materials used to make up artificial soil profile, grass (A), rock (B), and wood sticks (twigs) (C), in addition to sandy-loam soil taken from the experimental site field.

Table 3.1: Indication of fertilizer treatments in planting sacks

Artificial soil profile type	Fertilizer level (%)	Seedlings per sack
S	0	20
W	0	20
R	0	20
L	0	20
A	0	20
S	50	20
W	50	20
R	50	20
L	50	20
A	50	20
S	100	20
W	100	20
R	100	20
L	100	20
A	100	20
Total 15x3 = 45		300x3

3.2.3 Crop management

At the time of discing, fertilizer [2:3:2 (22) +0.32% Zn] was applied according to soil analysis recommendations (lettuce based) with different levels. The seedlings were planted by hand. The sacks and plots were routinely hand weeded to ensure there was no competition for water and solar radiation. The sacks were not changed, i.e., the same sacks were used after harvest between seasons. Harvesting was done manually according to their maturity date after planting - spinach was harvested first followed by lettuce, beetroot, green pepper lastly onion for both trials. Each of the harvested produce was cleaned of soil adhered to it and above-ground fresh mas was recorded.

3.2.4 Data collection

3.2.4.1 Crop growth and physiology

Data collection started 10 days after planting to allow seedling establishment, for plant size. Plant height was measured from the ground level to the tip of the fully matured leaf using a 30 cm ruler, leaf number was determined by counting the number of fully developed leaves. Photosynthetically active radiation (PAR) and leaf area index (LAI) was measured using the AccuPAR LP80 Ceptometer (Decagon Devices, USA). Two readings were taken in each plot and sack, one from above the canopy where the sensor was not shaded, and another below the canopy. Therefore, the difference between the above and below values was a measure of intercepted PAR. Chlorophyll content index (CCI) was measured on a fully expanded and solar radiation-exposed leaf using the SPAD 502 Plus (Konica Minolta, USA). Stomatal conductance (SC) was measured using a Model SC-1 steady leaf porometer (Decagon Devices, Inc., USA. Changes in soil water content (SWC) were measured using a theta probe.

3.2.4.2 Weather data

Weather data for the entire period of the study was obtained from measurements collected by an automatic weather station (AWS) located about 100 m away from the study site. Which include rainfall (mm), relative humidity (%), and air temperature (^{o}C).

3.2.4.3 Determination of soil water potential

Dielectric Water Potential Sensor model MPS-2 was used for measuring soil water potential and temperature. Sensors were soaked in water overnight, then four sensors were inserted at a depth of 20 cm into the sack connected to the data logger on S0, R0, L0, and W0.

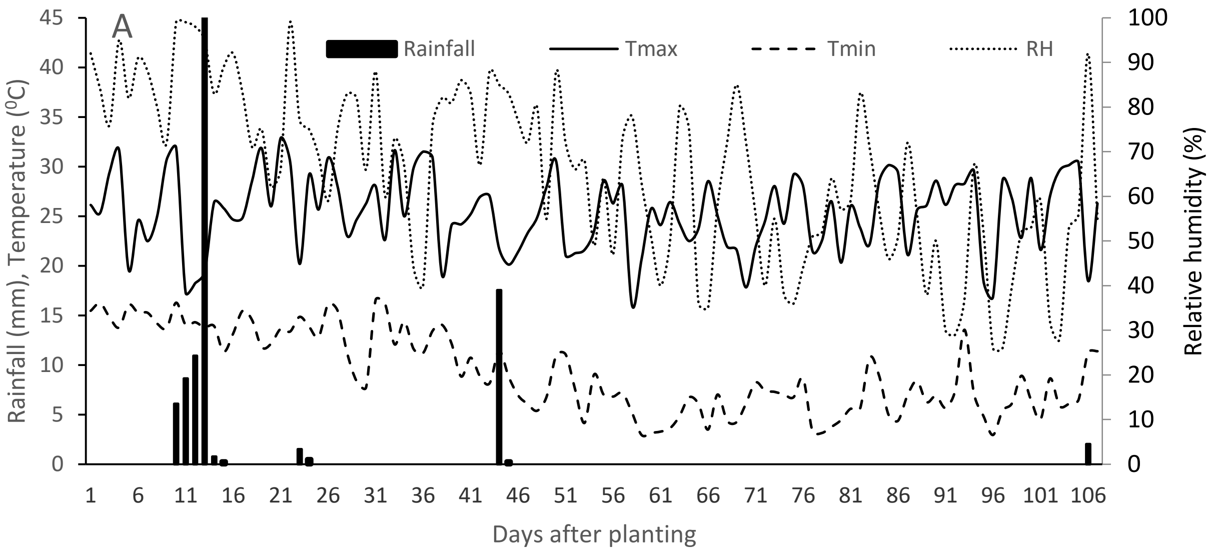
3.2.4.4 Statistical analysis

Collected data were analyzed using analysis of variance (ANOVA), GenStat® Version 18.2 (VSN International, UK) at the 5% level of significance. Tukey's test on GenStat® at the probability level of 5% was used to compare means.

3.3 Results

3.3.1 Meteorological data

The first planting date took place on the 13th of April while the second planting date happened on the 24th of August of the same year. Rainfall was irregular and low with uneven patterns throughout the winter season, with the trial having total rainfall of 98.05 mm and decreased significantly from April to July (26 to 106 DAP) and supplementary irrigation water had a contribution of 517 mm. Heavy rainfall was observed from the 10-15 days after planting (DAP) during the winter season, as from 45-105 DAP no rain was received, the maximum rainfall that was received was 49.5 mm. Summer received significant rainfall towards the end of the trial; from 65-105 DAP, the total rainfall was 315.23 mm and irrigation had a total of 278 mm. During the study, the winter season had a minimum temperature of 2.93°C while the maximum was 32°C, however, no frost was experienced. The summer trial had a minimum and maximum temperature of 5.3 and 41°C, respectively. Relative humidity fluctuated throughout the trial. Winter had a maximum and minimum of 99% and 26% respectively. Meanwhile, summer had a maximum and minimum of 99% and 39% respectively. Relative humidity results are the true opposite of maximum temperature and evaporation, which is not shown in figure 3.11.



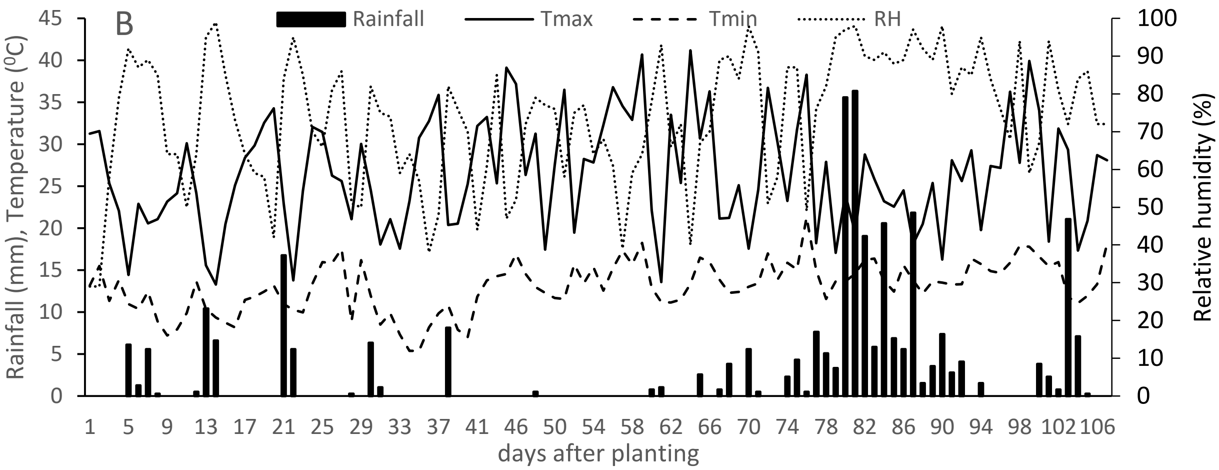


Figure 3.11: Daily meteorological data (rainfall, maximum temperature (Tmax), minimum temperature (Tmin)) of A (winter), and B (summer) during the vegetables growing period.

3.3.2 Soil properties

3.3.2.1 Soil temperature

Summer soil temperature at the beginning of the trial was lower relative to winter soil temperature (Figure 3.11). However, at 15 DAP both trial temperatures were equal and differed thereafter. Winter temperatures went lower towards June (24 DAP) whereas summer temperatures rose as it was approaching warmer months from 40 DAP. Soil minimum temperature was 6.4^{o}C and 13.4^{o}C for winter and summer, respectively. Soil maximum temperature was 25.8^{o}C and 29.6^{o}C for winter and summer. respectively.

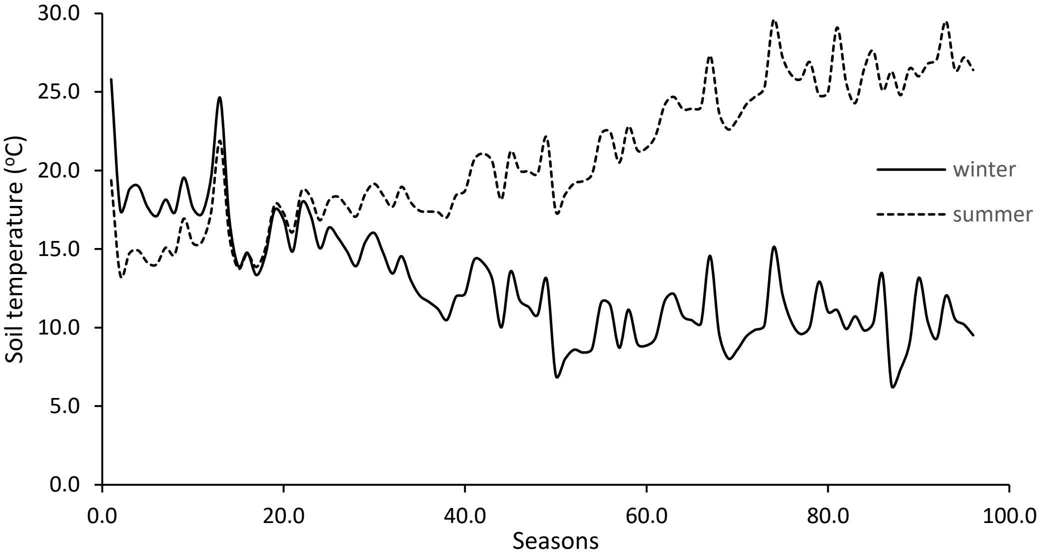
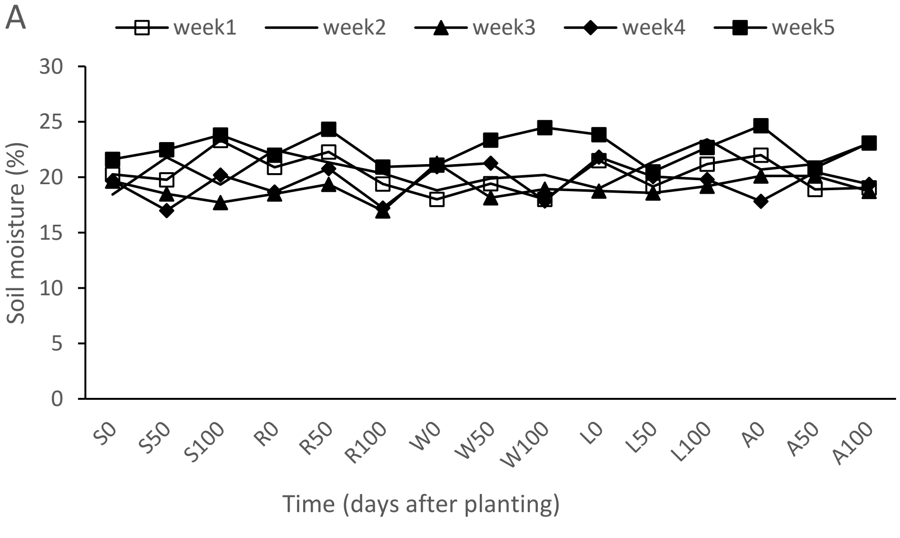


Figure 3.12: Soil temperature of the sacks for winter and summer growing season

3.3.2.2 Soil moisture content

The distribution of soil moisture in the field was less variable throughout the experiment (Figure 3.12). Winter season, (A) week 5, had the highest soil moisture. Treatments R100 and S50 had the lowest soil moisture of 17% in week 4. Summer (B) had the lowest soil moisture in week 2, while SO had the highest soil moisture in week 1.



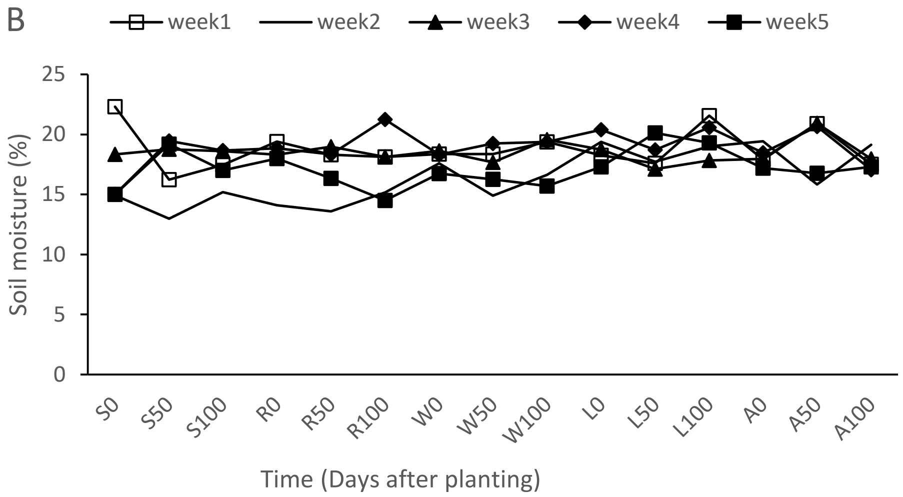


Figure 3.13: Soil moisture of sacks for winter (A) and summer (B) growing season.

3.3.2.3 Soil water potential

There was a great difference between summer and winter soil water potential (Figure 3.13). As expected, summer had higher soil water potential while winter had the lowest. Winter season lowest potential was -2843.3 kPa at 63 DAP while summer at DAP 57 was -197.3 kPa.

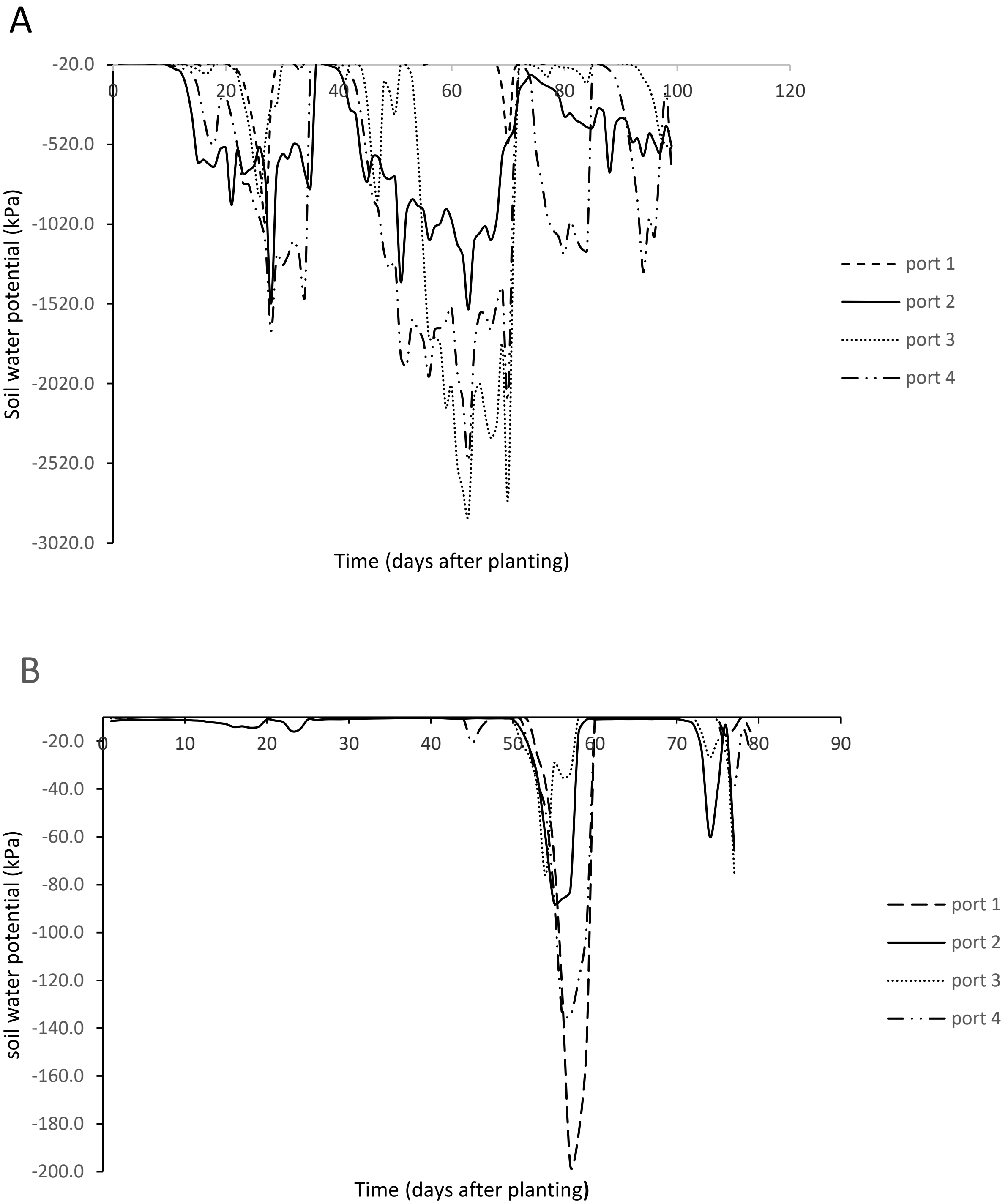


Figure 3.14: Soil water potential taken in sacks using four ports A (winter) and B (summer).

3.3.2.4 Soil characteristics

Table 3.2 depicts soil analysis for the entire trial from pre-planting, post-winter trial results, and after harvest for a summer trial. Clay percentage decreased from 33% for all soil profiles (sack) and fertilizer levels besides sack with litter at harvest. Clay percentage increased for all fertilizer levels to 35 and 36% for L0, L50, and, L100 respectively. Whereas organic carbon (C) percentage decreased for many sacks, it remained the same for S50 and W50 after the first trial. However, in the second trial only sacks with litter (LO, L50, and L100) had an increased percentage. Nitrogen (N) percentage, phosphorus (P) and potassium (K) concentration decreased for all the sacks throughout the trials. For micro-nutrients manganese (Mn), copper (Cu) and zinc (Zn) concentrations fluctuated throughout the trial, but the concentration increased after the addition of fertilizer and decreased at harvest. Soil pH increased with the increase of fertilizer level. When there was zero fertilizer application, soil pH decreased. Secondary macro-nutrients calcium (Ca) and magnesium (Mg) concentrations fluctuated throughout the study, with no noticeable trend.

Table 3.2: Soil analysis results for different article profiles before planting and after final harvest

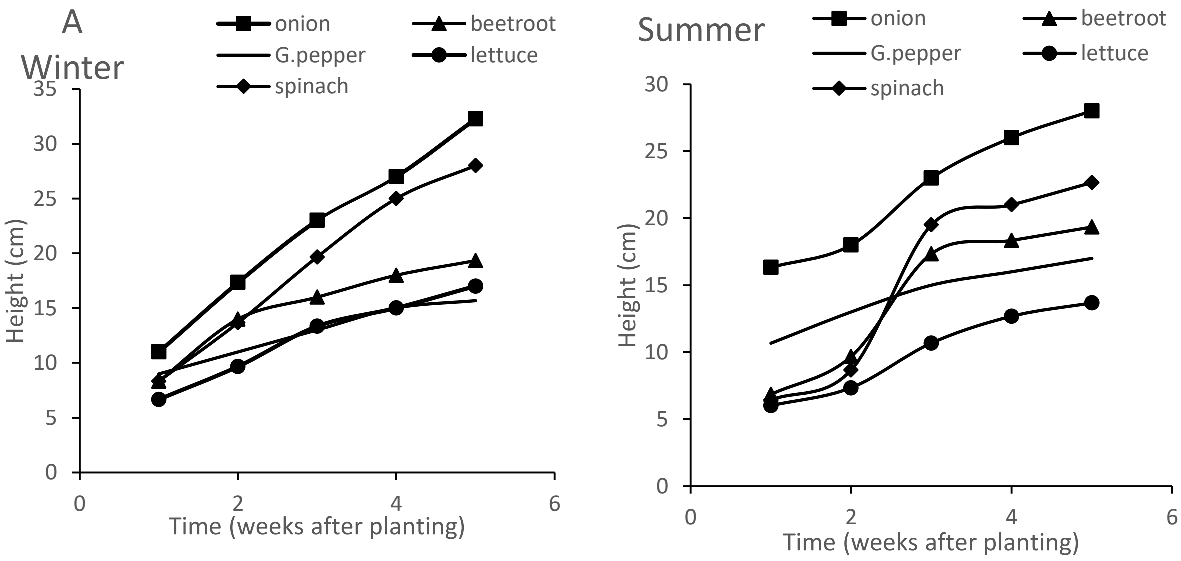
	Sack	P	K	Ca	Mg	Zn	Mn	Cu	$\text{pH}_{(\text{KCl})}$	org.C	N	Clay
		mg/L								%		
Pre-planting		62	397	1820	441	14.0	49	7.8	4.92	3	0.30	33
After harvesting of 1st trial	S0	53	332	1544	435	15.1	44	7.5	4.73	2.8	0.23	32
	S50	62	307	1952	587	17.9	52	7	5.28	3	0.24	31
	S100	63	377	2054	597	24.4	56	7.4	5.34	2.5	0.24	36
	A0	45	245	1635	439	14	45	6.8	4.31	2.1	0.21	27
	A50	55	263	1754	576	15	50	7.1	5.34	2.4	0.21	28
	A100	60	256	1826	532	16	53	8.6	5.33	2.5	0.23	30
	W0	53	234	1823	442	13.8	47	7.2	4.82	2.1	0.23	32
	W50	61	215	1841	528	18.7	40	7.6	5.34	3	0.22	27
	W100	63	243	1863	536	18.9	52	7.8	5.23	2.8	0.31	31
	L0	47	213	1723	446	15.7	47	6.2	4.24	2.5	0.24	28
	L50	49	233	1965	563	16.8	49	7.3	5.33	2.6	0.26	30
	L100	56	241	1954	523	17.2	51	7.4	5.2	2.7	0.28	31
	R0	44	261	1732	444	13.4	44	6.3	4.46	2.3	0.25	31
	R50	47	251	1826	553	14.7	51	7.4	5.22	2.8	0.23	32
	R100	51	264	1845	547	15.7	55	7	5.42	2.5	0.26	32

