GROWTH OF *TETRAGONIA DECUMBENS* (DUNE SPINACH) IN RESPONSE TO DIFFERENT PH AND ELECTRICAL CONDUCTIVITY LEVELS IN HYDROPONICS

By

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DECLARATION

I, Milile Nkcukankcuka, declare that the contents of this dissertation/thesis represent my unaided work and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

GENERAL ABSTRACT

The purpose of this research was to examine the growth of *Tetragonia decumbens* Mill. in hydroponics. A mother plant of *T. decumbens* was obtained from Assegaaibosch nursery in the south Western Cape province of South Africa. One hundred and eight plants were generated from the mother plant and cultivated in hydroponic system over 7 weeks. Four treatments were estimated with 9 sample replicates. Each treatment comprised of (silica sand) a soilless growing medium which was tested in aggregation with, 2 L head submersible pump. An analogue timer was used to control irrigation frequencies for all systems as follows: 2 ℓ/h for 15 minutes from 9 am - 5 pm at an intermission break of two hours during irrigation. Chapter 1 highlights relevant literature on research on leafy vegetables, food security, climate change, and hydroponics. It introduces empirical situations in which the research theme manifests itself. It defines the problems that need to be addressed and current gaps in scientific literature and research regarding *T. decumbens*. The chapter also delivers the rationale of the experiment and provides the aims and objectives of the study. Furthermore, it serves as an introduction to the research methods and procedures and scientific orientation concerning the research theme. It indicates the methods suitable for data collection and analysis.

In chapter 2 the importance of *T. decumbens* and its availability as a traditional leafy vegetable was reviewed. It was found that *T. decumbens* has clear edible parts, recognized for its high nutritional value and drought-resistant traits and function in stabilizing dunes. Chapter 3 describes the growth characteristics of *T. decumbens* under various treatments and significant effects in terms of shoot growth, wet weight, and dry weight. Treatment 1 (T1) showed the highest individual mean value for vegetative growth, while the average from the T2-T3 displayed the highest average value. The lowest individual value for root growth was observed in the control. Overall treatments with nutrient application in hydroponics had improved shoot growth, while the control, T2-T3 showed sub-optimal root growth. For wet weight and dry weight, the highest individual mean value was found in treatment 1, while the highest average value was observed in T2 and T3.

Chapter 4 discusses the nutrient uptake of *T. decumbens* under different fertigation treatments. The control consisted of 100% Silica sand with no nutrients; Treatment 1 (T1) - 100% Silica with 140g NPK /70 L; Treatment 2 (T2) - 100% Silica with 70g NPK/70 L; and Treatment 3 (T3) made of 100% Silica with 35g NPK /70 L, each of which was run for 2 hours every week at a pH range of 5.5 to 6.5. Post-harvest findings from the study showed that fertigation did not cause significant variability in the macronutrient concentrations of the species. However, micronutrient content was significantly affected.

Chapter 5 discusses the estimation of chlorophyll production levels in the leaves of *T. decumbens*. Findings from this research show that fertigation regimes did not have a significant effect on the chlorophyll contents measured in leaves from week 1 to week 4 except in week 3 when a slight variability occurred. At week 3, the highest chlorophyll was recorded in T1 while T2 and T3 showed an equivalent chlorophyll content.

Chapter 6 concludes the study with an urgent need in South Africa for more research into the commercial cultivation of wild species and an investigation into optimal propagation and growth requirements. Many stakeholders are re-kindling interest in the culinary use of Cape wild food plants. *T. decumbens*, has been revealed with phytonutrients that compare with or higher than most popular leafy vegetables present and are sourced for food security by as an alternative source of plant-based nutrients. Further studies would be required to investigate various growth substrates and, various fertigation regimes and how *T. decumbens* responds to these variables to further establish an optimal protocol for the cultivation of the plant in hydroponics.

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DEDICATION

This work is dedicated:

I dedicate this work to my late father Mbuyiseli Nkcukankcuka, mother Noncedisile Nkcukankcuka, and brother Sada-Saphiwa Nkcukankcuka as well as to Kwakhanya Likhakha Nkcukankcuka and my dear brother Seyiso Nkcukankcuka, I thank you them for their love, patience, and prayers through my academic career.