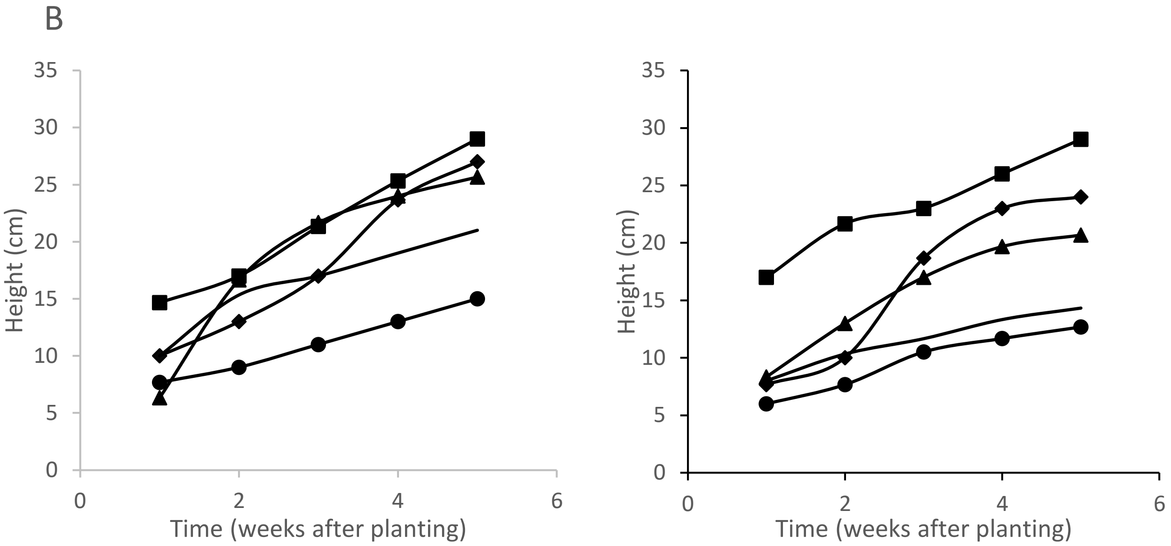
After harvest of 2nd trial	S0	42	344	1418	421	13.2	31	7.7	4.31	2.6	0.18	32
	S50	55	239	1657	503	15.4	34	7.9	5.13	2.6	0.22	31
	S100	57	272	1995	600	17.2	35	7.5	5.05	2.4	0.2	32
	A0	40	248	1592	428	10.6	25	6.4	4.22	2.5	0.18	31
	A50	50	261	1578	485	14.4	30	7.5	5.35	2.7	0.16	30
	A100	66	264	1707	452	14.8	33	9	5.22	2.7	0.2	32
	W0	50	269	1800	412	13.4	37	6.2	4.22	2.8	0.18	26
	W50	59	282	1739	494	17	49	7.4	5.23	2.6	0.19	31
	W100	60	253	1870	433	18.6	49	7.1	5.21	2.2	0.2	32
	L0	44	290	1853	447	13.7	30	6.5	4.44	3.2	0.18	35
	L50	50	301	1881	489	14.5	32	7.9	5.38	3	0.22	36
	L100	57	307	1929	583	25.4	45	8.1	5.7	3.3	0.21	36
	R0	42	296	1695	439	12.5	36	6.1	4.14	2.1	0.19	30
	R50	45	248	1792	461	14.4	43	7.2	5.15	2.3	0.2	31
	R100	49	286	1803	468	15.7	43	7.2	5.38	2.2	0.23	32

3.3.3 Crop growth parameters

3.3.3.1 Plant height

Height responded significantly to the fertilizer and soil profiles for both seasons winter and summer. During the winter season, plant height differed highly significantly (P<0.001) in the contexts of both fertilizer level and crop (Figure 3.14-16). Onion in winter showed the highest height on S100 while L0 gave beetroot maximum height. G pepper had maximum height on W50 while both R50 and R100 gave lettuce maximum height as well as S100 on spinach. W0 and R0 had the lowest height onion, beetroot, G pepper, lettuce, and spinach respectively. During summer, the onion had significant growth on sack R100 and A100, with a maximum height of 37 cm, lowest height (26 cm) was on the A0 sack. Beetroot had the highest height (25 cm) on S100 while R0 lowest height (18 cm). Artificial soil profile S100 (26 cm) had the highest height of green pepper, while R0 had the lowest height (18 cm). Lettuce responded very well on A50 having a maximum height of (17 cm) while W50 had the lowest (12 cm). Spinach growth was more or less the same across artificial soil profiles and fertilizer applications, however, R100 and A100 had the highest height of 27 cm while the lowest height (21 cm) was observed on W50. No trend was observed, i.e., the five contrasting crops development and growth was in different sacks and different fertilizer rate. However, R0 gave beetroot, green pepper, spinach, and onion the lowest height. Furthermore, R100 gave spinach for both trials (seasons) highest height and onion for summer only.




B
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Height (cm)
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Time (weeks after planting)
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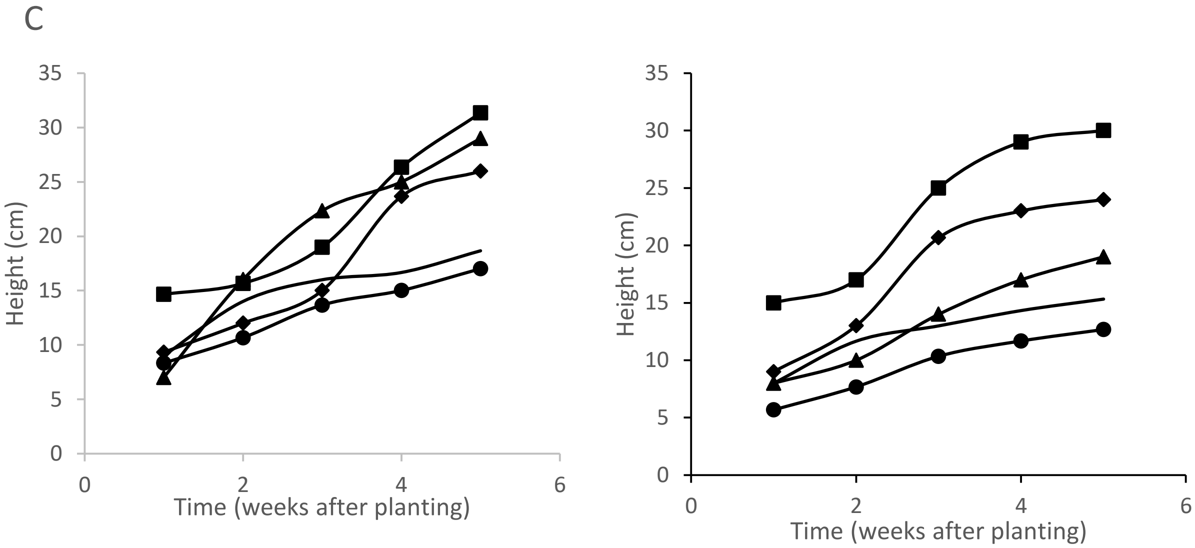
Time (weeks after planting)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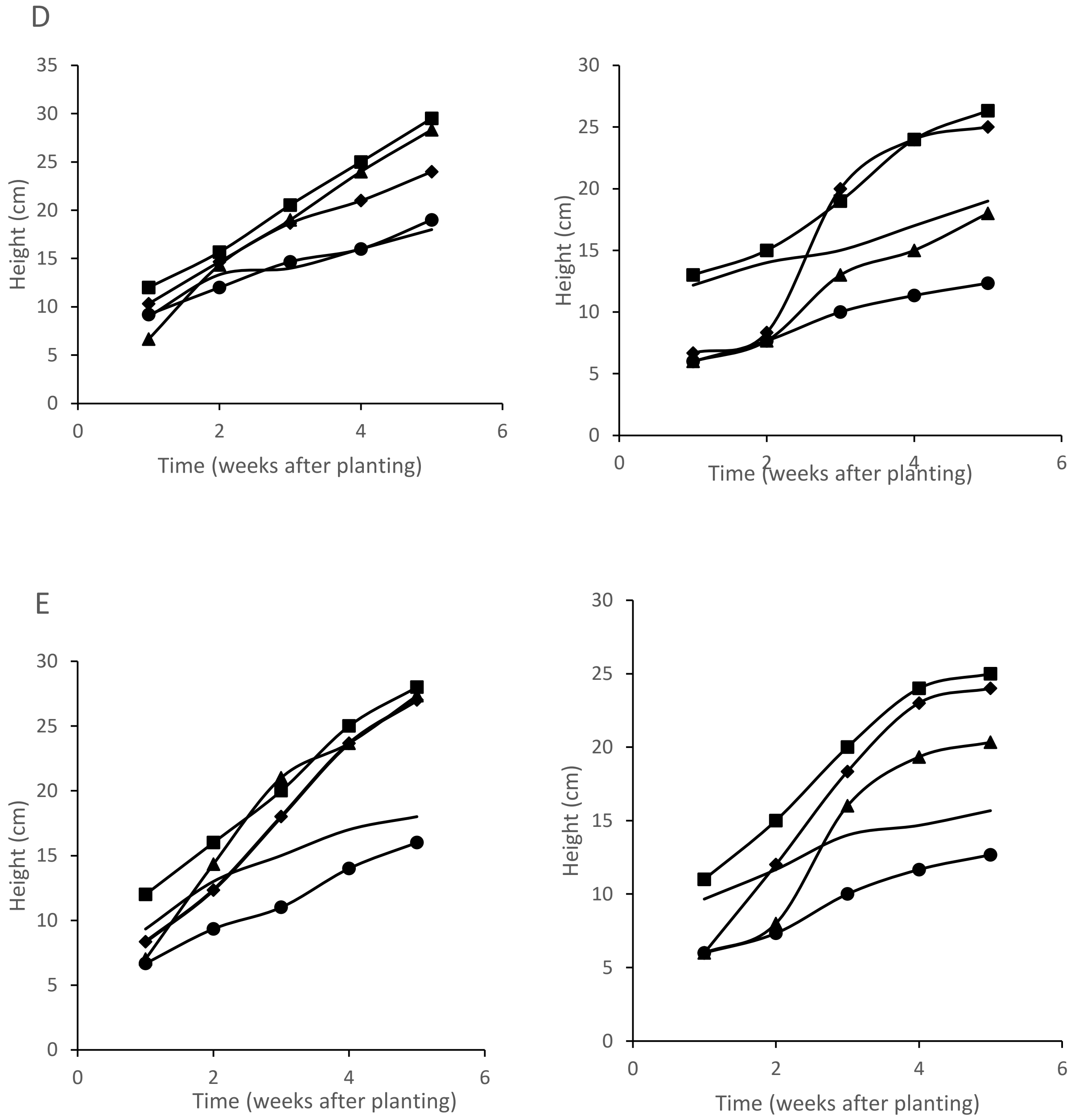
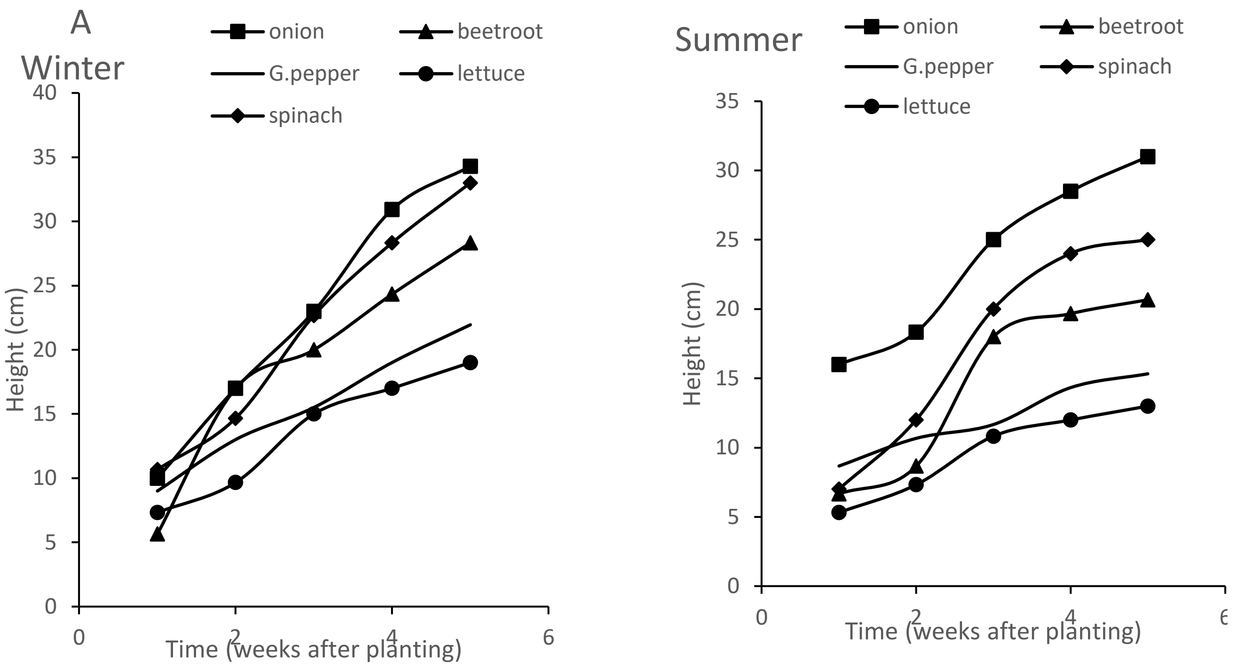


Figure 3.15: Height of five crops (beetroot, green pepper, lettuce, spinach, and onion) grown under 0% fertilizer treatment and five soil profiles (S, R, W, L, and A) during two growing seasons (winter and summer). SO (A), R0 (B), W0 (C), L0 (D), and A (E).


A
Winter
onion
beetroot
G.pepper
lettuce
spinach
Height (cm)
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5
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15
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25
30
35
40
Time (weeks after planting)
0
2
4
6
Summer
onion
beetroot
G.pepper
spinach
lettuce
Height (cm)
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Time (weeks after planting)
0
2
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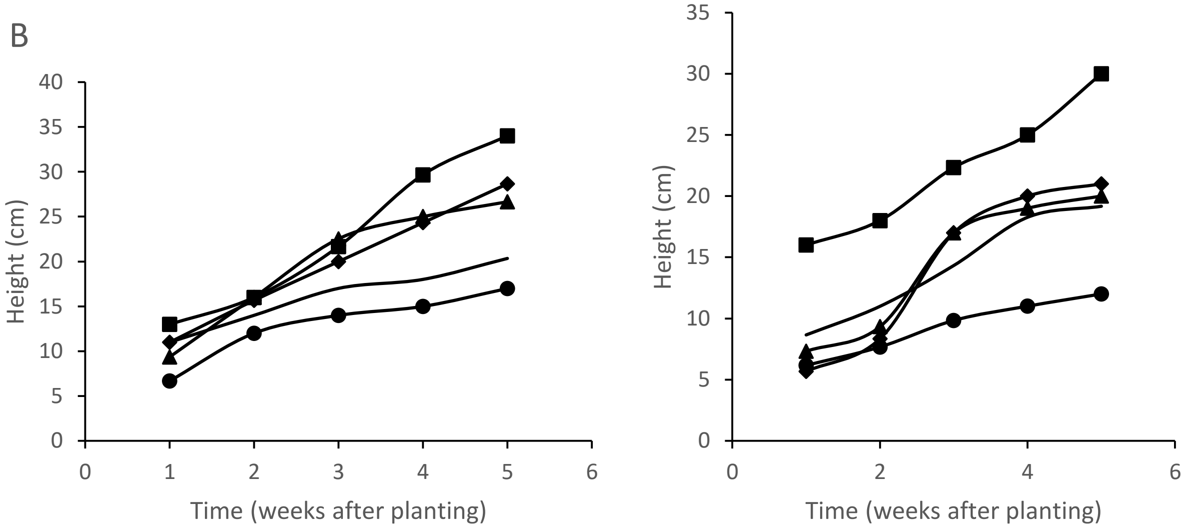
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Time (weeks after planting)
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Time (weeks after planting)
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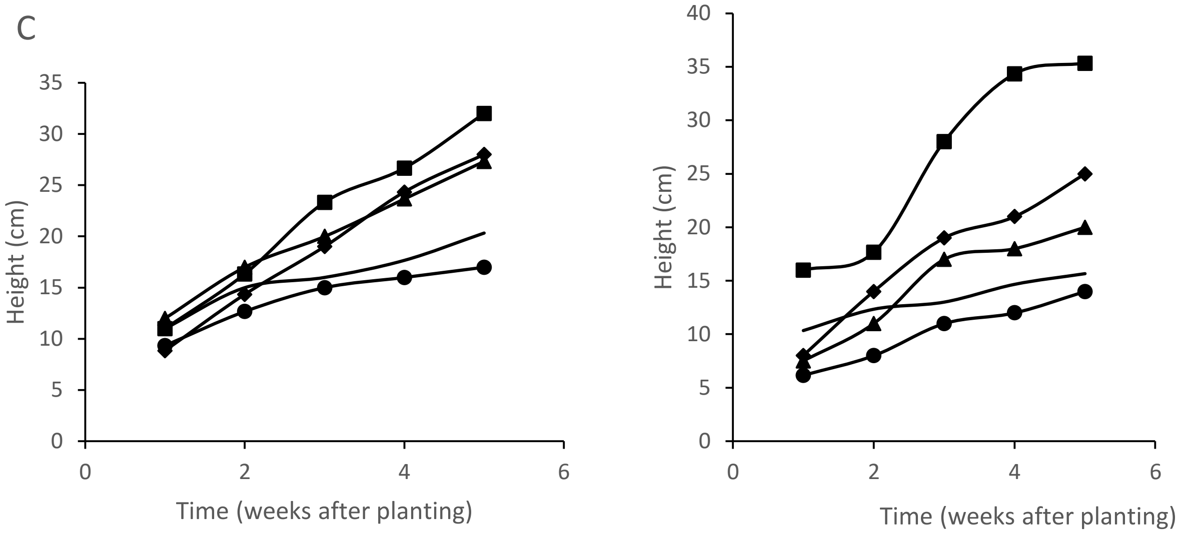
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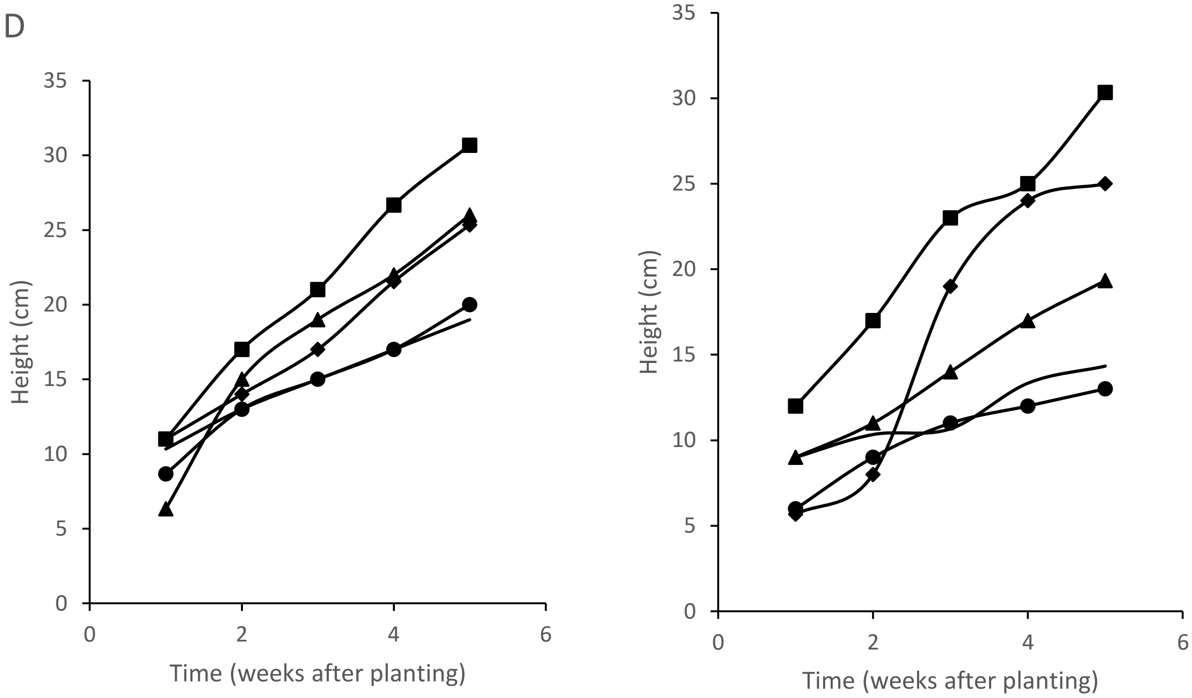
Time (weeks after planting)
Time (weeks after planting)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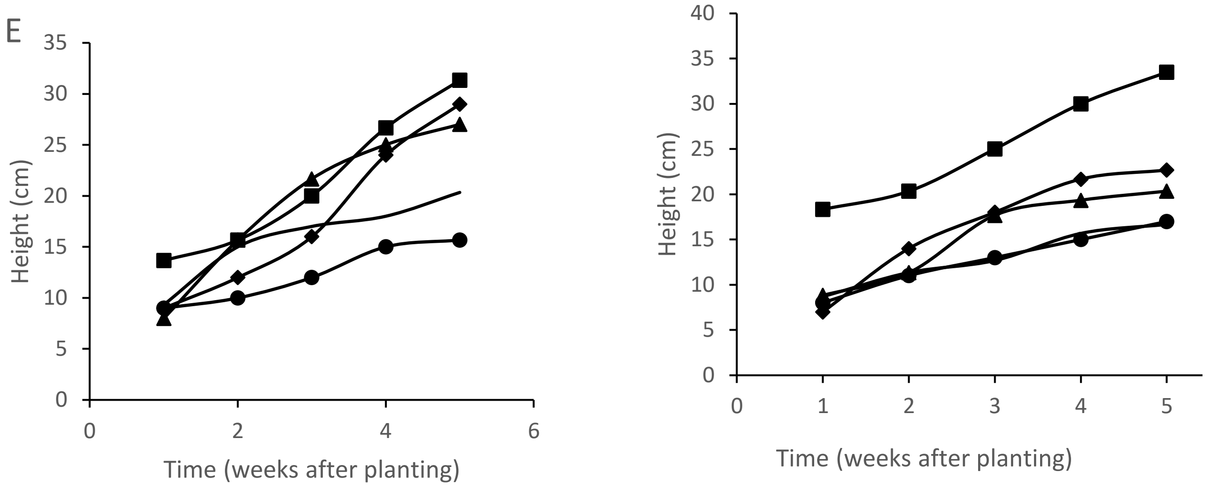
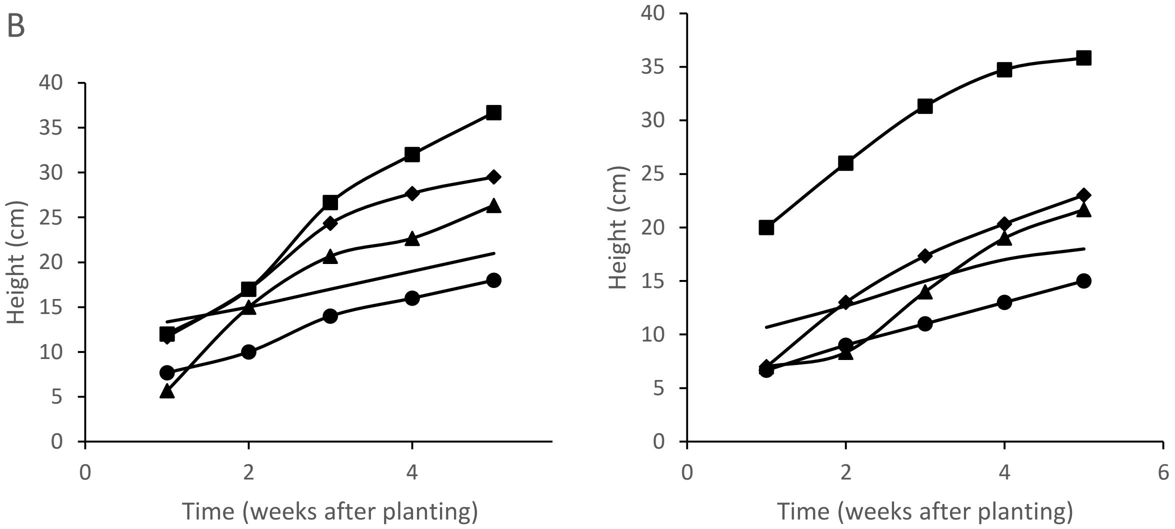