STRUCTURE OF THE THESIS

The thesis is drafted differently to the alternative of a traditional format for a thesis. The article-format thesis examples of published, co-published and/or "ready-for-publication" articles were prepared during candidature and applies to the format prescribed by CPUT for 100% master's studies which complies with the following guidelines:

1. The overriding principle of the thesis is that it remains an original contribution to the discipline or field by the candidate.

2. Chapters containing the journal articles form a coherent and integrated body of work, which focused on a single project or set of related questions or propositions. All journal articles form part of the sustained thesis with a coherent theme.

3. The study does not include work published prior to commencement of the candidature.

4. The number of articles included depending on the content and length of each article and take full account of the university's requirements for the degree as well as the one article already published or "ready-for-publication" expected for a master's degree in this discipline.

5. The thesis should be examined in the normal way and according to the normal requirements as set out by the "Guidelines for Examiners of Dissertations and Theses" (using form HDC 1.7).

The thesis consists of the following chapters, which are concisely discussed as:

Chapter One: This chapter provides the significance of the research, its aim and the overall list of specific objectives, which guided the study.

Chapter Two: This chapter provides insight on the potential of *T. decumbens* **(**Dune spinach) as a wild leafy green vegetable. It also highlights aspects of food security, prospects and potentials in hydroponically grown *T. decumbens* Mill.

Chapter Three: This chapter evaluated the vegetative growth responses of *T. decumbens* Mill. to different fertigation regimes in a hydroponic culture system. The research justification, materials and methods, results and discussions are presented.

Chapter Four: This chapter evaluated the effect of nutrient uptake of *T. decumbens* Mill. under different fertigation regimes in a hydroponic culture system. The research justification, materials and methods, results and discussions are presented.

Chapter Five: This chapter evaluated chlorophyll production levels in the leaves of *T. decumbens* Mill. The research justification, materials and methods, results and discussions are presented.

Chapter Six: General discussion, conclusions and recommendations.
This chapter deals with the general discussion, which connects the previous chapters and is followed by the conclusions of the study. Recommendations are made for further work; to introduce future research topics.

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ABBREVIATION AND ACRONYMS

WEP	Wild edible plants
TLVs	Traditional leafy vegetables
N	Nitrogen
P	Phosphorus
K	Potassium
NFT	Nutritional film technique
LECA	Lightweight expanded clay
DWC	Deep water culture
EC	Electronic conductivity
FAO	Food and Agriculture Organization
WC	Western Cape
Ca	Calcium
S	Sulfur
Mg	Magnesium
B	Boron
Cl	Chlorine
Mn	Manganese
Fe	Iron
Zn	Zinc
Cu	Copper
Mo	Molybdenum
Ni	Nickel
UN	United Nations
NO3	Nitrate

MS.cm-1	The SI unit of conductivity is Siemens per meter (S/m).
NH4	Ammonium
NH3	Ammonia
WHO	World Health Organization
HCl	Hydrogen chloride
L/h	Litres per hour
ANOVA	Analysis of Variance
°C	degrees Celsius
CPUT	Cape Peninsula University of Technology
SSA	Sub-Saharan Africa

CHAPTER ONE:

THE PROBLEM STATEMENT, AIMS, HYPOTHESIS, AND OBJECTIVES

Introduction, research problem, the background to the research, aims, hypothesis, and objectives

1.1 Statement of the research

For centuries, indigenous leafy vegetables have sustained rural communities in many parts of the world (Jansen van Rensburg, 2009; Dweba & Mearns, 2011). Typically, indigenous leafy vegetables have several advantages over their exotic counterparts, including superior adaptation to local environmental conditions and limited requirements for expensive external inputs, such as irrigation and agrochemicals (Hart *et al.,* 2017). However, with ample research done on the cultivation practices of these crops, limited information is available on production systems, including optimum plant and harvest times, spacing, propagation, and harvesting methodology (Araya *et al.,* 2020).

Wild and edible plant species mainly consist of leafy green vegetables however they may also be consumed as pickles, fruits, sweets, and spices, and drunk as cold and hot drinks (Dogan *et al.,* 2016). The consumption of vegetables is common, while their cultivation is very rare compared to fully domesticated species (Mncwango *et al.,* 2020). Compared to domestic food sources, wild plant foods tend to be neglected. However, there is considerable evidence that wild edible food is important in terms of the global food basket. Moreover, wild edible plants (WEP) are available for free in natural habitats and indigenous people know how to collect and prepare them (Lulekal *et al.,* 2011).

Wild edible plants play an important role in modern societies, as they are more resilient food systems, sustainable food choices, consumable, and environmentally friendly, social well-being, food sovereignty, and nutritional (Bvenura & Sivakumar, 2017; Borelli *et al*., 2020). For *T*. *decumbens* to live up to these claims, some challenges to its consumable and cultivation will have to be bypassed (Tembo-Phiri, 2019). There is also limited information on the effect of pH and electric conductivity on the growth of *T*. *decumbens* in hydroponics. This study was designed to address this gap by providing sufficient information on the cultivation of the plant in hydroponic systems. *T. decumbens* is one of many leafy vegetables in South Africa's Western Cape region with the potential to grow by using minimal water and no chemical additives. Cultivating *T. decumbens* in hydroponics could provide a source of nutritious, sustainable, inexpensive, and timeously delivered food for people faced with dietetic challenges that include hidden hunger, food insecurity as well as malnutrition (Lindow, 2017).

1.2 Research problem background

The agricultural sector faces some key challenges such as climate change, increasing human population growth, improved incomes, and shifting dietary patterns leading to increasing demand for food and other agricultural products (Izac & Sanchez, 2001; Masud *et al*., 2017). At the same time, however, the natural resource base sustaining agricultural production is under threat, with growing pressures on genetic diversity and degradation of land and water resources (Rasul, 2016). Agriculture improves food security in many ways not only by increasing the variety and availability of food but also by providing the means to purchase food (Nchuchuwe & Adejuwon, 2012). In South Africa, agriculture is an integral part of the economy with the revitalization strategies and resilience to minimizing poverty while solving food problems and nutritional scarcity in an ever-growing society (Mugambiwa & Tirivangasi, 2017). For instance, within the Limpopo Province, the agricultural sector is a crucial source of employment for rural people and it plays a major role in the reduction of poverty, unemployment, and food insecurity (Baloyi, 2010; Grany *et al.,* 2018). Being a reliable source of income for smallholder farmers, farmworkers, and street vendors, agriculture is an engine of the economic process. However, increasing demand for farm products with existing farming practices are likely to lead to more intense consumption of natural resources, increased greenhouse gas emissions, and further deforestation and land degradation (Sparovek *et al.,* 2012).

Gabiri, (2019) highlighted that with the continued population growth and related developments, water resources are becoming increasingly scarce in a growing number of countries and regions in the world. Against this background, studies concerning water scarcity, food security, and virtual water trade have flourished in recent years (Liu *et al*., 2019). The efforts have greatly helped the understanding of water and food challenges and provided useful information for formulating national and international policies to deal with them appropriately (Yang *et al.,* 2006).

Moreover, Garrity *et al*. (2010) and Maxwell (1999) agree that climate change portends a threat to food security in the world, considering the forecasted increase in population. Likewise, findings by Grivetti and Ogle (2000), confirmed that global agriculture focuses on several wild edible species although it was only in the 21st century that scientists, mostly plant enthusiasts decided to research most of the edible species. Previously, the botanical, nutritional, and social science literature had listed the use of such plants in the supply of important micronutrients and energy under a wide range of conditions. However, some researchers and health professionals who were interested in traditional medicines frequently neglected the important role of wild plant species in traditional healthcare systems and focused only on bioactive substances and medicinal plants. This approach must be revisited since many species were used as both medicines and foods (Grivetti & Ogle 2000; Mondi *et al.,* 2006; Ju *et al.*, 2013; Anywar *et al.*, 2014).