Figure 3.16: Height of five crops (beetroot, green pepper, lettuce, spinach, and onion) grown under 50% fertilizer treatment and five soil profiles (S, R, W, L, and A) during two growing seasons (winter and summer). S5O (A), R5O (B), W50 (C), L50 (D) and A50 (E).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Time (weeks after planting)
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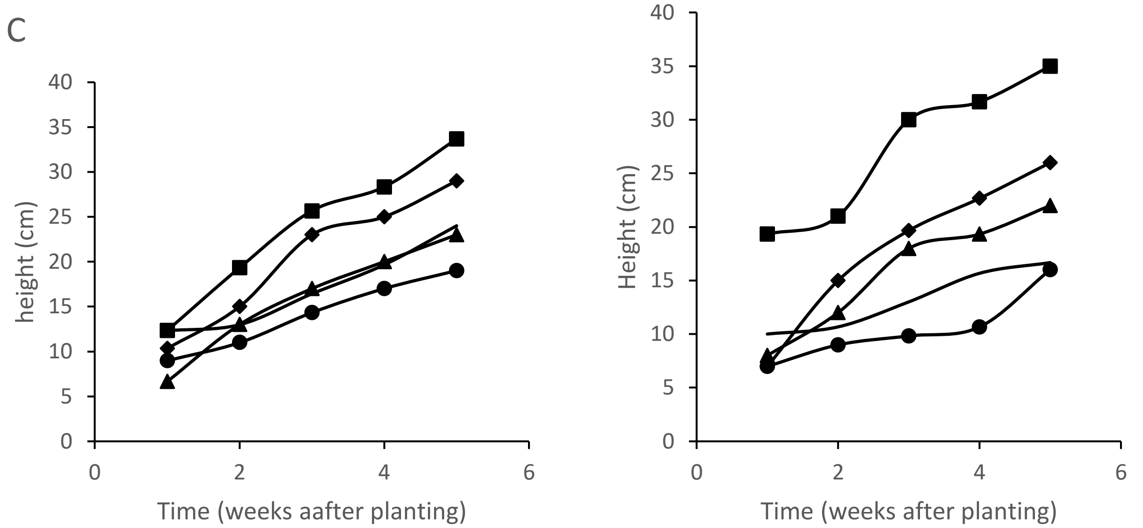
Time (weeks after planting)


C
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Time (weeks after planting)

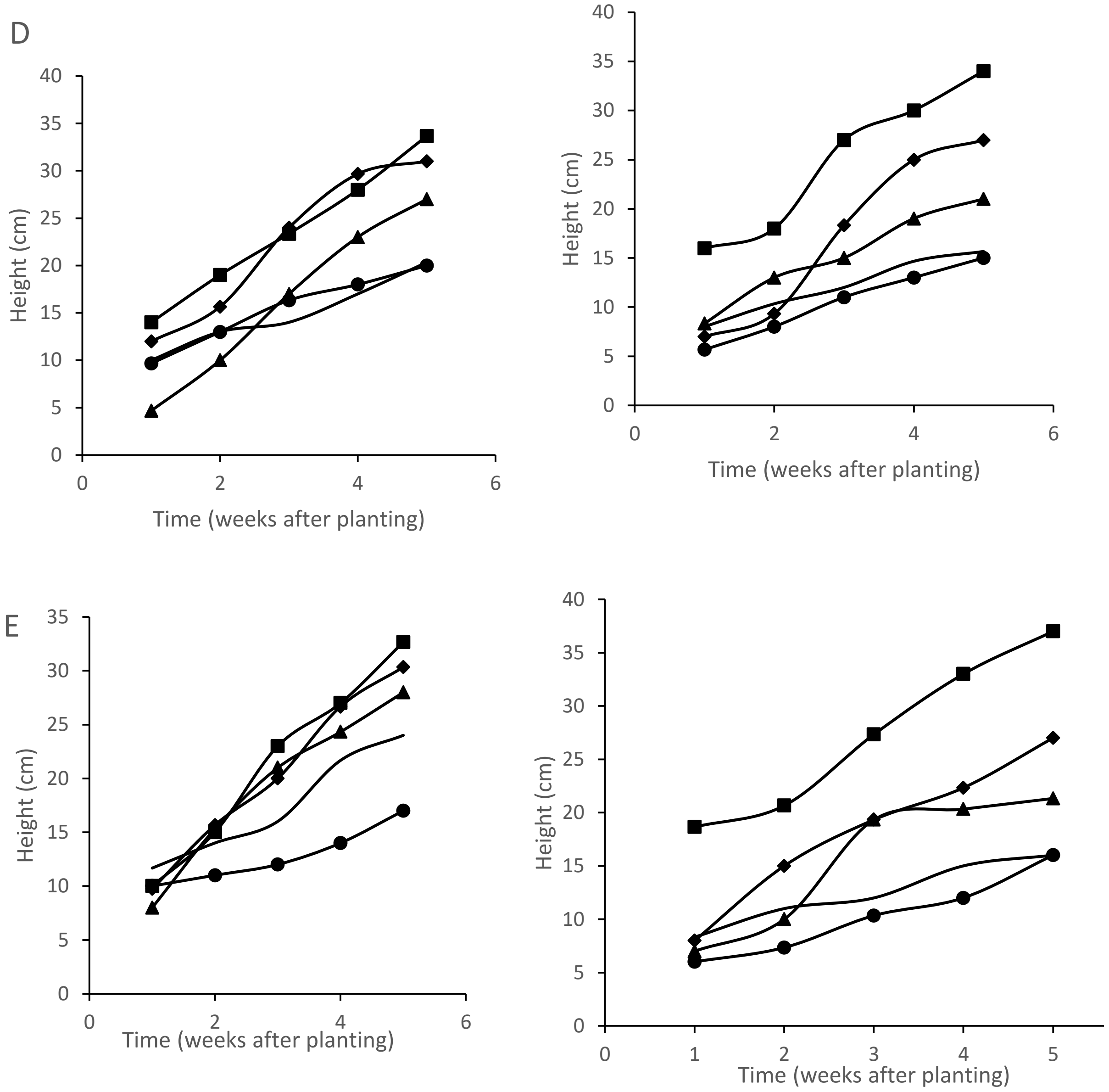
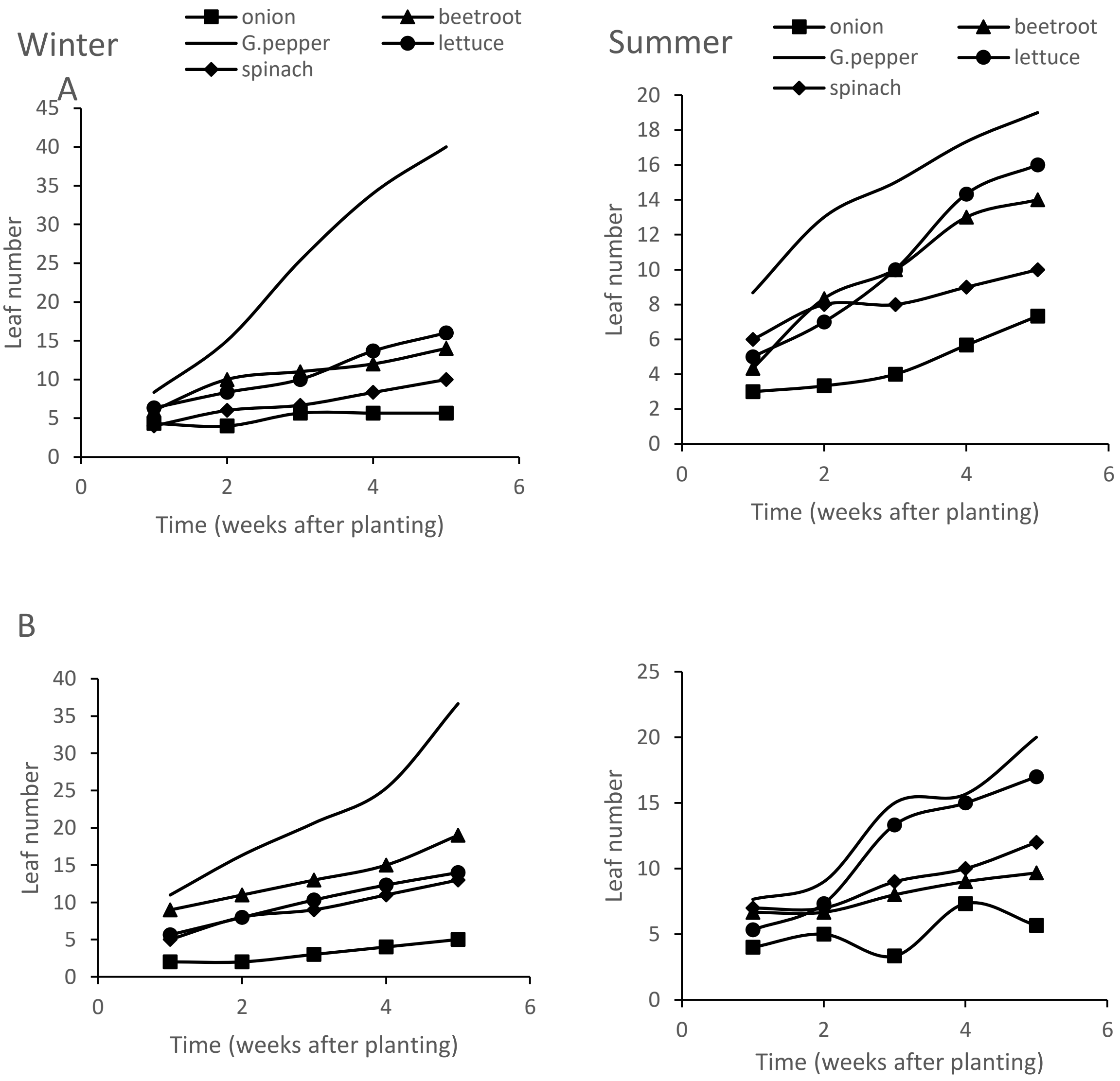


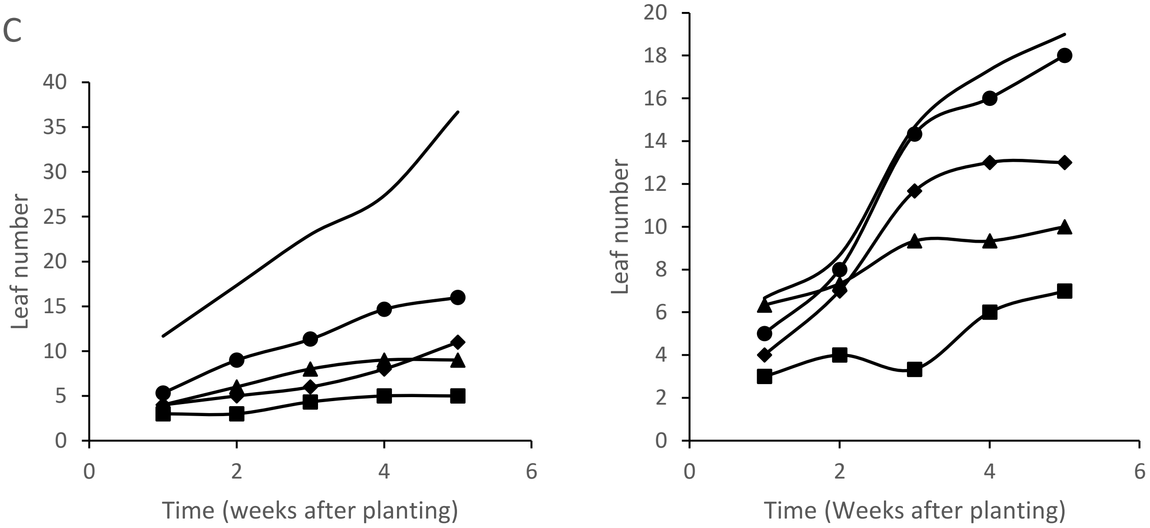
Figure 3.17: Height of five crops (beetroot, green pepper, lettuce, spinach, and onion) grown under 100% fertilizer treatment and five soil profiles (S, R, W, L, and A) during two growing seasons (winter and summer). S100 (A), R100 (B), W100 (C), L100 (D) and A100 (E)

3.3.3.2 Leaf number

There were significant differences (P<0.001) in leaf number for all the crops, across artificial soil profiles (Figure 3.17-19). During the winter season, the highest leaf number was observed on S100, R0, A100, and R100 for onion, beetroot, green pepper, and spinach, respectively. Lettuce most of the leaf numbers were equal while R100 had the lowest leaf number of 12. During the summer season onion had a maximum leaf number of 8 shown by S50, W50, and L100 while L0 and W0 had the lowest leaf number (7). Beetroot S100 had a maximum of 12 leaves, while R0 had the lowest (8) leaf number. Soil profile S50 and R0 had the lowest leaf number (14) while A100 had a maximum of 20 leaves for green pepper, overall did not have successful growth for the summer season. Some of the lettuce leaves senescence during growth and new leaves grew, however, there were almost equal in every sack. Spinach had successful growth on A0 having 20 leaves, while W0 had a minimum of 8 leaves.



C


Leaf number
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Time (weeks after planting)
Leaf number
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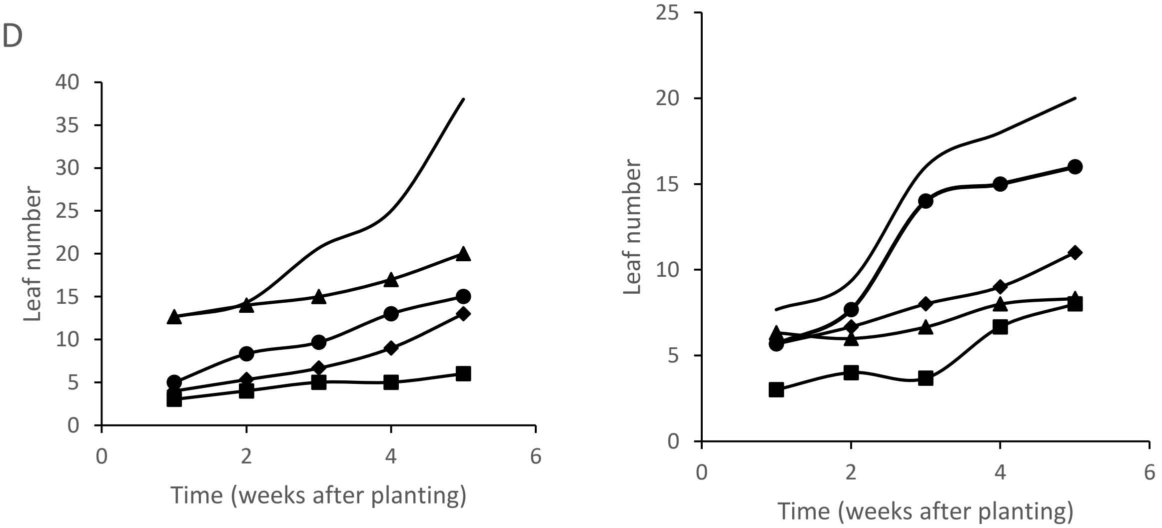
4
6
Time (Weeks after planting)

D


Leaf number
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Time (weeks after planting)

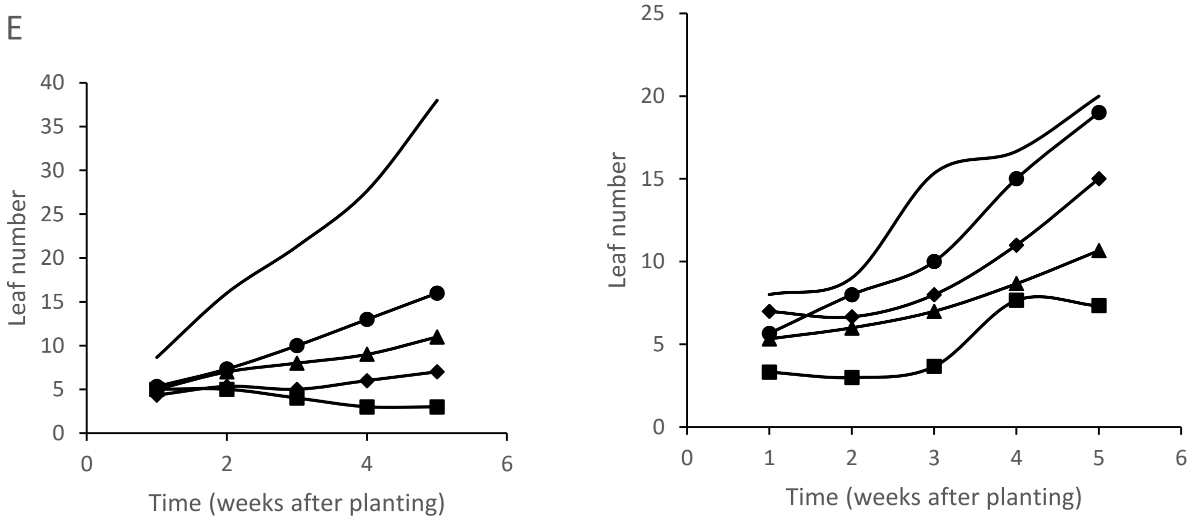
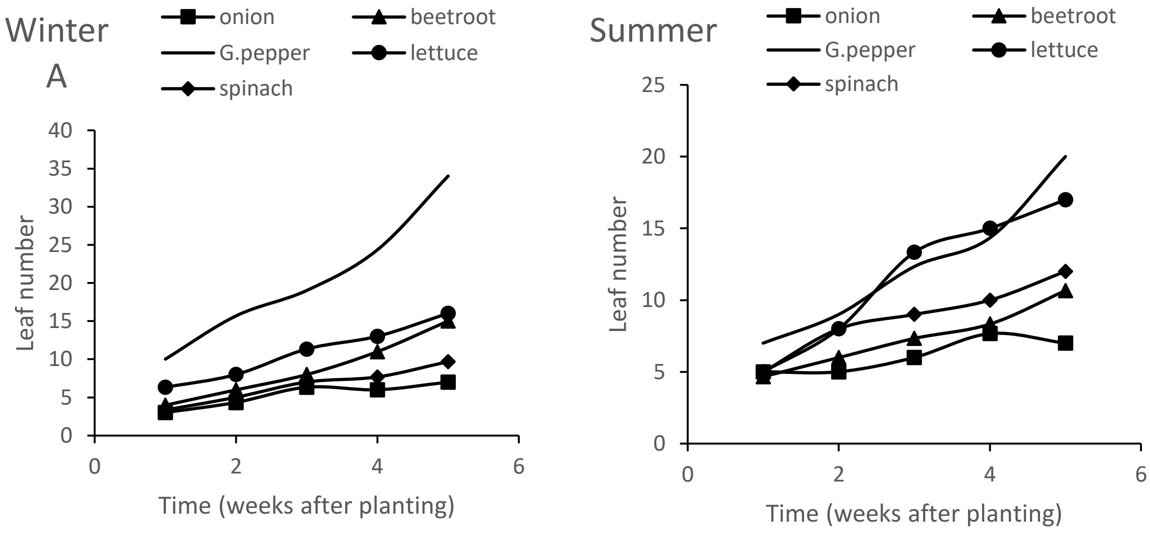
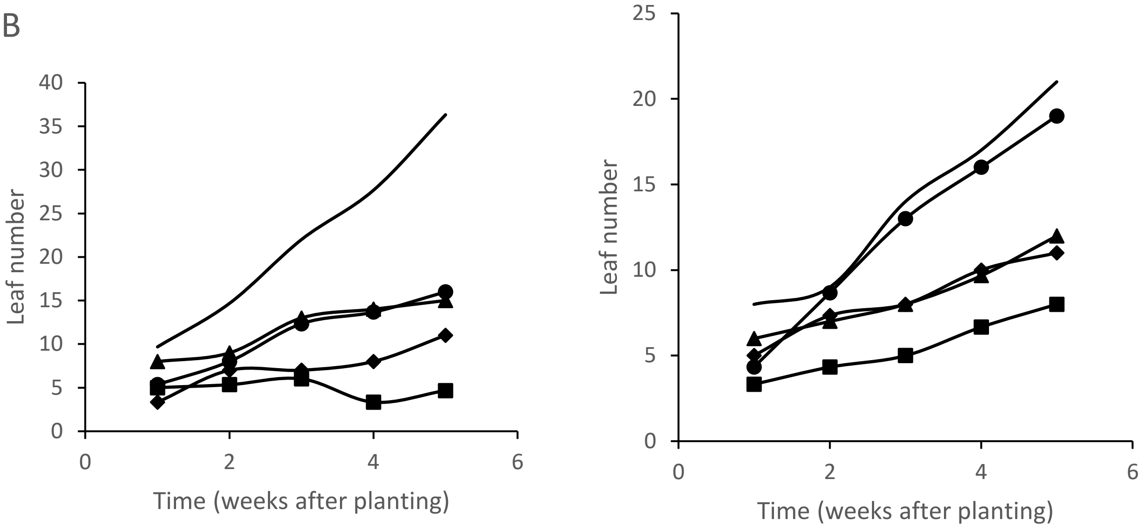


Figure 3.18: Leaf number of five crops (beetroot, green pepper, lettuce, spinach, and onion) grown under 0% fertilizer treatment and five soil profiles (S, R, W, L, and A) during two growing seasons (winter and summer) S0 (A), R0 (B), W0 (C), L0 (D) and A0 (E).



B


Leaf number
0
5
10
15
20
25
30
35
40
0
2
4
6
Time (weeks after planting)
Leaf number
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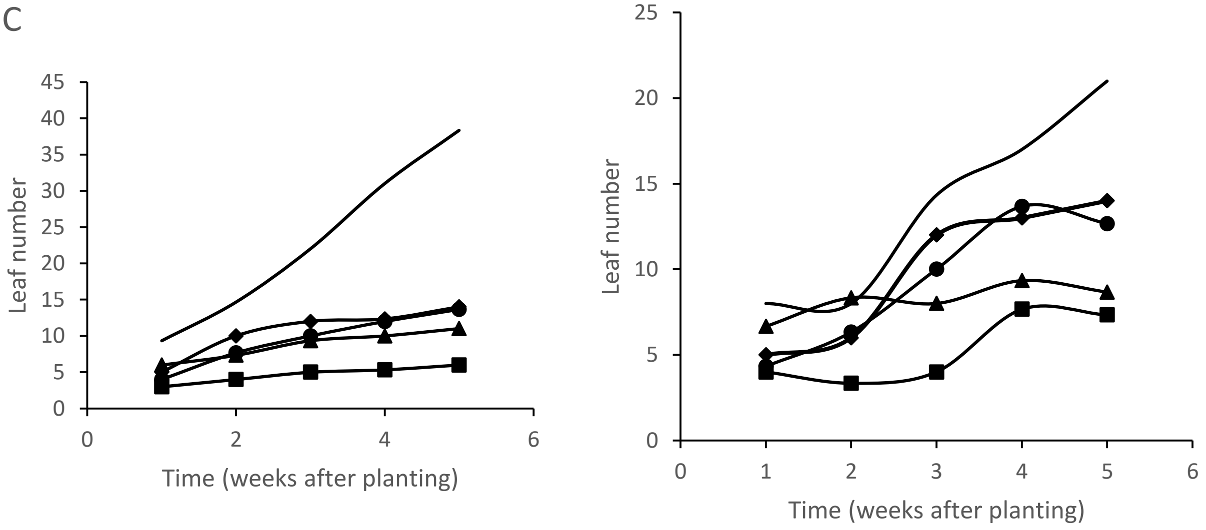
5
10
15
20
25
0
2
4
6
Time (weeks after planting)

C


Leaf number
0
5
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15
20
25
30
35
40
45
0
2
4
6
Time (weeks after planting)
Leaf number
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5
10
15
20
25
0
1
2
3
4
5
6
Time (weeks after planting)

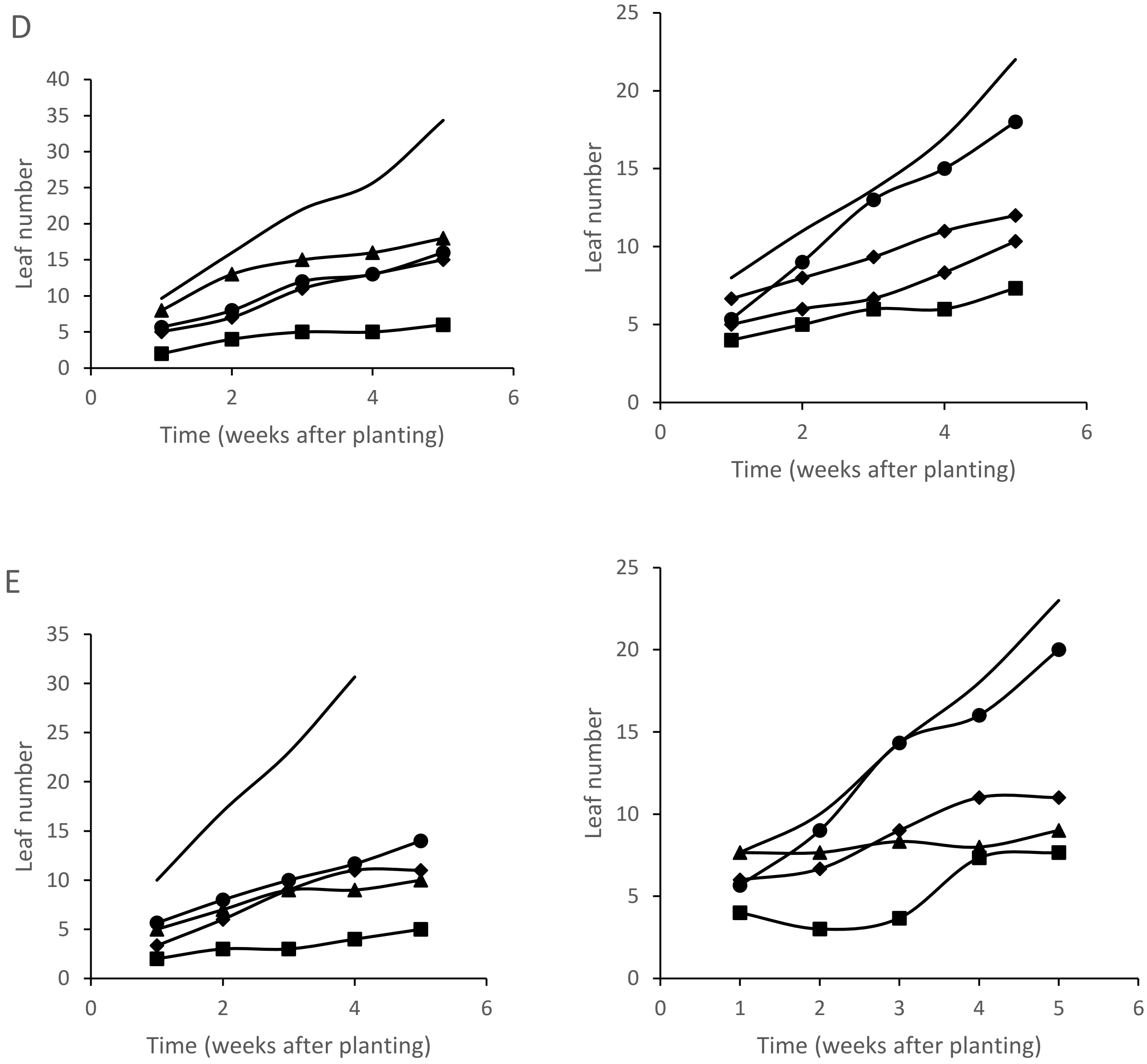
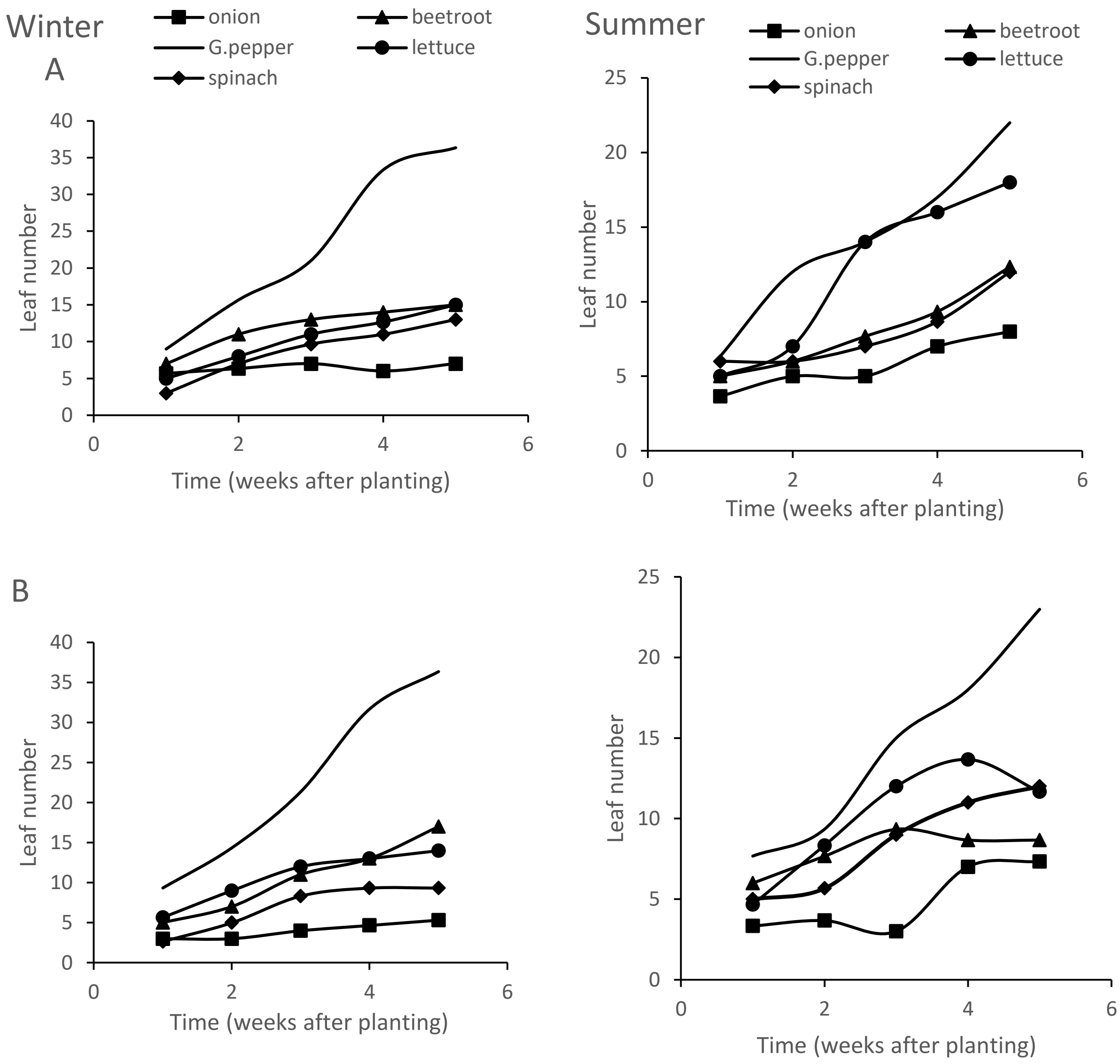
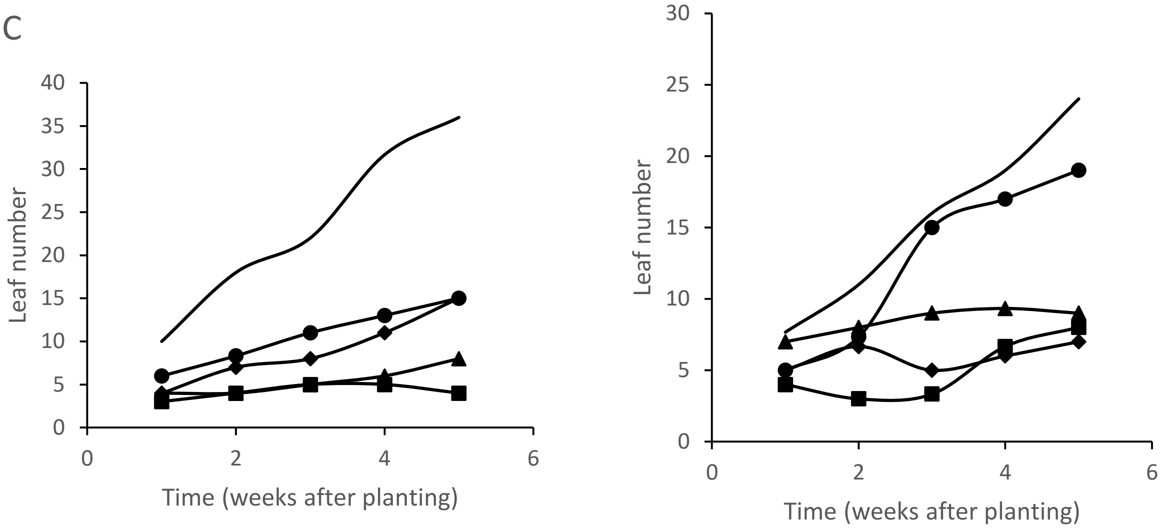


Figure 3.19: Leaf number of five crops (beetroot, green pepper, lettuce, spinach, and onion) grown under 50% fertilizer treatment and five soil profiles (S, R, W, L, and A) during two growing seasons (winter and summer) S50 (A), R50 (B), W50 (C), L50 (D) and A50 (E).


Winter
A
onion
beetroot
G.pepper
lettuce
spinach
Leaf number
0
5
10
15
20
25
30
35
40
0
2
4
6
Time (weeks after planting)
Summer
onion
beetroot
G.pepper
lettuce
spinach
Leaf number
0
5
10
15
20
25
0
2
4
6
Time (weeks after planting)
B
Leaf number
0
5
10
15
20
25
30
35
40
0
2
4
6
Time (weeks after planting)
Leaf number
0
5
10
15
20
25
0
2
4
6
Time (weeks after planting)

C


40
35
30
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15
10
5
0
Leaf number
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2
4
6
Time (weeks after planting)
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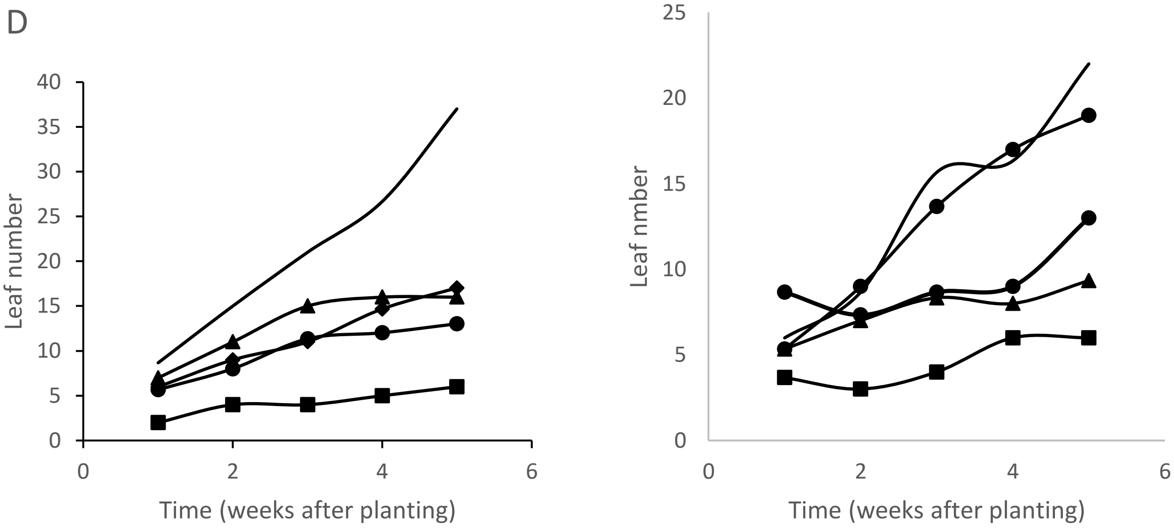
0
Leaf number
0
2
4
6
Time (weeks after planting)

D


40
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Leaf number
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Time (weeks after planting)
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Leaf nmber
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Time (weeks after planting)

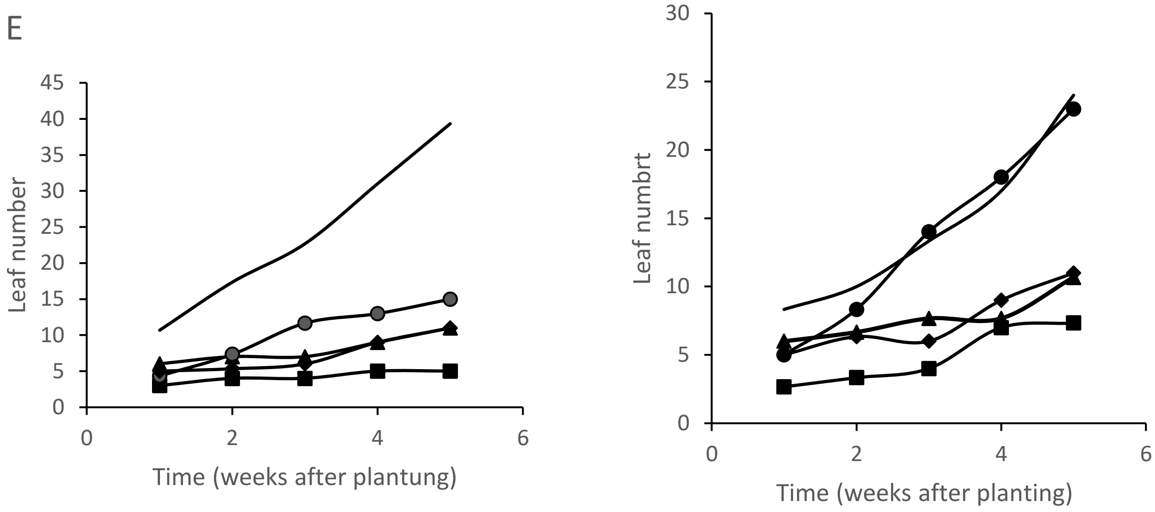

Figure 3.20: Leaf number of five crops (beetroot, green pepper, lettuce, spinach, and onion) grown under 100% fertilizer treatment and five soil profiles (S, R, W, L, and A) during two growing seasons (winter and summer) S100 (A), R100 (B), W100 (C), L100 (D) and A100 (E).

3.3.3.3 Leaf area index and intercepted photosynthetically active radiation (PAR)

There were significant differences(P<0.001) in the leaf area index and intercepted PAR under two growing seasons (Figure 3.20 and 3.22). Sunny days of summer led to higher LAI and PAR compared to winter. Summer had the highest average of 0.779 LAI while winter had 0.586. PAR for winter was 1016 µmol/m^{2}s while summer had 1185 µmol/m^{2}s.

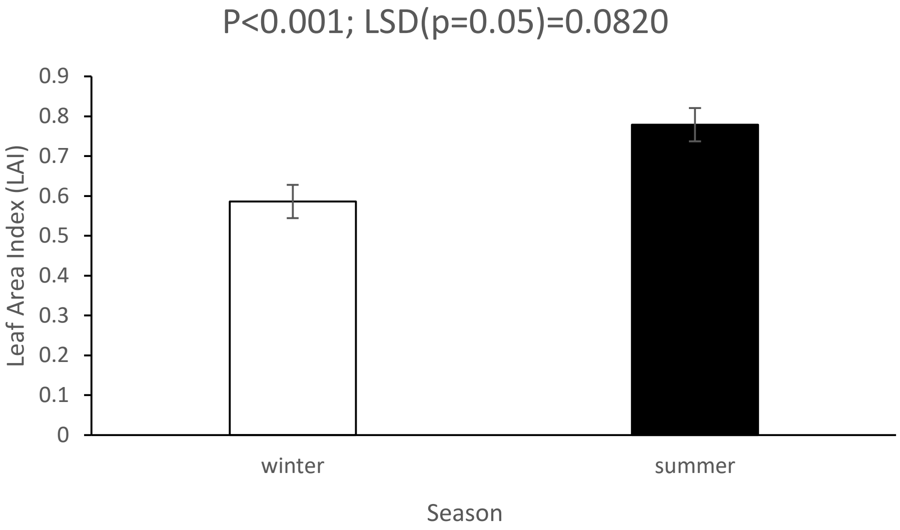

Figure 3.21: Leaf area index (LAI) for two seasons (winter and summer). The standard error bar represents the standard deviation (±0.0417).

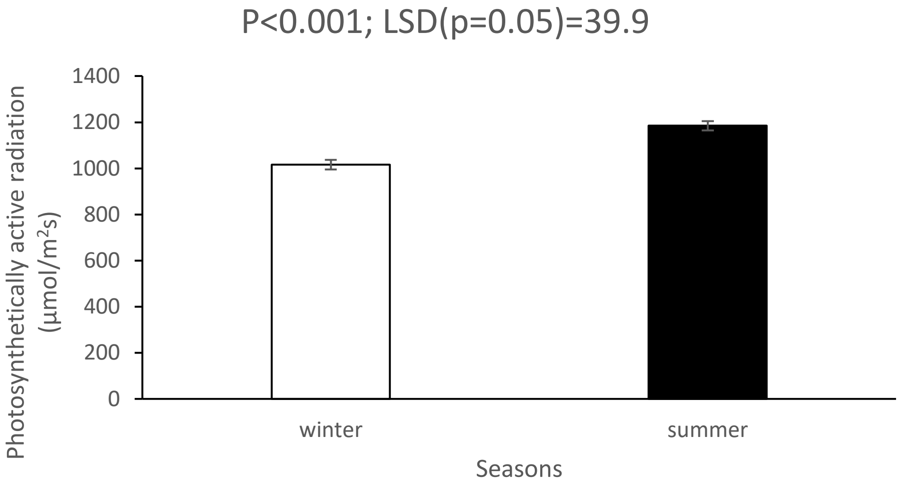

Figure 3.22: Intercepted photosynthetically active radiation (PAR) for two seasons (winter and summer). The standard error bar represents the standard deviation (±20.3).

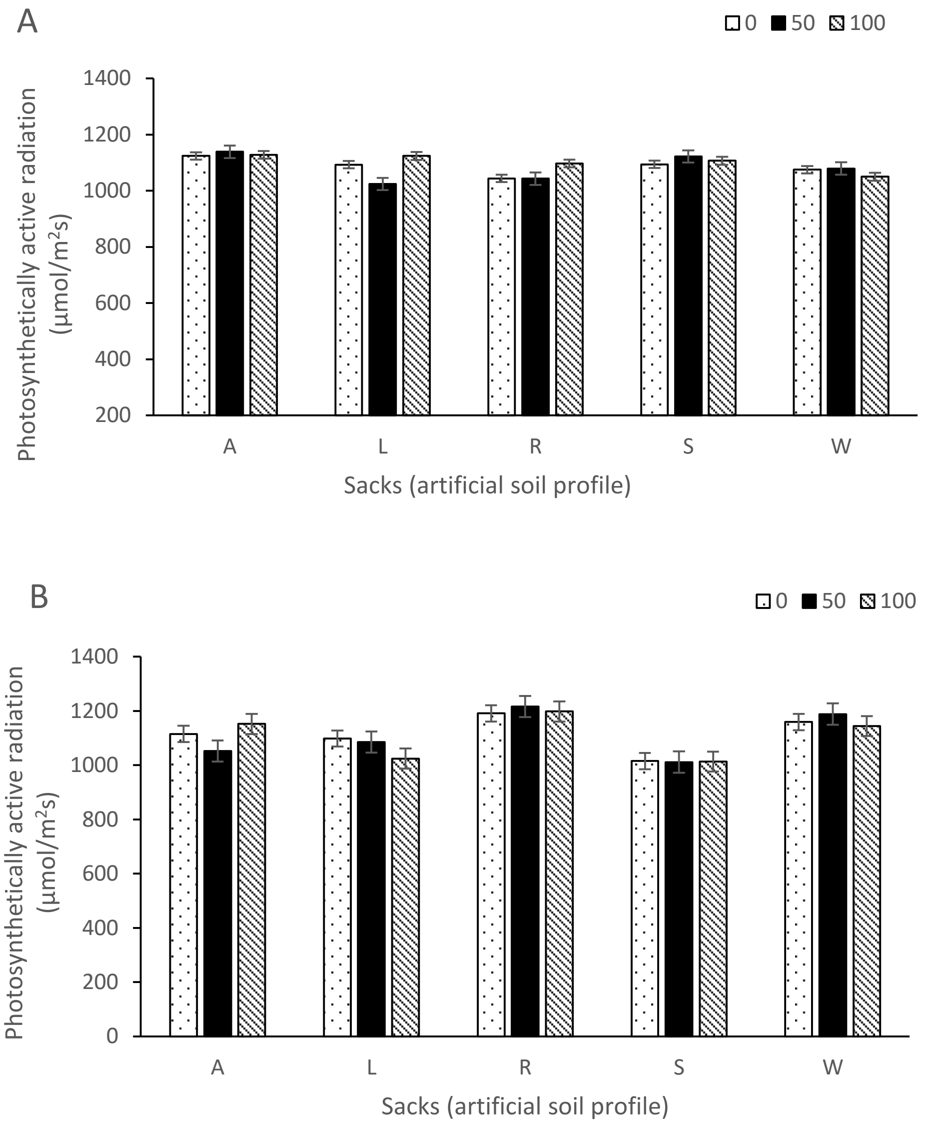

Figure 3.23: Intercepted photosynthetically active radiation (PAR) of sacks for different fertilizer levels (0, 50, and 100%) under two growing seasons winter (A) and summer (B).