According to Wu and Kubota (2008), the growing demand for vegetables and fruits comprising bioactive compounds has been a main public health concern for many centuries. Resh (2013), recommends hydroponic systems of cultivation for countries with a large population but limited arable land. Growing plants in hydroponics have numerous advantages, which include a reduced growing period from seed germination to maturity (Teto *et al*., 2016; Faber *et al.*, 2020). The root structure of the plants is protected from damages that prevent them from regenerating into a new plant. Also, hydroponic cultivation maximizes space utilization effectively throughout the growth cycle (Conn *et al., 2013*).

Therefore, it is imperative to investigate the growth of *T*. *decumbens* in response to different fertigation regimes in hydroponics develop a growth protocol for growing the halophytic species in hydroponics for the use of horticulture and agro-based industries in order to reduce the level of food security.

1.3 Aims

To assess the growth response of *T. ducumbens* from data collected from sub-objectives 1-5 to initiate a growth procedure for cultivating the plant in hydroponics.

1.4 Hypothesis

Results obtained will be useful in determining how different fertigation regimes have affected the growth of the species in hydroponics and establish the best treatment for optimal growth of *T. ducumbens*.

1.5 Objective of the research

1.5.1 Main Objective

To establish a growth protocol for the cultivation of *T*. *decumbens* in hydroponics under different pH and electrical conductivity levels.

1.5.2 Specific objectives

1. To develop a growth protocol for the assessment of the number of leaves in *T. decumbens* shoots under different fertigation regimes in hydroponics.

2. To assess the fresh and dry mass of *T. decumbens* in response to different fertigation regimes in hydroponics.

3. To examine the variability in the pre-planting and post-harvest shoot to root ratio of *T. decumbens* as influenced by variations in different fertigation regimes

4. To measure nutrient uptake (Nitrogen, Phosphorus, and Potassium) of *T. decumbens* in response to different fertigation regimes in hydroponics.

5. To establish a hydroponic protocol for the assessment and estimation of chlorophyll production levels in the leaves of *T. decumbens* under varying fertigation regimes.

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1.7 References

Anywar, G., Oryem-Origa, H. & Mugisha, M.K. 2014. Wild Plants Used as Nutraceuticalsfrom Nebbi District, Uganda. *European Journal of Medicinal Plants*, 4(6): 641–660.

Araya, H., Amoo, S., Laurie, R., Seetseng, K., Ibraimo, N., Masemola, C., Mamadi, N., Mndzebele, B., Ramusandiwa, T. & Lebese, J. 2020. Indigenous / Traditional African Leafy Vegetables. *Agricultural Research Council*. https://www.arc.agric.za/arc-vopi/Pages/Crop Science/Indigenous-Crops.aspx [22 November 2020].

Baloyi, J.K. 2010. *An analysis of constraints facing smallholder farmers in the Agribusiness value chain: A case study of farmers in the Limpopo Province* (Doctoral dissertation, University of Pretoria).

Borelli, T., Hunter, D., Padulosi, S., Amaya, N., Meldrum, G., Beltrame, D.M.D.O., Samarasinghe, G., Wasike, V.W., Güner, B., Tan, A. & Koreissi Dembélé, Y. 2020. Local solutions for sustainable food systems: The contribution of orphan crops and wild edible species. *Agronomy*, 10(2): 231.

Bvenura, C. & Sivakumar, D. 2017. The role of wild fruits and vegetables in delivering a balanced and healthy diet. *Food Research International*, 99: 15–30. http://dx.doi.org/10.1016/j.foodres.2017.06.046.

Conn, S.J., Bradleigh, H., Dayod, M., Athman, A., Henderson, S., Aukett, L., Conn, V., Shearer, M. K., Fuentes, S., Tyerman, S. D. & Gilliham, M. 2013. Protocol: optimizing hydroponic growth systems for nutritional and physiological analysis of Arabidopsis thaliana and other plants. *Plant Methods* 9: 4.

Dogan, Y. 2016. Wild edible plants: from the past to the future. *Austin Food Science Journal*, 1(2): 1006.

Dweba, T.P. & Mearns, M.A. 2011. Conservation indigenous knowledge as the key to the current and future use of traditional vegetables. *International Journal of Information Management* 31(6): 564–571.

Faber, R.J., Laubscher, C.P., Rautenbach, F. & Jimoh, M.O. 2020. Variabilities in alkaloid concentration of Sceletium tortuosum (L .) N . E . Br in response to different soilless growing media and fertigation regimes in hydroponics. *Heliyon*, 6: e05479. https://doi.org/10.1016/j.heliyon.2020.e05479.