3.3.3.4 Crop physiology

There were significant differences [(P<0.001 winters and (P=0.04) summer] regarding average stomatal conductance (SC) for artificial soil profile and crop type interaction (Figure 3.23). For both seasons, winter and summer, the onion had higher SC relative to other crops, sack with soil only (S) having higher SC in winter and summer, respectively. Green pepper SC was lower in summer whereas winter had higher values for SC. Spinach and lettuce had lower SC during summer relative to winter, however, sack L had low SC in winter relative to summer. Beetroot SC was low in summer relative to winter season (Figure 3.24). Artificial soil profiles did not depict many differences in SC and no trend was observed.

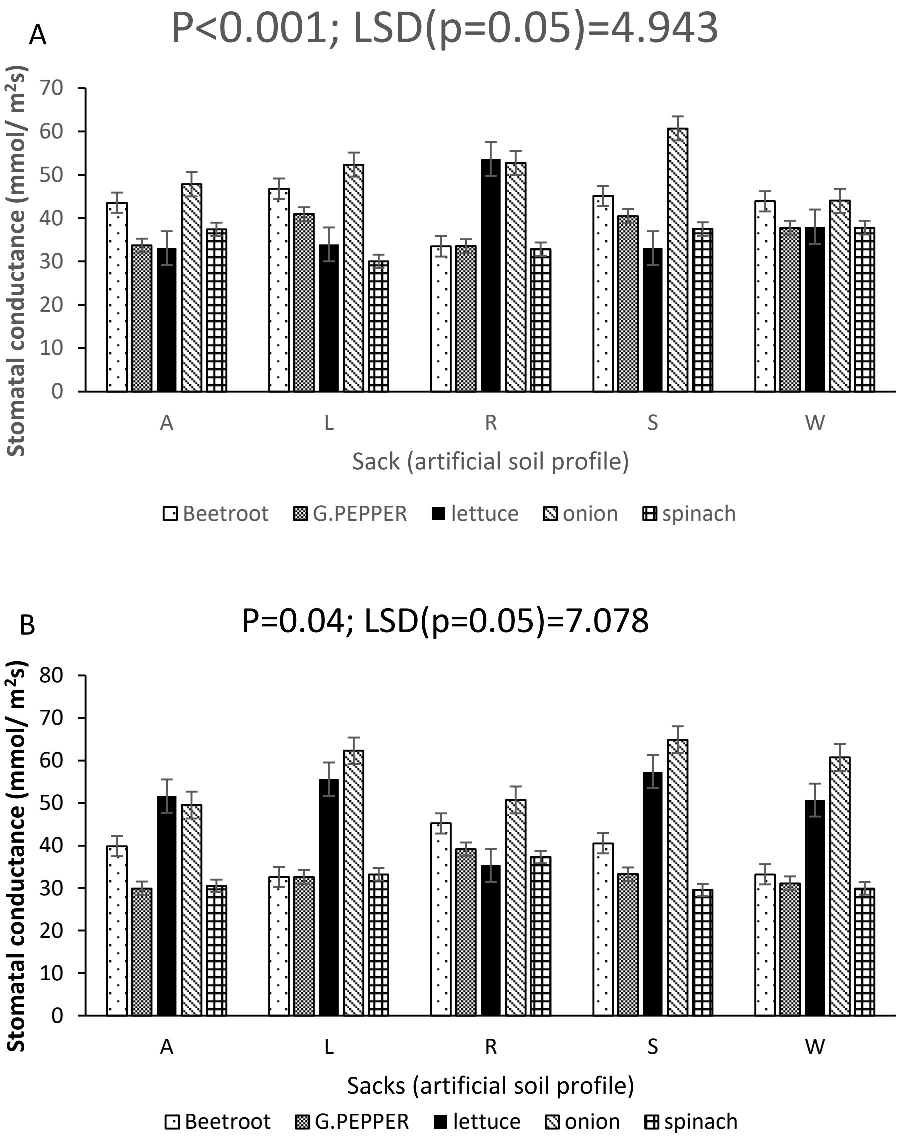

Figure 3.24: Stomatal conductance (SC) crops (beetroot, green pepper, lettuce, onion, and spinach) for different sacks (A, L, R, W, and W) under two seasons winter (A) and summer (B).

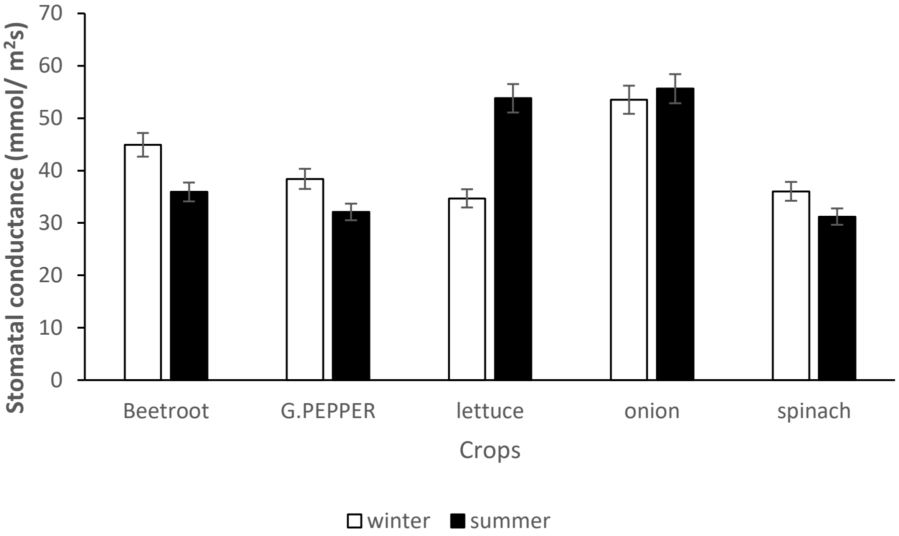

Figure 3.25: Stomatal conductance (SC) for beetroot, G. pepper, lettuce, onion, and spinach for different growing seasons summer and winter.

Interaction of artificial soil profile and crop had significant differences for chlorophyll content index (CCI) for both seasons [winter (P=0.014) and summer (P=0.006)]. Onion had higher CCI compared to other crops for both seasons. Lettuce had lower CCI in summer compared to winter. Fertilizer level and crop interaction had a significant difference for CCI in both seasons, winter and summer (P<0.001). All the crops had the highest CCI in the 100% fertilizer level. Spinach had low CCI in summer for all levels of fertilizer relative to the winter season. Lettuce had the lowest CCI compared to other crops (Figures 3.25 and 3.26).

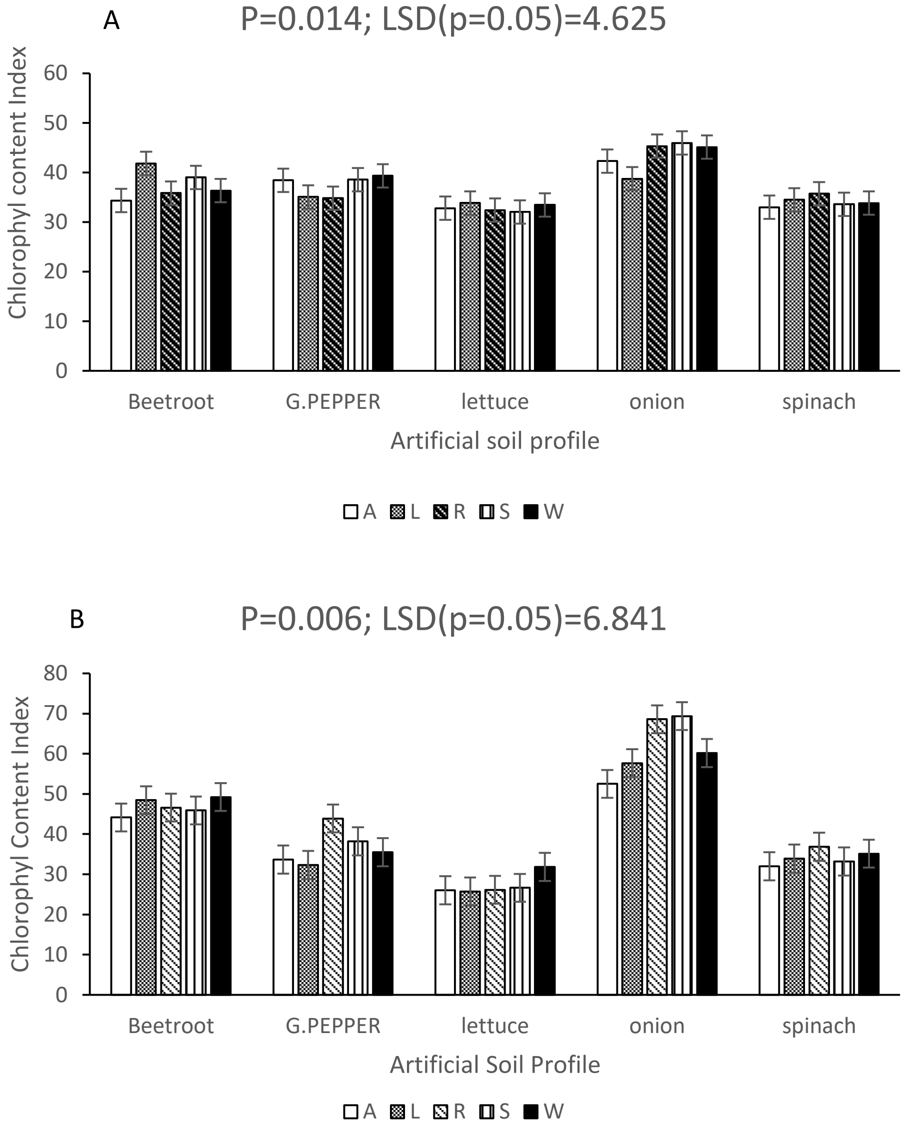

Figure 3.26: Chlorophyll content index (CCI) of crops (beetroot, green pepper, lettuce, onion, and spinach) for different sacks under two-season winter (A) and summer (B).

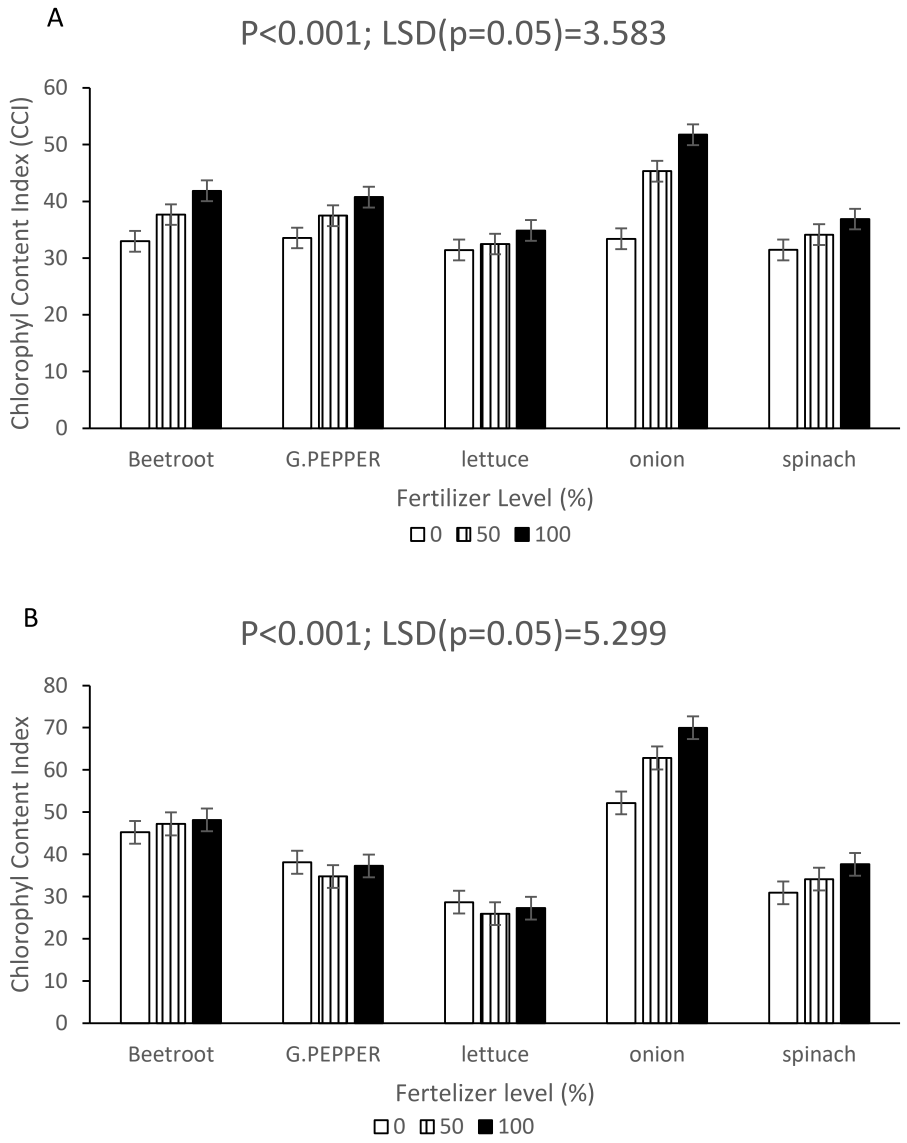

Figure 3.27: Chlorophyll content index (CCI) of crops (beetroot, green pepper, lettuce, onion, and spinach) under fertilizer level and two seasons winter (A) and summer (B).

3.3.4 Field plot results

3.3.4.1 Soil moisture content and soil temperature

There were significant differences (P<0.001) shown for soil moisture content (SM) and soil temperature (Figure 3.27 and 3.28). Winter had higher SM compare to summer while soil temperature was higher in summer compared to winter. This was likely due to less evapotranspiration in winter compared to summer.

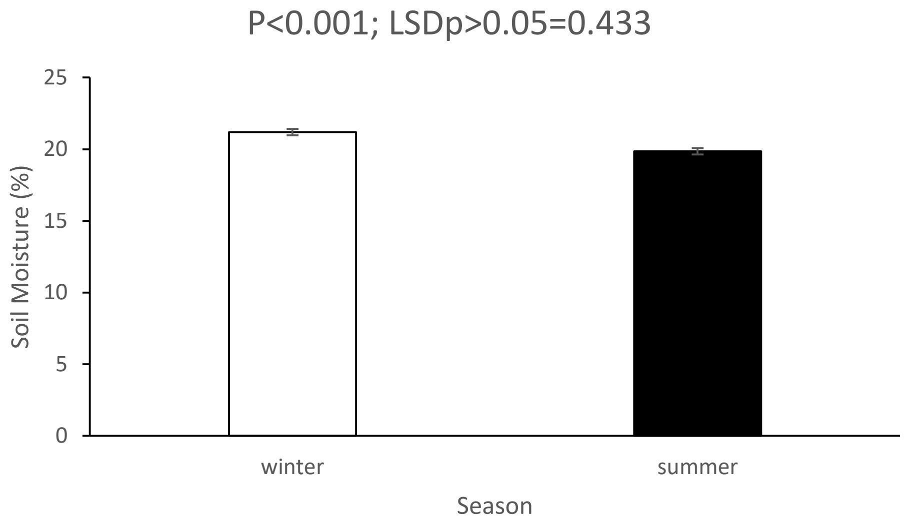

Figure 3.28: Soil moisture for winter and summer season. The standard error bar represents the standard deviation (±0.221).

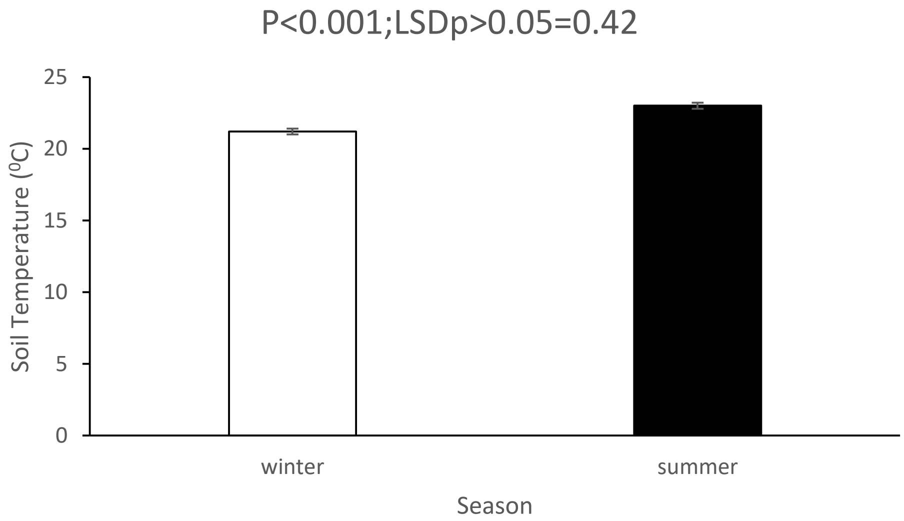

Figure 3.29: Soil temperature for winter and summer season. The standard error bar represents the standard deviation (±0.21).

3.3.4.2 Crop growth

There was a significant difference (P<0.001) regarding plant height and leaf number for beetroot, green pepper, lettuce, onion, and spinach in both seasons (Figure 3.29 and 3.35). Lettuce, beetroot, and green pepper had the lowest height in summer relative to winter while onion and spinach had the highest height in summer. During the summer trial, beetroot and spinach had the highest leaf number than other crops. Winter gave the highest leaf number for green pepper, lettuce, and onion. Crops have different morphology hence leaf number varies, the descending sequence of leaf number was green pepper> lettuce> beetroot> spinach> onion. There were significant differences (P<0.001) regarding PAR for the two seasons and between crops. Summer had higher PAR than winter, while onion had the highest PAR and spinach had the lowest. Summer showed higher LAI than winter, while spinach and lettuce had higher LAI compared to other crops, where onion had the lowest LAI.

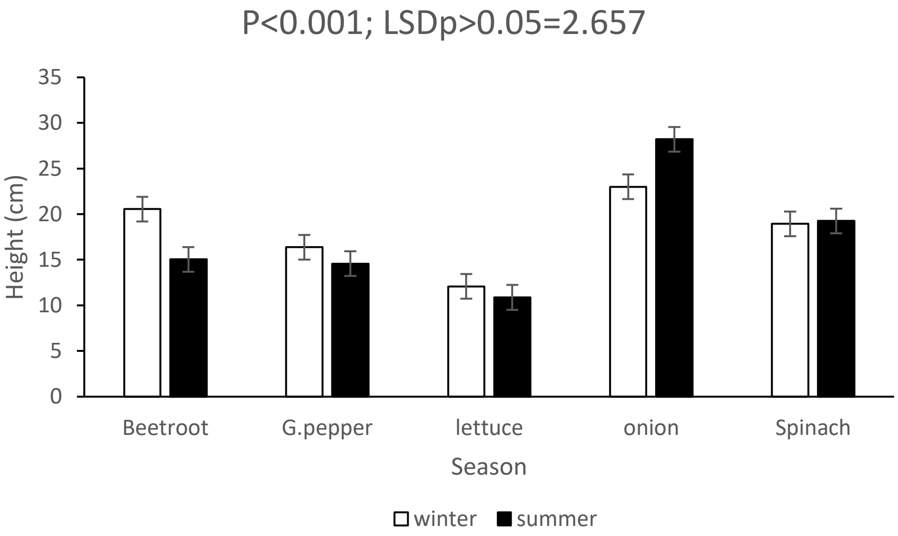

Figure 3.30: Height of beetroot, green pepper, lettuce, onion, and spinach cultivated under winter and summer season. The standard error bar represents the standard deviation (±1.353).

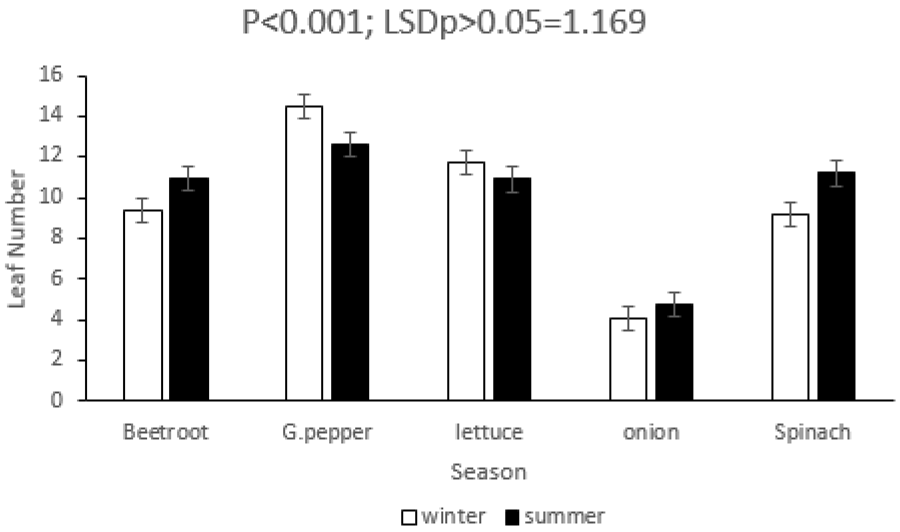

Figure 3.31: Leaf number of beetroot, green pepper, lettuce, onion, and spinach cultivated under winter and summer season. The standard error bar represents the standard deviation (±0.595).

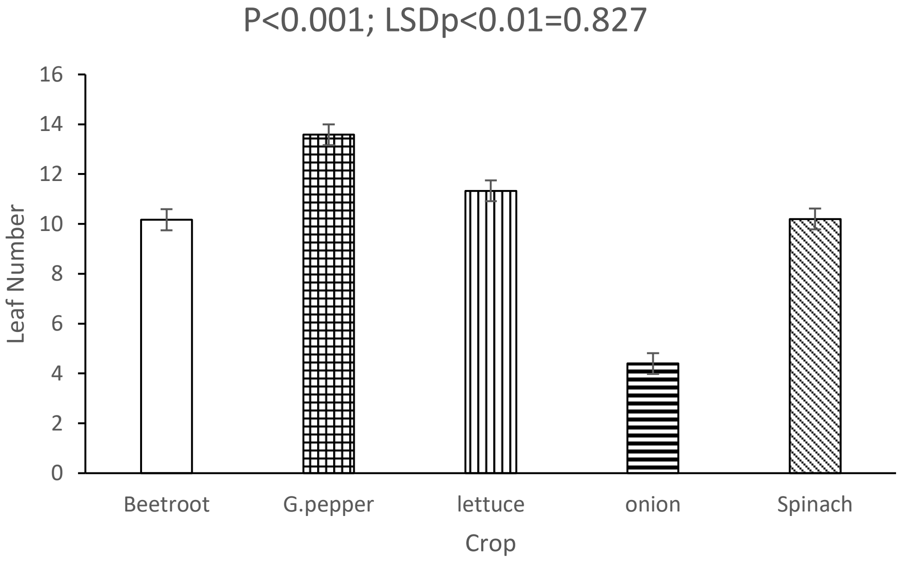

Figure 3.32: Leaf number for five different crops (beetroot, green pepper, lettuce, onion, and spinach). The standard error bar represents the standard deviation (±0.421).

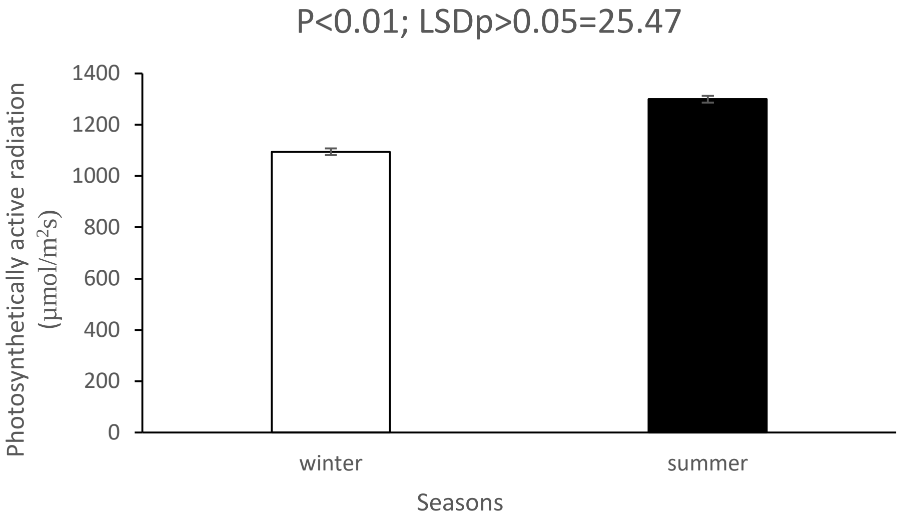

Figure 3.33: Intercepted PAR for winter and summer season. The standard error bar represents the standard deviation (±12.97).

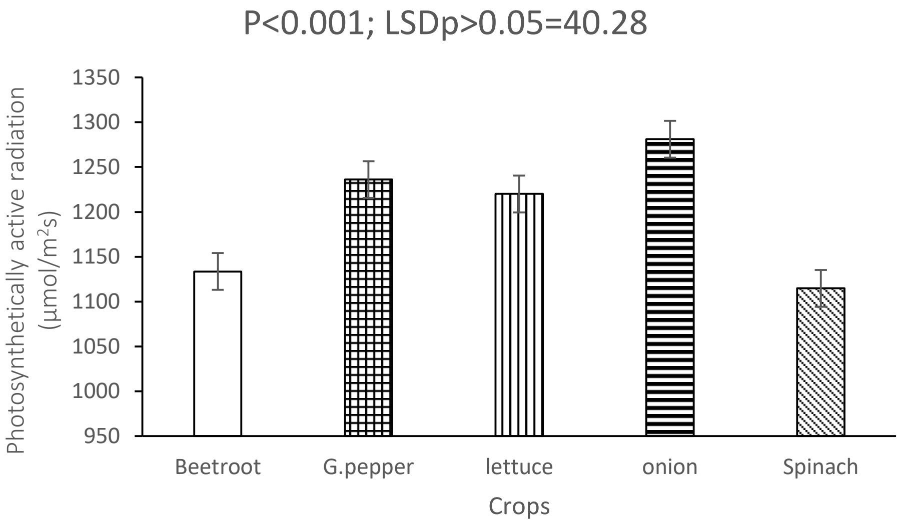

Figure 3.34: Intercepted PAR for different crops (beetroot, green pepper, lettuce, onion, and spinach. The standard error bar represents the standard deviation (±20.51).

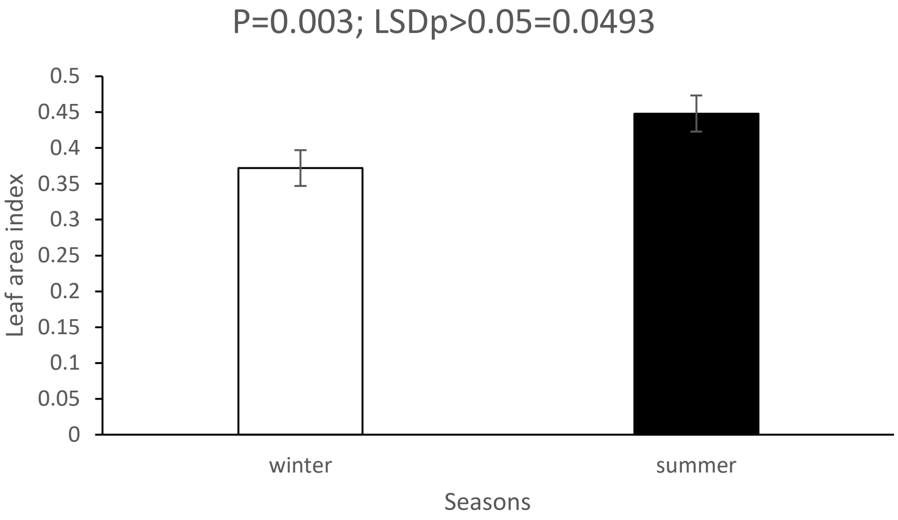

Figure 3.35 Leaf area index for two different seasons (winter and summer). The standard error bar represents the standard deviation (±0.0251).

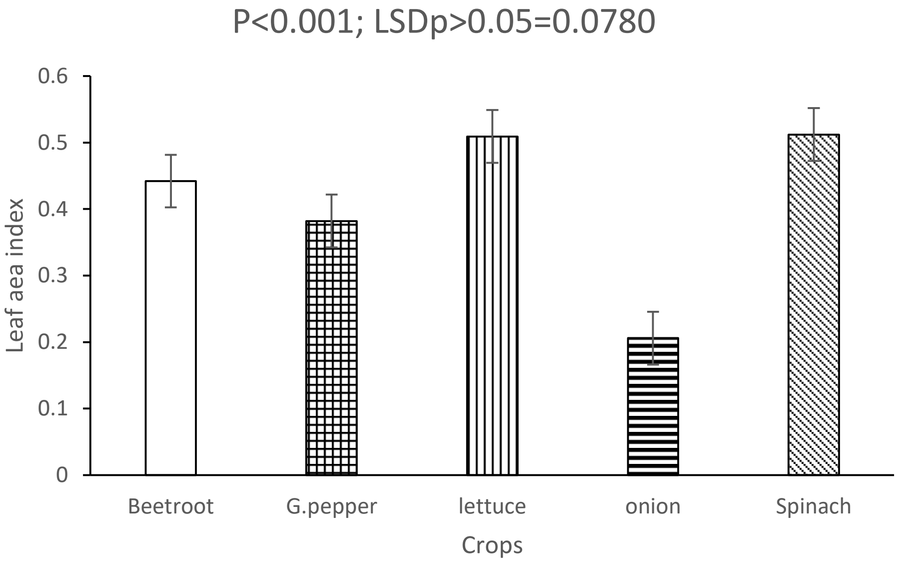

Figure 3.36: Leaf area index for different crops (beetroot, green pepper, lettuce, onion, and spinach). The standard error bar represents the standard deviation (±0.0397).

3.3.4.3 Crop physiology

There were significant differences (P<0.001) for stomatal conductance (SC) across all crops (Figure 3.36-3.38), where winter had higher SC for beetroot, onion, and spinach, but the reverse is true for summer. Amongst crops, the onion had the highest SC while spinach had the lowest. Overall, winter had high SC compared to summer. There were significant differences (P<0.001) for CCI between seasons (Figure 3.39-3.40), where summer had high CCI than winter, while onion had high CCI and lettuce had the lowest CCI.

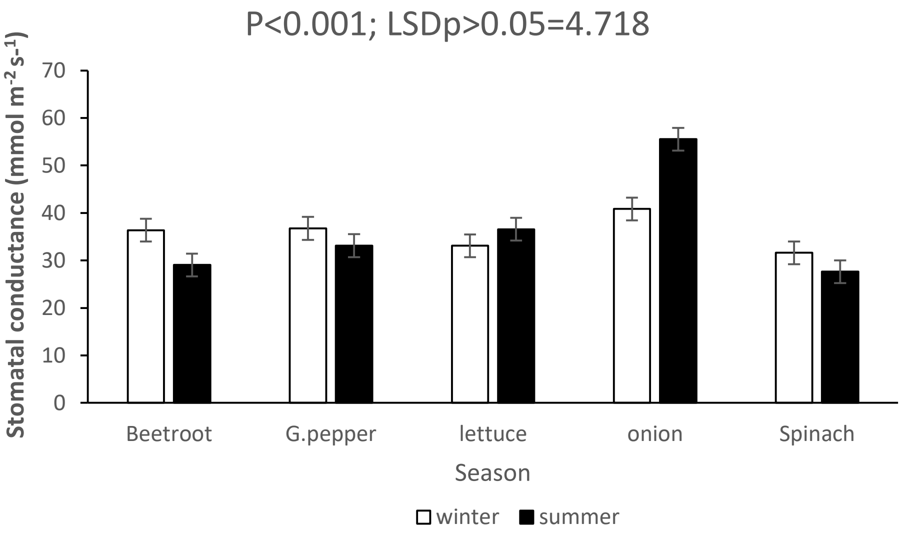

Figure 3.37: Stomatal conductance for different crops (beetroot, green pepper, lettuce, onion, and spinach under different seasons (winter and summer). The standard error bar represents the standard deviation (±2.402).

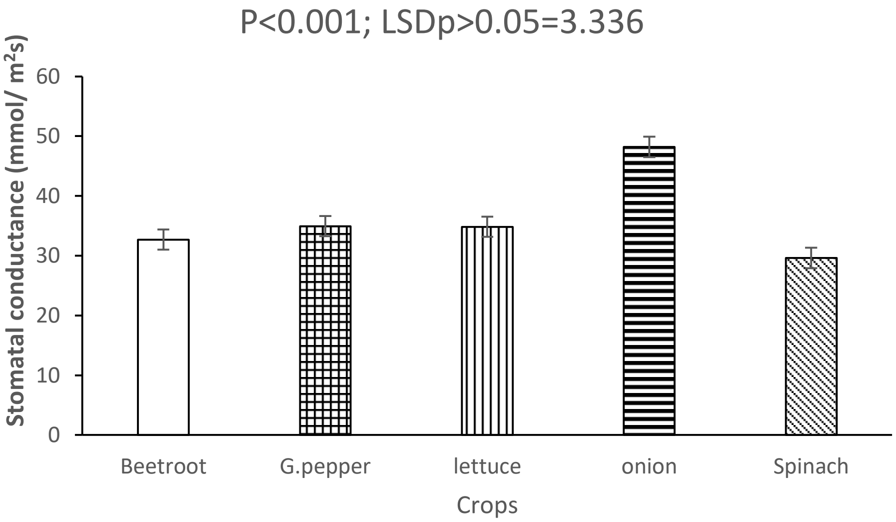

Figure 3.38: Stomatal conductance for different crops (beetroot, green pepper, lettuce, onion, and spinach. The standard error bar represents the standard deviation (±1.699).

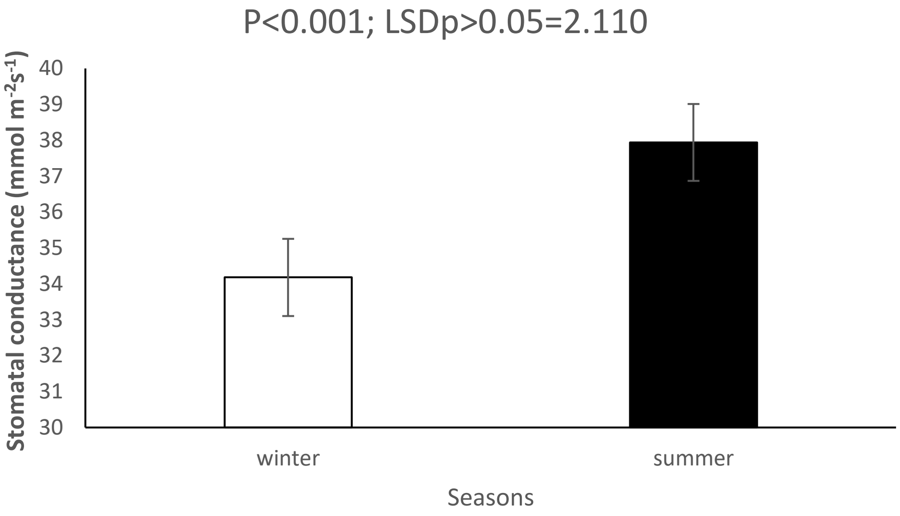

Figure 3.39: Stomatal conductance for two different seasons (winter and summer). The standard error bar represents the standard deviation (±1.074).

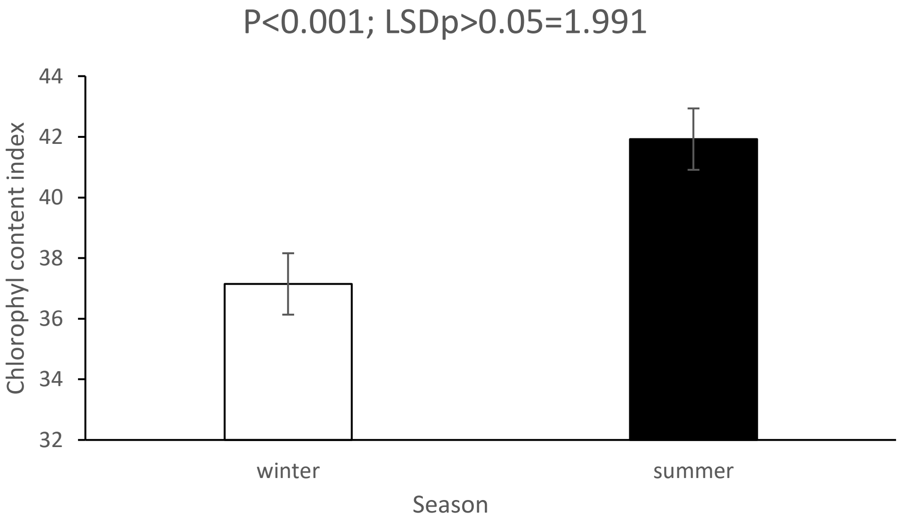

Figure 3.40: Chlorophyll content index for two different seasons (summer and winter). The standard error bar represents the standard deviation (±1.014).

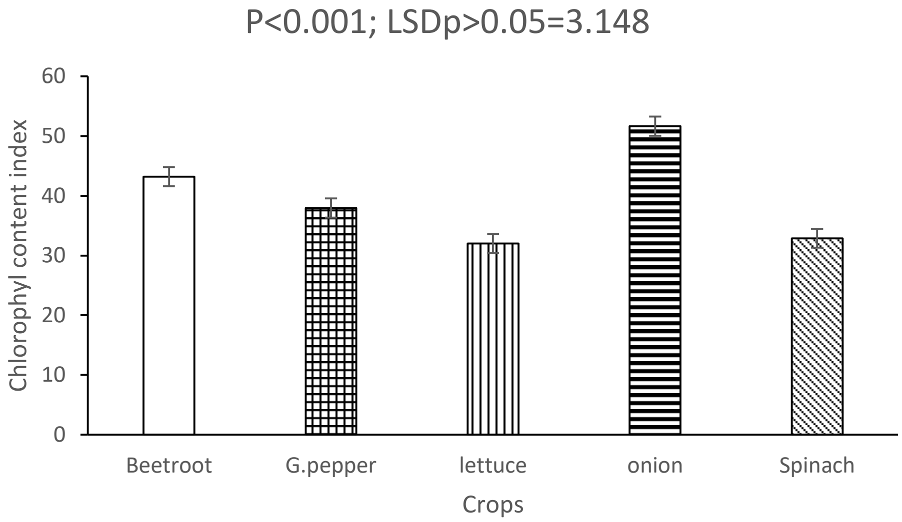

Figure 3.41: Chlorophyll content index for different crops (beetroot, green pepper, lettuce, onion, and spinach. The standard error bar represents the standard deviation (±1.603).

3.4 Discussion

In the context of the current study, lettuce, onion, spinach, green pepper, and beetroot are five contrasting crop species from all different points of view including shape, the posture of the leaves, plant architecture, type of storage organs, edible parts, and length of the growth cycle (Tei et al., 1996). Furthermore, each crop responds differently to the environment and has its environmental requirements for optimum growth, however, environmental conditions are not always complimentary to crop growth (Mabhaudhi et al., 2013). Under unconducive environmental conditions plants rely on adapting to the current conditions (Mabhaudhi et al., 2013). Plant growth and development largely depend on the availability of resources such as water, nutrients, and radiation (Tei et al., 1996). Previous studies that have been conducted on the physiological, growth and development of crops: onion (Ortega et al., 2013), (Córcoles et al., 2015) (Brewster, 2008) and (Kabura et al., 2008); lettuce (Saito and Shimizu, 2002) (Scaife and Jones, 1976; Wurr and Fellows, 1991; Wurr *et al*., 1992); (Limantara et al., 2015); beetroot (Benjamin and Sutherland, 1989) (Mampa et al., 2017); Green pepper (Terry and Boyhan, 2006), (Dı, 2013), (Lopes et al., 2016), (Kabura et al., 2008); spinach (Limantara et al., 2015), (Di et al., 2019) and (Nxawe et al., 2009). All these studies were conducted to evaluate the effect of environmental conditions on crop physiology, growth, and development.

The variation in weather parameters caused challenges for onion growth and development. Temperature caused cold stress on the onion during the winter trial, however, no heat stress was observed in all different phenological stages for all the crops. According to DAFF (2013) and Hasanuzzaman et al. (2013), the optimum air temperature for green pepper is 20-30 ^{o}C, beetroot (18-20 ^{o}C), onion (18-22 ^{o}C), lettuce (15-20 ^{o}C), and spinach (7-24 ^{o}C). The present study had an air temperature range of 2-32 ^{o}C and 5-41 ^{o}C for winter and summer, respectively. As for the winter season temperatures decrease went lower than 10 ^{o}C, exposing onion to cold stress when crops are subjected to temperatures that do not meet their optimal for growth it leads to physical and biological damage (Rivero et al., 2001). Lower temperatures have been intensively reported to cause a reduction of plant growth and crop productivity because it prevents cell division and photosynthesis (Hasanuzzaman et al., 2013). As it was depicted for onion in the current study during the winter season, the low temperature was a limiting factor for onion bulbing, whereas the other four crops were not affected by lower temperatures. In summer onion bulbing was promoted by higher temperatures. The winter cool air temperatures reduced the convective flow of water and nutrients from the soil to the onion roots, leading to slow growth (Fernández and Hoeft, 2009). Similarly, low light intensity reduced photosynthetic rates and nutrient uptake by onion during the winter season (Fernández and Hoeft, 2009). As it was shown by the results, the minimum air temperature was 2^{o}C at 96 DAP but in summer at 96 DAP it was 14^{o}C, therefore temperatures indeed limit photosynthesis.

The availability of water in the soil, nutrients, and optimal temperatures profoundly influence crop growth (Sithole, 2014). The height for this study revealed that beetroot, green pepper, spinach, and lettuce had their lowest height in summer relative to winter while onion had the highest height in summer. This can be related to soil nutrients, temperature, and the position of a crop in a sack. Fertilizer was only applied once during the first trial winter season, then after soil nutrients were gradually depleted from the soil as crops take up nutrients, the application of irrigation or rainfall transported soil nutrients to lower-profile positions, in this case at the bottom of a sack. Beetroot, spinach, pepper, and lettuce did very well in the first trial winter season and this can be related to the high availability of soil nutrients and temperatures were conducive for them before they reached their maturity, unlike onion which had cold stress because soil temperature was very low during a bulbing stage. Whereas in summer soil temperature was warm enough to facilitate bulbing, the growth of leaf number was less the same with plant height. The presence of water in the soil is vital not just for supplying the water needs of the crop but also to dissolve nutrients and making them available for uptake (Fernández and Hoeft, 2009). For instance, in the current study soil moisture was adequate for the crop uptake, hence irrigation was done daily to overcome dry conditions. Summer and winter had a contribution of 278 mm and 517 mm, respectively. Soil chemical processes that affect nutrient availability for plant uptake are facilitated by temperature. Under cool-season soil temperatures, during winter trial, chemical reactions and root activity decreased resulting in fewer nutrients being available for onion (Fernández and Hoeft, 2009). Winter soil temperatures went lower to 6.4^{o}C 87 DAP during bulbing of onion while summer had minimum soil temperature of 13.4^{o}C at 87 DAP. During the summer trial, water potential was very high during the establishment and vegetative stage, but for onion 50 DAP, 50-60 DAP water potential was low reaching a minimum of -200 kPa, which affected bulb formation and development (Wisniewski, 1996). At the maturity stage, soil water potential was high. Soil water for lettuce, beetroot and spinach phenological growth stages was high throughout the growing period. Green pepper growth and development was poor and it was likely not just soil water potential, that affected it.

The opening and closing of stomata are highly facilitated by weather conditions, for example, relative humidity influences water loss from the plant during transpiration as well as photosynthesis (Wisniewski, 1996). The decrease of stomatal conductance for onion during the winter season was attributed to the decrease of temperature (<10^{o}C), lower intercepted PAR and lower soil water potential led to the closure of stomata (Gaastra, 1959; Wisniewski, 1996). During the winter season, when temperatures went very low, the other four crops, besides onion had reached their maturity and they were not affected by cold stress significantly. The reduction of stomatal conductance restricts the ability of plants to assimilate carbon dioxide leading to reduced photosynthesis, consequently affect biomass accumulation (Ocheltree et al., 2014). Hence onion had a small size of bulbs in winter compared to the summer season. Limitation of onion growth is related to low temperature hence temperature is environmental stress (Ocheltree et al., 2014).

Increased stomatal conductance for the summer trial was attributed to higher soil water potential, intercepted PAR, and an increase in temperature (Wisniewski, 1996). The stomatal conductance for other crops was not affected by weather conditions significantly. Crops planted on field plots mimic the physiological growth of crops that were planted in sacks.

Low temperature leads to many changes in physiological indices including chlorophyll content (Ilunga, 2014). The decrease of CCI for winter onion is related to cold stress. Higher CCI suggests that the plant had a high photosynthetic rate leading to high plant growth and yield components (Chaves et al., 2002). This was observed for summer onion and led to a pre-mature bulb, the leaves were wider and long resulting in a higher photosynthetic rate and accumulation of carbon dioxide (CO_2) (Brewster, 2008).

So far, the assessment of LAI based on the AccuPAR-LP-80-ceptometer instrument on the horticulture vegetable crops leaves has been popular (Al Mamun Hossain et al., 2017). The quality of light absorbed by leaves is vital and the efficiency of converting light into sucrose through the photosynthesis process and biochemical constituents influence the final harvest also on the yield of a crop (Brewster, 2008). The temperature and water status of the leaves determines the efficiency of absorbed light conversion into primary photosynthesis products (Brewster, 2008). Under water stress conditions stomata are closed and leaves reduce the entry of CO_2, hence photosynthetic efficacy will be reduced (Brewster, 2008; Ocheltree et al., 2014). The leaf surface area per unit ground determines the total amount of intercepted incident light; the canopy structure is generally important for the display of leaves for light interception for photosynthesis in crop plants (September, 2015). The present study has shown that the larger the canopy structure such as leafy vegetables (spinach, lettuce and beetroot) have more light interception, thus increased rate of photosynthesis as previously sown (September, 2015). Under normal circumstances, onion has a relatively low proportion of incident light interception per unit of area compared with leafy vegetables because onion has upright leaves (Brewster, 2008). However, onion had higher PAR and LAI during summer season leading to fast rate of photosynthesis resulting in early bulbing stage and premature bulbs.

Tei et al., 1996 conducted a study to evaluate the growth and development of lettuce, onion, and beetroot where absorbed radiation into biomass and dry matter partitioning was determined.