Gabiri, G. 2019. *Multi-scale modeling of water resources in a tropical inland valley and a tropical floodplain catchment in East Africa*. Universitäts- und Landesbibliothek Bonn. https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/7871 [22 November 2020].

Garrity, D.P., Akinnifesi, F.K., Ajayi, O.C., Weldesemayat, S.G., Mowo, J.G., Kalinganire, A., & Bayala, J. 2010. Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security,* 2(3):197–214.

Grivetti, L.E., & Ogle, B.M. 2000. Value of traditional foods in meeting macro and micronutrient needs: *The Wild Plant Connection*, 13: 31–46.

Hart, T., Vorster, H.J., Hart, T.G.B. & Vorster, H.J. 2007. African Indigenous Knowledge Systems in Agricultural Production. Department of Science and Technology, South Africa.

Izac, A.M.N. & Sanchez, P.A. 2001. Towards a natural resource management paradigm for international agriculture: The example of agroforestry research. *Agricultural Systems*, 69(1–2): 5–25.

Jansen van Rensburg, W.S., van Averbeke, W. Slabbert, R., Faber, M., van Jaarsveld, P., van Heerden, I., Wenhold, F. & Oelofse, A. 2009. African leafy vegetables in South Africa. *Water South Africa,* 33(3): 317-326.

Ju, Y., Zhuo, J., Liu, B. & Long, C. 2013. Eating from the wild: Diversity of wild edible plants used by Tibetans in Shangri-la region, Yunnan, China. *Journal of Ethnobiology and Ethnomedicine*, 9(1): 28. DOI: 10.1186/1746-4269-9-28

Lindow, M. 2017. Rediscovering local wild food in South Africa's Western Cape. *Re.Think*. https://rethink.earth/rediscovering-local-wild-food-in-South-Africas-Western-Cape/ [22 November 2020].

Liu, W., Antonelli, M., Kummu, M., Zhao, X., Wu, P., Liu, J., Zhuo, L. & Yang, H. 2019. Savings and losses of global water resources in food-related virtual water trade. *Wiley Interdisciplinary Reviews: Water*, 6(1):e1320.

Lulekal, E., Asfaw, Z., Kelbessa, E. & Van Damme, P. 2011. Wild edible plants in Ethiopia: a review on their potential to combat food insecurity. *Afrika Focus* 24(2): 71–121.

Masud, M.M., Azam, M.N., Mohiuddin, M., Banna, H., Akhtar, R., Alam, A.S.A.F. & Begum, H. 2017. Adaptation barriers and strategies towards climate change: Challenges in the agricultural sector. *Journal of Cleaner Production*, 156: 698–706.

Maxwell, D. 1999. The Political Economy of Urban Food Security in Sub-Saharan Africa. *World Development,* 27(11): 1939 –1953.

Mncwango, N.C., Mavengahama, S., Ntuli., & van Jaarsveld, C.M. 2020. Diversity, consumption dynamics, and ethnomedical claims of traditional leafy vegetables consumed by a rural community in the KwaMbonambi area, northern KwaZulu-Natal, South Africa. *Journal of Biological Diversity,* 21(3): 1201–1207.

Modi, M., Modi, A. & Hendriks, S. (2006). Potential role for wild vegetables in household food security: a preliminary case study in Kwazulu-Natal, South Africa. *African Journal of Food, Agriculture, Nutrition and Development,* 6(1): 1–13.

Mugambiwa, S.S. & Tirivangasi, H.M. 2017. Climate change: A threat towards achieving 'sustainable development goal number two' (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. *Jamba: Journal of Disaster Risk Studies*, 9(1): 1–6.

Nchuchuwe, F.F. & Adejuwon, K.D. 2012. The Challenges of Agriculture and Rural Development in Africa : The case of Nigeria. *International Journal of Academic Research in Progressive Education and Development*, 1(3): 45–61.

Rasul, G. 2016. Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environmental Development*, 18: 14–25. http://dx.doi.org/10.1016/j.envdev.2015.12.001.

Senyolo, G.M., Wale, E. & Ortmann, G.F. 2018. Analysing the value chain for African leafy vegetables in Limpopo Province, South Africa, *Cogent Social Sciences*, 4(1): 1509417.

Tembo-Phiri, C. 2019. *Edible Fynbos Plants: A Soil types and irrigation regime investigation on Tetragonia decumbens and Mesembryanthemum crystallinum*. Stellenbosch University. http://scholar.sun.ac.za/handle/10019.1/105974.

Teto, A.A., Laubscher, C.P., Ndakidemi, P.A. & Matimati, I. 2016. Paclobutrazol retards vegetative growth in hydroponically-cultured Leonotis leonurus (L.) R.Br. Lamiaceae for a multipurpose flowering potted plant. *South African Journal of Botany*, 106: 67–70. http://dx.doi.org/10.1016/j.sajb.2016.05.012.

Resh, H.J. 2013. *Hydroponic Food Production.* A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower, 7th Edition, CRC Press.

Sparovek, G., Berndes, G., Barretto, A.G.D.O.P.& Klug, I.L.F. 2012. The revision of the Brazilian Forest Act: increased deforestation or a historic step towards balancing agricultural development and nature conservation? *Environmental Science & Policy*, *16*: 65–72.

Wu, M. & Kubota, C. 2008. Effects of electrical conductivity of hydroponic nutrient solution on leaf gas exchange of five greenhouse tomato cultivars. *HortTechnology*, 18(2):.271–277

Yang, H., Wang, L., Abbaspour, K.C. & Zehnder, A.J.B. 2006. Virtual water highway: Water use efficiency in global food trade. *Hydrology and Earth System Sciences Discussions*, 3: 1–26.

CHAPTER TWO:

FOOD SECURITY: PROSPECTS AND POTENTIALS IN HYDROPONICALLY GROWN *TETRAGONIA DECUMBENS* MILL.: A REVIEW

Food security: Prospects and potentials in hydroponically grown *Tetragonia decumbens* Mill.: A review

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2.1 Abstract

Tetragonia decumbens, commonly known as duinespinasie (Afr.) or dune spinach (Eng) is a species under Aizoaceae. The species is native to the winter rainfall coastline of South Africa where it grows close to the seawater edge in poor nutrient sands. It has adapted as a resilient species with low water requirements and adapted to coastal sea spray. The species is an under-utilized wild leafy green vegetable that shows great promise as an edible food crop or even possible animal fodder. It has never been cultivated commercially but is being piloted for possible commercial cultivation at a community garden in Khayelitsha, Cape Town, along with other potential winter rainfall crops. Records show that it was used as a food crop by Koi-san people who lived along the Cape coast historically. There is however a growing group of chefs, food innovators, gardens, community farmers, and local knowledge holders who are re-kindling interest in the culinary use of Cape wild food plants. This review explores the species interest as a new edible leafy green vegetable and raises the need to develop cultivation protocols especially in hydroponics to improve its future growth potential.

Keywords: Aizoaeace, food security, hydroponics, climate change, dune spinach

2.2 Introduction

A cornerstone approach to alleviating food insecurity and ill-health in developing countries is increased food production (Misselhorn *et al*., 2012). Across the world, at least one in seven people is faced with the challenges of chronic hunger. The situation is worse in developing countries particularly in sub-Saharan Africa where cases of malnutrition, hunger, and food insecurity are more prevalent (Mugambiwa & Tirivangasi, 2017). However, various food-related studies conducted over the last few decades indicate that food consumption shifts in South Africa have been towards a more western-orientated diet, with nutritional consequences contributing to increased obesity, stunted growth in children, and other non-communicable diseases (Misselhorn, 2005; Ronquest-Ross *et al*., 2015). Central to this problem is institutional fragmentation and poor sectoral coordination that has stalled crop diversity and anticipated growth in the agricultural sector, leading to avoidable abuse of natural resources that support life (Rasul, 2016). The impacts of climate change on food security have so far been extensively examined with the effects on plant productivity and therefore on food production (Gregory *et al*., 2005).