Lettuce had high light interception and growth throughout the growth cycle whereas onion showed a lower early relative growth rate than lettuce and beetroot due to the low light interception per unit leaf area in the latter stages of growth and partly to the low initial radiation use efficiency compared with the other two crops (Tei et al., 1996). However, the current study was carried out in different conditions, and a comparison of the findings may not be simple or reliable.

Previous containerized production of the vegetable study was conducted in Kenya and Ghana. Both the studies were responding to food insecurities for the increasing population in the urban areas (Peprah, 2014). Sacks were filled with soil and gravel, a vent was created in the middle of the sack from bottom to top to allow water movement to the soil, and vegetables that were planted were kale, tomato, and spinach (Peprah, 2014). The sides of the sacks were holed to create planting spaces for inserting seedlings (Peprah, 2014). Findings revealed that sack farming enhances household vegetable consumption and the surplus produce is sold to supplement income (Peprah, 2014). Furthermore, in the second case study in Ghana, tomato seedlings were planted, tomato crops fall to the ground and fruits were not able to hang on the sides of the sacks (Peprah, 2014). Kale and spinach were planted successfully for growth and development compared to tomato. The current study uses sacks as well and spinach as well, which showed significant growth throughout the trial. Previous studies did not evaluate the growth and development of crops, and they were done simply to evaluate the impact of containerized production on food security.

3.5 Conclusion

In conclusion, this study is a variation of previous studies and showed the potential to select suitable crops for winter and summer season growth. The findings suggest that degradable sacks are efficient for containerized production of vegetables for cultivating contrasting vegetables throughout the year. Also, the cultivation of vegetables is efficient with minimal application of fertilizer. Furthermore, the crop performance was very similar for those that were planted on sacks and the ground.

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4. VEGETABLE MINERAL CONTENT IN RESPONSE TO GROWTH UNDER CONTAINERISED ARTIFICIAL SOIL PROFILES

Abstract

Vegetables contain valuable food minerals which are utilized to build up and repair the body. The study evaluated yield parameters and plant tissue mineral composition of selected vegetables produced under containerized production for suitability in urban agriculture. Beetroot, lettuce, green pepper, onion, and spinach were grown in sacks filled with five different artificial soil profiles to make growing media. These were 100% sandy loam soil only (S), 50% rocks with 50% soil (R), 50% soil with 50% wood sticks (W), 50% soil with 50% grass (L), and lastly 25% each of soil, grass, rocks and wood sticks (A) under irrigated field with three recommended fertilizer application levels (0, 50 and 100%). Largely dryland production with supplemental irrigation was used for summer and winter seasons in one year. The five plots were done with minimal addition of fertilizer. At harvest, dry mass samples were taken for mineral analysis using microwave plasma atomic emission spectrometry (MP-AES 4200). Results showed that mineral content concentration showed a general trend, irrespective of season: K>Ca>Mg>P>Na>Fe>Mn>Zn. Overall, 100% fertilizer level showed the highest concentration of minerals in all crops, but the best performing soil profiles were W100 and S100 throughout the study.

Keywords: Artificial soil profile, minerals, urban agriculture, vegetables

4.1. Introduction

The major contribution of vegetables to diet are minerals and vitamins, more than common staples (Dzomeku et al., 2011; Iboyi and Jibrin, 2016; Sonni Alvarez, 2002). Vegetables are highly beneficial for the maintenance of health and prevention of diseases (Dzomeku et al., 2011). They contain valuable food ingredients that can be successfully utilized to build up and repair the body (Iboyi and Jibrin, 2016). Fresh vegetables provide the best nutritional value food security option than processed preserved types (Dzomeku et al., 2011).

The proportion of the urban population living below the poverty line continues to rise and levels of urban poverty continue to deepen (Gallaher et al., 2013). Urban poverty is more pronounced because there are fewer options for subsistence farming compared with rural areas (Gallaher et al., 2013). Food insecurity at the household level is a major challenge in South Africa due to nutrient deficiencies such as iron, zinc, vitamin A and vitamin C (Maseko et al., 2017). South Africa is recognized as one the countries with high levels of malnutrition, with 27% of children under the age of five having low height for age and 12% underweight, 5% are low weight for age, and 15% of infants are born with a low birth weight (Kim et al., 2016; Oniang'o et al., 2003). Food for consumption should be safe, pleasant, affordable with good quality that meets up with requirements for the mental, emotional, physiologic, and physical health of a human being (Oniang'o et al., 2003). Studies have shown that locally produced foods have high nutritional and natural value (Oniang'o et al., 2003).

Population differences concerning food preference depend on several factors such as the availability of food, economy, cultural, social habits, nutritional knowledge physiological the ecological zone within which people live, psychological and marketing methods (Oniang'o et al., 2003). In urban areas, processed food is commonly used (Oniang'o et al., 2003). Urban agriculture is expected to play a significant role in minimizing the utilization of processed vegetables (Oniang'o et al., 2003). However, food quality is more important than food quantity in the context of access for meaningful food security. This study aimed to evaluate yield parameters and plant tissue minerals composition of selected vegetables produced under containerized production for urban agriculture potential. The use of artificial soil profiles and vegetable crop response to different fertilizer levels was determined.

4.2. Materials and methods

4.2.1 Yield components

Crops used are from the previous chapter. Fresh mass and dry mass were determined for above-ground biomass at harvest. Dry mass was determined after oven-drying at 105ºC for 24 hours. Fresh mass for spinach was determined by a single leaf.

4.2.2 Plant tissue mineral content analysis

One gram of oven-dry plant material was homogenized and ashed in a muffle furnace at 500 °C for 4 hours. The ash was then digested by gentle heating on a hotplate in 5 mL of 16% hydrochloric acid in silica crucibles. The digested samples were filtered through pre-wetted Whatman no. 42 filter paper (Merck, Germany) and made up to 50 mL with deionized water in a volumetric flask, for further analysis. Mixed standard solutions were prepared from certified reference standards (De Bruyn Spectroscopic Solutions, South Africa) for Ca, K, Mg, Na, Fe, Mn, Zn, and P. Samples were analyzed on a microwave plasma atomic emission spectrometry (MP-AES 4200) (Agilent, USA) against standard reference curves and results were reported in mg/g.

4.2.3 Data analysis

Data collected were analyzed using analysis of variance (ANOVA) from GenStat® Version 18.2 (VSN International, UK) at the 5% level of significance. Tukey's test on GenStat® at the probability level of 5% was used to compare means.

4.3. Results

4.3.1 Yield component

There was a significant difference between fertilizer levels and crops, for fresh vegetable yield (Table 4.1). Lettuce had the largest fresh weight among other crops, whereas spinach fresh mass was the true reverse of lettuce across treatments. Changes in moisture content are shown in Table 4.2. Green pepper in the summer season fruit never set, hence no weight was recorded for this crop in the summer season.

Table 4.1: Fresh mass of crops at harvest [LSD (crops_= 2.2; profiles = 3.5)]

	Crop	Fertilizer Level	A	L	R	S	W
					g/plant		
Winter	Beetroot	0	33.4	54.23	63.7	36.67	66.53
	Beetroot	50	55.37	45.77	61.57	55.9	58.83
	Beetroot	100	37.03	54.3	40.23	62.4	63.87
	G.PEPPER	0	40	14	15	47	37
	G.PEPPER	50	44	15	16	40	20
	G.PEPPER	100	38	24	37	41	21
	lettuce	0	95.33	145.5	183.03	303.7	326.93
	lettuce	50	135.53	175.1	155.4	281.5	165
	lettuce	100	233.63	187.37	235.5	519.36	157.03
	onion	0	3.43	5.23	8.17	9.5	6.6
	onion	50	7	6.2	5.87	8	5.8
	onion	100	7.77	5.2	6.47	8.53	6.33
	spinach	0	0.89	0.52	0.82	0.25	0.62
	spinach	50	0.46	0.81	0.28	0.9	0.61
	spinach	100	0.82	0.52	0.7	0.89	0.93
Summer	Beetroot	0	28.73	69.10	57.70	33.00	57.00
	Beetroot	50	44.57	45.70	55.93	45.13	44.47
	Beetroot	100	33.07	46.47	30.47	53.17	52.50

lettuce	0	173.00	143.10	348.27	272.53	317.00
lettuce	50	163.97	159.60	254.93	262.50	118.50
lettuce	100	122.67	56.39	257.70	236.56	117.63
onion	0	23.00	19.00	14.33	19.00	13.67
onion	50	17.00	17.67	12.67	13.33	21.00
onion	100	16.00	13.33	16.33	14.33	22.00
spinach	0	0.70	0.61	0.63	0.58	0.65
spinach	50	0.74	0.70	0.54	0.63	24.16
spinach	100	0.62	0.58	0.70	0.68	0.69

Table 4.2: Dry mass of five crops at harvest. [LSD (crops) = 0.11; (profiles) = 1.6)]

	Dry mass	Fertilizer Level	A	L	R	S	W
					g/plant		
Winter	Beetroot	0	1.8	5.067	1.6	1.633	2.6
	Beetroot	50	4.567	2.3	2.567	2.6	1.333
	Beetroot	100	2.6	2.6	0.433	1.333	6.333
	G.PEPPER	0	0.283	0.025	0.033	0.298	0.264
	G.PEPPER	50	0.312	0.032	0.06	0.045	0.079
	G.PEPPER	100	0.249	0.161	0.307	0.034	0.011
	lettuce	0	8.633	5.3	6.4	13.7	6.133
	lettuce	50	5.1	7.233	5.867	12.167	4.933
	lettuce	100	6.133	7.167	9.2	8.033	5.533

	onion	0	0.047	0.043	1.333	1.7	0.607
	onion	50	0.513	0.667	0.043	0.733	0.03
	onion	100	0.453	0.05	0.203	0.057	0.167
	spinach	0	0.045	0.2	0.043	0.037	0.037
	spinach	50	0.037	0.04	0.04	0.03	0.047
	spinach	100	0.02	0.034	0.08	0.067	0.5
Summer	Beetroot	0	2.30	4.11	7.97	7.00	3.00
	Beetroot	50	1.90	2.57	8.43	4.97	1.94
	Beetroot	100	5.73	3.10	4.40	7.40	2.77
	lettuce	0	8.93	9.30	6.27	9.17	7.30
	lettuce	50	6.77	8.13	8.30	7.67	6.93
	lettuce	100	6.80	7.20	8.13	33.00	8.37
	onion	0	1.40	1.40	0.36	0.67	0.26
	onion	50	0.95	0.33	0.29	0.47	0.18
	onion	100	0.23	0.06	0.24	0.40	0.91
	spinach	0	0.16	0.28	0.04	0.05	0.05
	spinach	50	0.14	0.20	0.02	0.04	0.17
	spinach	100	0.21	0.35	0.04	0.05	0.03

4.3.2 Mineral composition of vegetables

The elemental composition of dry samples is given in Tables 4.3- 4.8. All elements measured were present in significantly different ($P < 0.005$) concentrations in vegetables. There was no consistent pattern according to which vegetables had the highest and lowest concentration of each element. The distribution of mineral nutrients varied among the artificial soil profile sacks, fertilizer level, and crops. However, the concentration of potassium (K) was significantly higher in all crops for both winter and summer. Zinc (Zn) concentration is a true reverse of K. Concentration of minerals was found to be in descending order of K>Ca>Mg>P>Na>Fe>Mn>Zn. Overall, a 100% fertilizer level showed the highest concentration of minerals in all crops. The best performing artificial soil profiles were W100 and S100 throughout the study, while 0% fertilizer level gave most crops minimum concentration of selected minerals.

Highest concentration of phosphorus (P) in lettuce was obtained from L100 (5.047 mg/g), minimum concentration was from S0 (2.927 mg/g) in the winter season while summer had maximum and minimum P concentration in W100 (7.886 mg/g) and S0 (4.782 mg/g), respectively. In the winter season K concentration was much higher in S100 (73.653 mg/g), S100 (81.948 mg/g), S100 (30.666 mg/g), L100 (44.173 mg/g), L100 (80.033 mg/g) and S100 (29.286 mg/g) for lettuce, spinach, green pepper, onion, beetroot leaves and beetroot roots, respectively. Whereas lowest concentrations were observed S0 (37.921 mg/g), R0 (55.958 mg/g), A0 (24.478 mg/g), A50 (35.252 mg/g), RO (52.669 mg/g) and RO (13.055 mg/g), respectively. Potassium in summer season lettuce had maximum and minimum from S100 (77.805 mg/g) and W50 (26.938 mg/g), respectively, meanwhile spinach had R0 (80.623 mg/g) and A100 (44.941 mg/g) maximum and minimum, respectively. Onion K concentration was lowest at A100 (9.243 mg/g) and highest at W100 (11.858 mg/g).

For lettuce (Table 4.4) during winter season sodium (Na) was observed to be higher in S100 (1.604 mg/g) and lowest in R0 (0.803 mg/g). Calcium (Ca) had maximum concentration in S100 (13.877 mg/g) and a minimum of 7.701 mg/g in R0. Magnesium (Mg) maximum was highest in S100 (5.260 mg/g) and lowest was 2.884 mg/g in R0, A and R sacks had lowest iron (Fe) concentration in all fertilizer levels relative to W, S and L, whereas S100 showed highest concentration of 9.148

mg/g. Manganese (Mn) S100 (0.690 mg/g) was the highest while A0 (0.149 mg/g) was the lowest, Zn concentration was high at S100 (0.063 mg/g) and low at L0 (0.013 mg/g). Meanwhile, summer season Na, Ca, Mg, Fe, Mn and Zn had their highest concentration in S100 (1.811 mg/g), R100 (17.992 mg/g), S100 (6.429 mg/g), A100 (8.296 mg/g), A100 (0.714 mg/g) and W100 (0.147 mg/g), respectively, while lowest concentration was in S0 (0.664 mg/g), S0 (8.522 mg/g), s0 (3.600 mg/g), S50 (0.546 mg/g), W50 (0.151 mg/g) and A100 (0.051 mg/g) for Na, Ca, Mg, Fe, Mn and Zn, respectively.

Spinach mineral concentrations (Table 4.5) for the winter season had the high concentration of P, Na, Ca, Mg, Fe, Mn and Zn on L100 (6.090 mg/g), W50 (17.381 mg/g), W100 (20.585 mg/g), S100 (23.788 mg/g), S100 (1.480 mg/g), W100 (1.764 mg/g) and A50 (0.645 mg/g), respectively. Again summer highest concentration of P, Na, Ca, Mg, Fe, Mn and Zn were found on W100 (21.966 mg/g), R0 (15.012 mg/g), R50 (16.829 mg/g), W100 (15.063 mg/g), A100 (0.791 mg/g), A100 (0.794 mg/g) and W100 (0.396 mg/g), respectively. Meanwhile, minimum concentration was observed in R0 (2.094 mg/g), L0 (9.322 mg/g), W0 (10.637 mg/g), R0 (10.925 mg/g), A0 (0.305 mg/g), R0 (0.434 mg/g) and R0 (0.074 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively, whereas summer season had different concentrations of P, Na, Ca, Mg, Fe, Mn and Zn concentration in S100 (5.472 ng/g), W100 (6.542 mg/g), R0 (6.492 mg/g), R0 (7.565 mg/g), W100 (0.119 mg/g), R100 (0.336 mg/g) and A0 (0.170 mg/g), respectively.

Green pepper in the winter season (Table 4.6) showed various concentrations in R50 (5.375 mg/g), R50 (0.253 mg/g), L50 (2.111 mg/g), S100 (2.880mg/g), S100 (0.099 mg/g), R50 (0.051 mg/g) and R100, S100 (0.012 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively, while concentrations were low in W0 (3.039 mg/g), S0 (0.157 mg/g), A100 (0.565 mg/g), W0 (1.931 mg/g), W100 (0.061 mg/g), R0 (0.032 mg/g) and W0 (0.007 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively. Onion mineral nutrients was distributed unevenly for both the two growing seasons. Winter maximum concentration was in A100 (5.654 mg/g), R100 (0.564 mg/g), S100 (19.903 mg/g), R100 (4.779 mg/g), A100 (0.747 mg/g), L100 (0.280 mg/g) and A100 (0.020 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively, while summer had maximum of P, Na, Ca, Mg, Fe, Mn and Zn on R100 (3.378 mg/g), L100 (0.426 mg/g), A50 (3.560 ng/g), A50 (1.620 mg/g), L100 (1.755 mg/g), L100 (0.140 mg/g) and A100 (0.033 mg/g), respectively. Lowest concentration in the winter was in R0 (4.622 mg/g), A0 (0.474 mg/g), A0 (16.262 mg/g), W0 (4.412 mg/g), S0 (0.240 mg/g), S0 (0.257 mg/g) and R0 (0.015 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively. Meanwhile, summer had lowest concentration of P, Na, Ca, Mg, Fe, Mn and Zn in A100 (2.427 mg/g), R100 (0.235 mg/g), W50 (2.356 mg/g), W50 (1.034 mg/g), R100 (0.429 mg/g), A0 (0.021 mg/g) and S50 (0.013 mg/g), respectively.

Beetroot leaves (Table 4.7) mineral composition varied significantly among artificial soil profiles. Winter season P, Na, Ca, Mg, Fe, Mn and Zn had maximum concentration of R100 (4.935 mg/g), A100 (14.423 mg/g), R100 (18.008 mg/g), L100 (17.188 mg/g), R100 (1.284 mg/g), S50 and R100 (1.108 mg/g) and R100 (0.138 mg/g), respectively, while minimum concentration was in W50 (4.141 mg/g), W0 (10.505 mg/g), S50 (13.972 mg/g), S0 (14.924 mg/g), A0 (0.750 mg/g), W0 (0.842 mg/g) and S0 (0.128 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively. As for summer season, it was observed that P, Na, Ca, Mg, Fe, Mn and Zn had highest concentration in S50 (25.285 mg/g), L0 (17.930 mg/g), W50 (15.257 mg/g), L0 (17.606 mg/g), W100 (1.426 mg/g), S50 (1.037 mg/g) and W0 (0.302 mg/g), respectively, while lowest concentration was observed in W100 (9.846 mg/g), S0 (9.412 mg/g), S0 (7.438 mg/g), S0 (9.579 mg/g) W50 (0.603 mg/g), L0 (0.337 mg/g) and L50 (0.126 mg/g), respectively.

Beetroot root mineral concentration (Table 4.8) of P, Na, Ca, Mg, Fe, Mn and Zn in the winter season was found to be high in W100 (6.444 mg/g), R100 (2.969 mg/g), W100 (3.070 mg/g), S100 (3.892 mg/g), W100 (1.539 mg/g), W100 (0.389 mg/g) and W100 (0.088 mg/g), respectively. Low concentration was found in R0 (3.060 mg/g), L0 (0.655 mg/g), R0 (1.621 mg/g), A0 (2.397 mg/g), R0 (0.407 mg/g), R0 (0.192 mg/g) and L0 (0.052 mg/g) for P, Na, Ca, Mg, Fe, Mn and Zn, respectively. Summer lowest and highest concentration of P, Na, Ca, Mg, Fe, Mn and Zn was found in L50 (3.610 mg/g), S50 (0.400 mg/g), L0 (1.182 mg/g), L0 (2.066), S0 (0.266 mg/g), L0 (0.073 mg/g) , L100 (0.051 mg/g) and W0 (6.140 mg/g), W100 (1.651 mg/g), W50 (2.162 mg/g), S0 (3.921 mg/g), W50 (1.754 mg/g), W50 (0.253 mg/g) and W100 (0.123 mg/g), respectively.

Table 4.3: Mineral composition of lettuce for winter and summer season. LSD (soil profile) = 0.21.

lettuce	Sack	**P**	**K**	**Na**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**
					mg/g				
Winter	S0	2.927	37.921	1.432	9.382	3.409	0.275	0.174	0.041
	S50	3.929	60.469	1.462	10.178	4.821	2.166	0.327	0.043
	S100	4.266	73.653	1.604	13.877	5.260	9.148	0.690	0.063
	R0	3.657	45.089	0.803	7.701	2.884	0.448	0.153	0.034
	R50	3.938	63.115	1.143	10.972	3.856	1.674	0.383	0.040
	R100	4.034	64.387	1.324	12.629	4.067	3.183	0.512	0.044
	W0	4.342	49.963	1.117	10.778	3.654	0.510	0.182	0.047
	W50	4.508	54.182	1.159	11.162	3.729	0.739	0.205	0.047
	W100	4.607	55.493	1.106	11.111	3.883	0.837	0.254	0.049
	L0	4.984	52.060	0.909	10.391	3.488	0.870	0.192	0.013
	L50	5.031	52.859	1.058	10.475	3.533	1.065	0.243	0.044
	L100	5.047	63.443	1.086	10.671	3.710	1.161	0.269	0.053
Summer	A0	3.551	43.639	1.141	9.563	3.206	0.559	0.149	0.032
	A50	3.488	46.442	1.264	10.088	3.304	0.766	0.152	0.039

A100	4.141	50.441	1.588	10.287	3.417	1.874	0.239	0.053
S0	4.782	46.072	0.664	8.522	3.600	0.958	0.160	0.083
S50	6.055	65.297	1.642	16.322	6.043	0.546	0.308	0.138
S100	7.540	77.808	1.687	12.079	6.429	2.488	0.345	0.088
R0	6.491	64.961	1.586	8.893	4.929	0.644	0.328	0.132
R50	5.618	52.766	0.815	15.662	5.390	1.195	0.538	0.131
R100	6.436	66.092	1.465	17.992	5.515	1.550	0.549	0.075
W0	5.734	75.134	1.799	16.397	5.944	1.255	0.458	0.062
W50	5.396	26.938	1.623	12.086	4.467	1.043	0.151	0.051
W100	7.886	72.557	5.599	14.588	4.819	2.563	0.489	0.147
L0	7.031	75.351	1.708	13.520	5.614	0.931	0.429	0.083
L50	7.543	53.168	0.870	14.648	5.117	0.976	0.223	0.067
L100	5.885	77.429	1.302	11.496	5.399	1.722	0.157	0.062
A0	6.858	71.560	1.723	12.641	4.410	2.737	0.296	0.115
A50	6.470	55.880	1.757	17.561	6.147	3.466	0.368	0.055
A100	6.744	56.000	1.811	17.542	5.798	8.296	0.714	0.051

Table 4.4: Mineral composition of spinach for winter and summer season. LSD (soil profile) = 0.9

spinach	Sack	**P**	**K**	**Na**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**
					mg/g				
Winter	S0	2.438	57.415	11.198	13.167	12.805	0.835	0.685	0.132
	S50	3.800	60.439	14.048	16.517	12.856	0.965	0.879	0.214
	S100	4.228	81.940	16.730	16.588	23.788	1.480	1.154	0.309
	R0	2.094	55.958	13.615	13.656	10.925	0.353	0.434	0.074
	R50	2.724	59.433	15.560	15.369	11.800	0.821	0.828	0.106
	R100	4.161	72.238	17.326	16.538	20.315	1.022	0.988	0.192
	W0	4.458	58.726	12.397	10.637	12.069	0.448	0.901	0.173
	W50	4.829	62.461	17.381	15.304	13.485	0.472	1.540	0.237
	W100	5.060	65.318	14.575	20.585	14.849	0.682	1.764	0.300
	L0	2.146	69.755	9.322	13.509	14.372	0.429	0.569	0.085
	L50	5.541	73.219	11.404	16.315	14.972	0.493	0.927	0.137
	L100	6.090	75.785	13.055	16.629	16.289	0.497	1.005	0.145
	A0	2.716	54.128	13.911	15.380	11.100	0.305	0.609	0.124
	A50	2.982	57.549	14.226	16.199	14.545	0.563	0.640	0.645

	A100	3.635	62.776	16.621	18.470	15.149	0.621	1.258	0.166
Summer	S0	7.562	72.096	14.877	6.502	10.688	0.410	0.350	0.254
	S50	14.897	57.001	8.593	9.305	10.747	1.156	0.565	0.244
	S100	5.472	70.423	13.994	6.775	12.044	0.367	0.407	0.303
	R0	8.472	80.623	15.012	6.495	7.565	0.640	0.377	0.270
	R50	8.327	58.328	12.516	16.829	8.478	0.656	0.459	0.245
	R100	11.515	63.582	14.829	7.730	12.025	0.546	0.336	0.171
	W0	13.153	59.430	11.764	8.758	10.796	0.280	0.455	0.243
	W50	10.137	55.316	13.758	7.939	10.153	0.386	0.550	0.234
	W100	21.966	57.292	6.542	15.480	15.063	0.119	1.481	0.396
	L0	10.580	56.741	10.926	8.355	9.500	0.669	0.489	0.284
	L50	9.537	55.239	11.563	10.156	11.767	0.422	0.498	0.301
	L100	11.127	65.423	10.985	7.895	12.814	0.439	0.431	0.212
	A0	6.264	51.529	13.596	10.856	14.922	0.269	0.318	0.170
	A50	19.535	62.365	7.514	8.295	10.764	0.567	0.745	0.233
	A100	13.088	44.941	6.708	10.334	11.534	0.791	0.794	0.262

Table 4.5: Mineral composition of onion for winter and summer season. LSD (soil profile) = 0.17

	Sack	**P**	**K**	**Na**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**
					mg/g				
Winter	S0	5.019	37.915	0.487	17.538	4.533	0.240	0.257	0.017
	S50	5.007	37.144	0.493	19.854	4.668	0.245	0.263	0.017
	S100	5.139	37.746	0.508	19.903	4.712	0.250	0.263	0.017
	R0	4.622	35.696	0.560	16.630	4.594	0.348	0.263	0.015
	R50	4.689	40.371	0.563	16.839	4.649	0.386	0.271	0.017
	R100	4.842	41.665	0.564	17.200	4.779	0.381	0.274	0.018
	W0	4.929	36.664	0.552	17.461	4.412	0.351	0.263	0.016
	W50	5.145	40.565	0.553	17.535	4.582	0.357	0.264	0.016
	W100	5.330	43.246	0.561	17.630	4.731	0.362	0.266	0.017
	L0	5.055	41.025	0.541	16.382	4.554	0.348	0.276	0.017
	L50	5.117	42.608	0.550	17.155	4.686	0.475	0.275	0.018

	L100	5.406	44.173	0.552	17.436	4.696	0.498	0.280	0.019
	A0	5.547	36.206	0.474	16.262	4.546	0.647	0.266	0.018
	A50	5.543	35.252	0.485	17.362	4.657	0.714	0.271	0.019
	A100	5.654	36.742	0.496	17.861	4.723	0.747	0.276	0.020
Summer	S0	3.159	11.174	0.307	2.410	1.156	1.067	0.051	0.024
	S50	3.059	11.831	0.295	3.203	1.072	0.818	0.048	0.013
	S100	3.040	11.090	0.297	2.359	1.152	0.864	0.056	0.024
	R0	3.074	11.661	0.242	3.446	1.140	0.805	0.035	0.021
	R50	3.149	11.181	0.260	3.316	1.222	0.657	0.047	0.018
	R100	3.378	11.770	0.235	3.355	1.057	0.429	0.026	0.029
	W0	2.846	10.640	0.257	3.533	1.138	0.693	0.037	0.022
	W50	2.974	9.922	0.238	2.356	1.034	1.360	0.038	0.021
	W100	3.154	11.858	0.259	3.454	1.133	0.811	0.032	0.020
	L0	3.056	10.852	0.352	3.504	1.160	1.131	0.060	0.021
	L50	3.025	11.467	0.310	3.277	1.057	1.068	0.031	0.019
	L100	3.069	10.531	0.426	3.417	1.059	1.755	0.140	0.030

A0	2.904	9.708	0.249	2.376	1.070	0.825	0.021	0.023
A50	2.498	10.384	0.330	3.560	1.620	0.833	0.026	0.023
A100	2.427	9.243	0.251	3.523	1.045	1.386	0.053	0.033

Table 4.6: Mineral composition of green pepper for winter and summer season. LSD (soil profile) = 0.05.

	Sack	**P**	**K**	**Na**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**
					mg/g				
Winter	S0	4.543	24.874	0.157	2.053	2.512	0.080	0.036	0.010
	S50	4.947	28.000	0.234	1.591	2.738	0.095	0.036	0.011
	S100	5.273	30.666	0.238	1.573	2.880	0.099	0.043	0.012
	R0	4.655	26.960	0.242	1.479	2.645	0.084	0.032	0.009
	R50	5.375	29.269	0.253	1.877	2.842	0.068	0.051	0.010
	R100	4.970	27.526	0.252	1.249	2.573	0.078	0.044	0.012
	W0	3.039	24.659	0.226	1.508	1.931	0.068	0.033	0.007
	W50	3.343	26.946	0.239	1.486	2.045	0.066	0.034	0.008
	W100	4.281	27.456	0.242	1.644	2.339	0.061	0.047	0.011

L0	4.060	24.510	0.216	1.775	2.537	0.063	0.041	0.009
L50	4.223	27.261	0.247	2.111	2.618	0.065	0.046	0.010
L100	4.426	26.735	0.221	1.435	2.437	0.072	0.046	0.012
A0	4.051	24.478	0.218	1.820	1.938	0.068	0.034	0.008
A50	4.097	26.670	0.227	1.193	2.643	0.073	0.046	0.010
A100	4.142	26.009	0.221	0.565	2.280	0.081	0.047	0.010

Table 4.7: Mineral composition of beetroot leaves for winter and summer. LSD (soil profile) = 0.06.

	Sack	**P**	**K**	**Na**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**
					mg/g				
Winter	S0	4.260	59.337	12.824	14.180	14.924	1.006	1.100	0.128
	S50	4.686	68.074	12.302	13.972	15.340	1.078	1.080	0.133
	S100	4.753	73.657	13.142	16.208	17.031	1.204	1.072	0.138
	R0	4.565	52.669	11.797	15.513	15.531	1.060	0.978	0.126
	R50	4.756	75.098	12.814	16.712	17.286	1.112	1.073	0.134

	R100	4.935	76.638	13.070	18.008	17.029	1.284	1.108	0.138
	W0	4.290	68.701	10.505	14.980	16.657	0.946	0.842	0.130
	W50	4.141	70.077	11.531	16.016	17.133	0.929	0.914	0.130
	W100	4.259	70.427	12.151	16.819	17.151	1.036	0.897	0.134
	L0	4.576	72.584	13.167	16.552	16.614	0.849	0.915	0.132
	L50	4.464	75.522	13.209	16.501	16.599	0.930	0.850	0.131
	L100	4.745	80.033	13.358	17.135	17.188	0.953	0.977	0.135
	A0	4.399	75.451	14.156	14.990	16.245	0.750	0.889	0.132
	A50	4.581	75.568	14.211	15.197	15.989	0.795	0.932	0.132
	A100	4.548	76.966	14.423	15.658	16.609	0.852	0.972	0.134
Summer	S0	13.709	52.828	9.412	7.438	9.579	0.988	0.466	0.211
	S50	25.285	45.788	16.169	15.045	16.649	0.611	1.037	0.237
	S100	24.623	44.543	12.650	12.052	12.447	0.747	0.593	0.231
	R0	26.109	61.553	13.791	12.738	12.955	0.661	0.535	0.225
	R50	25.217	48.036	11.747	12.084	11.630	0.934	0.644	0.269
	R100	32.110	50.879	12.842	11.846	12.512	0.893	0.535	0.150

	W0	18.446	45.378	13.344	13.350	13.217	1.054	0.491	0.302
	W50	21.862	34.332	15.615	15.257	15.245	0.603	0.708	0.230
	W100	9.846	40.507	13.541	11.493	13.141	1.426	0.625	0.186
	L0	14.055	33.298	17.930	12.949	17.606	0.831	0.337	0.141
	L50	14.415	49.621	13.108	11.590	12.955	0.865	0.500	0.126
	L100	15.413	37.526	12.622	11.860	12.938	0.900	0.528	0.132
	A0	20.136	49.859	11.161	10.764	11.321	0.832	0.425	0.167
	A50	19.996	34.252	9.702	13.141	9.799	0.589	0.428	0.056
	A100	16.177	43.463	11.072	11.890	11.255	1.202	0.432	0.153

Table 4.8: Mineral composition of beetroot tuber for winter and summer season. LSD (soil profile) = 1.02.

	Sack	**P**	**K**	**Na**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**
					mg/g				
Winter	S0	4.680	27.423	1.598	2.334	3.397	0.982	0.205	0.074
	S50	5.564	28.231	1.632	2.407	3.547	1.226	0.256	0.070
	S100	7.095	29.286	1.841	2.358	3.892	1.486	0.340	0.106

	R0	3.060	13.055	0.771	1.621	2.517	0.407	0.192	0.051
	R50	4.933	26.328	1.191	1.835	3.035	0.561	0.244	0.061
	R100	5.259	28.007	2.969	1.982	3.175	0.800	0.303	0.070
	W0	6.170	21.224	0.964	1.948	2.904	0.616	0.264	0.064
	W50	6.262	21.883	1.055	2.108	2.976	0.933	0.334	0.075
	W100	6.444	23.169	1.081	3.070	3.621	1.539	0.389	0.088
	L0	4.611	20.885	0.655	2.032	2.736	0.458	0.208	0.052
	L50	5.463	24.228	0.794	2.225	3.114	0.518	0.250	0.063
	L100	6.226	27.880	0.957	2.763	3.183	0.993	0.262	0.077
	A0	4.615	21.979	0.737	1.863	2.379	0.454	0.203	0.054
	A50	4.951	20.993	1.191	1.929	2.876	0.822	0.256	0.063
	A100	5.435	28.945	1.411	2.916	3.576	0.865	0.349	0.084
Summer	S0	4.645	26.370	1.571	1.662	3.921	0.266	0.175	0.126
	S50	4.555	18.193	0.400	1.486	2.505	0.745	0.129	0.075
	S100	4.079	16.027	0.492	1.673	2.719	1.045	0.173	0.083
	R0	4.767	17.659	0.761	1.778	2.869	0.923	0.139	0.116

R50	4.895	19.217	0.736	1.647	2.776	1.178	0.141	0.079
R100	5.047	18.989	0.451	1.645	2.768	0.742	0.152	0.076
W0	6.140	24.843	0.934	1.945	3.520	0.842	0.112	0.097
W50	4.431	18.582	1.201	2.162	3.418	1.754	0.253	0.081
W100	4.388	18.807	1.651	1.686	2.852	1.234	0.182	0.123
L0	3.759	25.626	1.253	1.182	2.066	0.907	0.073	0.065
L50	3.610	23.819	1.063	1.257	2.558	0.923	0.081	0.060
L100	3.733	17.921	0.845	1.432	2.145	1.120	0.111	0.051
A0	3.715	19.726	1.373	1.773	3.360	1.466	0.143	0.082
A50	3.695	15.774	0.746	1.924	3.508	0.862	0.171	0.052
A100	4.094	17.534	0.631	1.576	2.389	1.054	0.141	0.081

Vegetable crops planted on land showed significant differences ($P<0.05$) within and between seasons, winter (W), and summer (S) season (Table 4.9). It was noted that beetroot leaves (BL) had the highest concentration of K (75.79 mg/g), whereas onion (O) had the lowest concentration (14.36 mg/g). Lettuce (L) had a much higher concentration (6.38 mg/g) of P than other crops while green pepper (G.P) had the lowest (3.29 mg/g). Green pepper gave a low Ca concentration (1.05 mg/g) while onion had the highest of (28.16 mg/g). Spinach (S) had a higher concentration of Na (16.52 mg/g) than other crops whereas onion gave the lowest of 0.249 mg/g. Magnesium concentration was higher on beetroot leaves (17.52 mg/g) and lower at green pepper (1.849 mg/g) compared to other crops. Iron, Mn, and Zn were found to be higher on beetroot roots (BR), spinach, and lettuce.

Table 4.9: Mineral composition of vegetables planted on plots in winter (w) and summer (s). [LSD (season) = 5.01; (crops) = 4.3].

	K		**P**		**Ca**		**Na**		**Mg**		**Fe**		**Mn**		**Zn**	
	mg/g															
Crop	w	s	w	s	w	s	w	s	w	s	w	s	w	s	w	s
BL	75.79	41.16	4.44	7.41	5.41	12.1	14.78	15.64	16.05	17.52	0.71	1.86	0.96	0.47	0.13	0.16
BR	25.23	37.06	5.21	5.79	2.25	1.39	2.37	3.09	3.53	3.14	1.36	0.27	0.23	0.05	0.08	0.10
G.P	29.43	33.65	3.29	4.43	1.646	1.05	0.234	0.147	3.551	1.849	0.07	0.71	0.02	0.03	0.00	0.02
L	49.19	46.48	4.48	6.38	10.91	9.67	1.936	1.167	3.471	2.931	0.78	0.64	0.18	0.08	2.30	0.04
O	39.72	14.36	4.97	3.64	28.16	3.02	0.514	0.249	4.746	1.348	0.31	0.48	0.27	0.03	0.01	0.02
S	56.11	63.93	3.76	6.92	15.12	6.34	16.52	14.14	12.04	10.47	1.27	1.13	1.17	0.32	0.22	0.17

4.4. Discussion

In this study, the onion had notable differences of fresh mass for summer and winter, compared to other vegetables. This can be attributed to climatic weather conditions as it was depicted, winter onion experienced cold stress. With the observed weather data during the growing season of the vegetables, the low temperature might have affected the final harvest mass of onion. The proportion of the total incident light intercepted by leaves depends on the area of leaf surface per unit of ground (Brewster, 2008). The indirect effects of weather were observed in plant nutritional values in terms of mineral composition. This observation confirmed previous studies on soil type and fertilizer application (Bozokalfa. et al, 2011). Soil analysis showed a higher concentration of K and Ca in the soil more than other elements, hence plant tissue of vegetables abundant elements was K and Ca with other elements. Onion planted on plots showed higher PAR and LAI during the summer trial leading to a fast rate of photosynthesis as a result bulbing stage was observed before time leading to premature bulbs. Under normal circumstances, onion has a relatively low proportion of incident light interception per unit of the area compared with broader and more horizontal leaves such as leafy vegetables while onion has upright leaves, resulting PAR absorbed by onion crop averaged about 93% of the PAR intercepted (Brewster, 2008). The efficiency with which absorbed light is converted to primary photosynthesis products can be affected by the temperature and water status of the leaves (Brewster, 2008). If leaves are water-stressed to the extent that stomata are closed and diffusive resistance of CO_2 entry is increased, then this too will reduce photosynthetic efficiency (Brewster, 2008). The growth of crops from the ground and on sack was the same (Brewster, 2008).

Low consumption of vegetables is among the top ten risk factors contributing to mortality worldwide (Nishida et al., 2004). The World Health Organization (WHO) recommends that a person should take off more than 400 g of vegetables and fruit per day to protect against diet-related chronic diseases (Nishida et al., 2004). In developing countries including South Africa, diets of the poor are dominated by cereals, having poor nutrition with very little foods of protein, vegetables, and fruit (Nishida et al., 2004). It was noted that in sub-Saharan Africa, consumption of vegetables is below the minimum of 200 kg per person/ year, furthermore, suffering from micronutrient deficiency causes chronic diseases (Nyathi et al., 2019). Humans need a wide selection of essential nutrients for normal growth and development (Nyathi et al., 2019). To enhance the intake of micro and macronutrients urban people either used supplements such as pills or processed foods to increase intake (Davey et al., 2009).

This health information is relevant in the current study. The selected vegetables were found to be good sources of P, K, Ca, Mg, Na, Fe, Mn, and Zn. These vegetables are considered a good source of macro and micronutrients (Hussain et al., 2011). Nutrition determines the health of a human being and there is increasing evidence suggesting that diets rich in phytochemicals of fruits and vegetables may prevent a wide range of diseases (Rikitu et al., 2019). According to Abou-Hussein (2012), fresh fruits and vegetables assist with several biologically important components to the human organism, hence they are essential for a healthy and well-balanced diet. Mampa et al. (2017) reported that beetroot had high levels of Fe (1.680-2.882 mg/kg) and Zn (22.57-27.64 mg/kg). This was confirmed with data including other minerals (Straus et al., 2016), when it was found that P (2-2.6 g/kg), K (28.6-36.6 g/kg), Ca (1.4-1.5 g/kg), Mg (1.9-2.3 g/kg), Na (1.8-3.2 g/kg), Fe (189.1-2.52.5 mg/kg), Mn (94.4-133.5 mg/kg) and Zn (56.3-63.5 mg/kg) also occurred in good concentrations. The current study found mineral ranges: P (3.060-6.444 mg/g), K (13.055-37.08 mg/g), Na (0.400-3.09 mg/g), Ca (1.621-3.070 mg/g), Mg (2.066-3.921 mg/g), Fe (0.266-1.754 mg/g), Mn (0.073-0.389 mg/g) and Zn (0.051-0.123 mg/g). The current study found beetroot leaves had mineral ranges as follows: P (4.141-25.285 mg/g), K (33.298-80.033 mg/g), Na (9.412-17.930 mg/g), Ca (7.438-18.008 mg/g), Mg (9.579-17.606 mg/g) Fe (0.606-1.426 mg/g), Mn (0.337-1.108 mg/g) and Zn (0.126-0.302 mg/g)

An earlier study (Edet et al., 2015) found that Na (16.15 mg), K (185.05 mg), P (19.24 mg), Ca (375.15 mg), Fe (2.60 mg), (232.05 mg), and Mn (213.65 mg) are very common in a wide range of vegetables specific onion. Other studies found onion mineral content as follows Ca (47mg), P (50 mg), and Fe (0.7 mg) (Kumar et al., 2010). The current study revealed the onion range as P (2.427-5.654 mg/g), K (9.243-44.173 mg/g), Na (0.474-0.564 mg/g), Ca (2.356-19.903 mg/g), Mg (1.034-4.779), Fe (0.240-1.755), Mn (0.021-0.280 mg/g) and Zn (0.013-0.033 mg/g). This suggests that onion can contribute a meaningful amount of dietary Ca to enhance structural function, energy provision, osmotic regulation and, catalytic functions (Edet et al., 2015). The recommended daily allowance for phosphorus is in the range of 400 to1200 mg/100 g Na is 500 mg, and Fe is 10 to 15 mg for onion (Edet et al., 2015).

In the current study, mineral content in lettuce ranged from P (2.927-7.886 mg/g), K (26.938-77.808 mg/g), Na (0.664-1.811 mg/g), Ca (7.701-17.992 mg/g), Mg (2.884-6.429 mg/g), Fe (0.546-9.148 mg/g), Mn (0.08-0.714 mg/g) Zn (0.013-0.147 mg/g). Previous studies that have conducted evaluating minerals nutrient composition of lettuce including Kim et al., 2016 found that Na (0.8-28 mg/g), Zn (30-46 µg/g), Fe (59.9-112.4 µg/g), Ca (4.1-20.6 mg/g), P (4-6 mg/g) and K (53.7-87.6 mg/g). The variation of results from both studies can be due to heterogeneous growing media, conditions and cultivar but the ranges are within the FAO/WHO recommendation for adult: Na (1.2-1.5 g/day), P (700 mg/day), Mg (310-420 mg/day), Fe (8-18 mg/day), Zn (8-11 mg/day) and Na (1.2-1.5 g/day). Green pepper minerals ranged: P (3.039-5.375 mg/g), K (24.478-30.666 mg/g), Na (0.157-0.253 mg/g), Ca (0.565-2.111 mg/g), Mg (1.931-2.880 mg/g), Fe (0.061-0.099 mg/g), Mn (0.032-0.051 mg/g) and Zn (0.007-0.012 mg/g) from this study. An earlier study (Hanif et al., 2006) found in green pepper Ca (12 mg/100g), P (30 mg/100g), Na (5 mg/100g), K (12 mg/100g) and Fe (1 mg/100g).

Leafy vegetables play a considerable role in the human diet and their consumption increases every day because they contain significant nutritional sources and minerals (Bazokalfa. et al, 2011). Spinach mineral composition from the present study ranged from P (2.094-21.966 mg/g), K (44.941-81.940 mg/g), Na (6.542-17.381 mg/g), Ca (6.495-20.585 mg/g), Mg (7.565-23.788 mg/g), Fe (0.119-1.480 mg/g), Mn (0.336-1.764 mg/g) and Zn (0.074-0.645 mg/g). An earlier study (Kawashima and Soares, 2003) revealed that fresh leaves of spinach mineral ranged as K (537 mg), Na (94 mg), Ca (64 mg), Mg (55 mg), Fe (1 mg), Mn (1 mg) and Zn (0.3 mg). Consumption of green leafy vegetables is increasingly becoming crucial even for the poor as a cheap alternative to supplementary medication. Thus, the growing number of diseases can be countered through food security (Limantara et al., 2015). This information, together with relevant social and economic studies, would be useful for government policy interventions.

4.5 Conclusion

It was found that mineral composition in all the selected vegetables was different with no constant pattern for the concentration of elements, vegetables were rich in some minerals such as Ca, K, and were poor in Zn and Mn. From this study, it was found that vegetable consumption in different combinations is essential for the maintenance of healthy life and normal body functioning because it brings the variation of minerals altogether. Overall, 100% fertilizer level showed the highest concentration of minerals in all crops, but the best performing soil profiles were W100 and S100 throughout the study.

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5. GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Concluding remarks

Biodegradable bags are suitable for vegetable production under conditions of limited space for normal cultivation because they are movable. This study showed that the extra advantage of this option may be the usefulness of alternative growth media together with limited soil. Vegetable production was successful, whether soil only was used or soil was used as a separate layer of a created profile. The soil had the advantage of being able to absorb retain water and nutrients for longer periods than other artificial profiles of layers. That is why the highest yield of biomass and mineral nutrient content was consistently higher in soil with the optimum level of recommended fertilizer. However, it is encouraging that, even when the soil was combined with a layer that has low levels of decomposition, some yield was obtained in both summer and winter. This suggests that poor producers can use organic material in their environment for a measurable contribution to their subsistence needs.

The growth, development, and mineral content of onion, beetroot, spinach, green pepper, and lettuce that grew directly from the ground was almost the same. Therefore there was an insignificant difference between the crops from a sack and the ground. Additionally, it was found easy to maintain sack unlike the old traditional system require more labour.

The occurrence of urbanization seems to be taking all the vacant land, and introducing innovative strategies like containerized production of vegetables seems to have the potential to combating hunger for poor urban dwellers.

5.2 Recommendations

The following recommendations may be made based on the findings obtained during the study to enhance and promote containerized production;

- Selecting the right vegetables is crucial, hence leafy vegetables are more favourable for containerized production. Minimal cultivation of root and bulb vegetables is recommended.

- Research on the use of other organic materials to fill up sacks to improve the growth, development, and yield of vegetables should be considered. In this research sack that had organic material had improved organic carbon and clay at harvest.
- The results of this study could be combined with evidence from socio-economic studies to influence government policy in terms of food security interventions for the urban and peri-urban areas.