Food security will continue to be a global problem for the next coming 50 years or longer. This can be attributed to the failures of various economic development policies. Available data shows that the world is producing sufficient food to an extent that some agricultural products are rotting away. However, low-income earners are denied access to agricultural products of their choice due to volatile prices thereby subjecting millions of vulnerable populations to hunger and malnutrition (Alexandratos, 1999; Charles *et al*., 2014). In many regions, crop yields have recently declined due to lower investment in research and infrastructure and increasing water scarcity. Climate change is also an important factor for food insecurity in many regions. While agricultural approaches promise to improve yields, food security in developing countries can be significantly improved through increased investment and political reform (Rosegrant & Cline, 2003; Fischer *et al*., 2014).

Leafy vegetables are critical to mitigating food insecurity in South Africa and the world at large. Wild edible plants are available locally and are relatively inexpensive in low-income areas. Many plants are said to be adapted to different conditions, including arid land. Since several plant species grow on their own in the wild, information about their cultivation is limited in available literature. (Maseko *et al*., 2018). The ethnobotanical uses of leafy vegetables in native communities have been documented in many reports while in some instances, concerns were raised about the lack of knowledge of these plants (van Rensburg *et al*., 2007).

However, information on production rates of leafy vegetables is limited as data on the per capita consumption. The introduction of exotic species is thought to be a major contributing factor to low production and underutilization of these vegetables and only recently, this fact was being recognized by researchers (Venter *et al*., 2007). These reports provide at best only a sight into the consumption patterns of leafy vegetables on the sub-continent but the information provided is very limited and so should be interpreted with caution and should not be considered as baseline information for the respective countries or regions (Smith & Eyzaguirre, 2007). The ability to recognize leafy vegetables in the environment subject to extremely high temperature or irregular rainfall particularly, at times when regular provisions of food items are limited is on-going (Grivetti & Ogle, 2000).

Tetragonia decumbens is a water-wise within Aizoaceae family. It is endemic to the coastline of South Africa receiving winter rainfall, stretching from the borders in the coastal part of the Western Cape to east of the Kei River. Though this plant is not at risk of extinction, it is a greatly underutilized vegetable that shows great promise as an undemanding resilient winter crop. It has never been cultivated commercially but is being piloted for possible commercial cultivation at a community garden in Khayelitsha, Cape Town, along with other potential winter rainfall crops (Hoare *et al*., 2006). This review seeks to encourage low-income earners to patronize this underutilized vegetable and to explore exciting prospects in the cultivation of *T*. *decumbens* for commercial purposes and to mitigate hidden hunger, malnutrition, and poverty ravaging developing countries and advanced economies. This study will also advance further research to investigate the growth of Dune Spinach in response to fertigation regimes in hydroponics to generate a growth protocol for the species to support cultivation of *T. decumbens* for small-hold farmers, and communities with a limited source of freshwater.

2.3 Aizoaceae Family

Aizoaceae are herbaceous small annual or perennial succulent plants, except for one species, *Stoeberia arborescens*, which is shrubby, up to 3.5 m tall. Their roots are fibrous, more rarely tuberous, while stems can be underground, often erect or prostrate and lurking. Fruits are sometimes septicidal, winged nut, or horn-shaped, and most times loculicidal (Willert *et al*., 1984; Rundel *et al*., 1999; Tembo-Phiri, 2019). Largely, a few Aizoaceae species such as *Lithops, Conophutum, Pleiospilos*, and many *Mesembryanthemum* are of ornamental interest (Kellner *et al*., 2011; Klak *et al*., 2017). However, the fruit of some, including *Carpobrous edulis* is edible while the leaves of *Tetragona* is edible. Aizoaceae are divided into five subfamilies Sequoioideae, Tetragonioides, Molluginaceae Mesembryanthemoideae, and the Ruschioideae (Valente *et al*., 2014). The family is concentrated in southern Africa (Figure 2.1) in the Greater Cape Floristic Region or Succulent Karoo where much diversity of Aizoaceae is found, but a few pan-tropical species extend to the West Indies, southwestern parts of North America, Florida, South America, and Australia (Born *et al*., 2007; Mulder, 2003; Soliman *et al*., 2017; Gray, 1997; Klak *et al*., 2017).

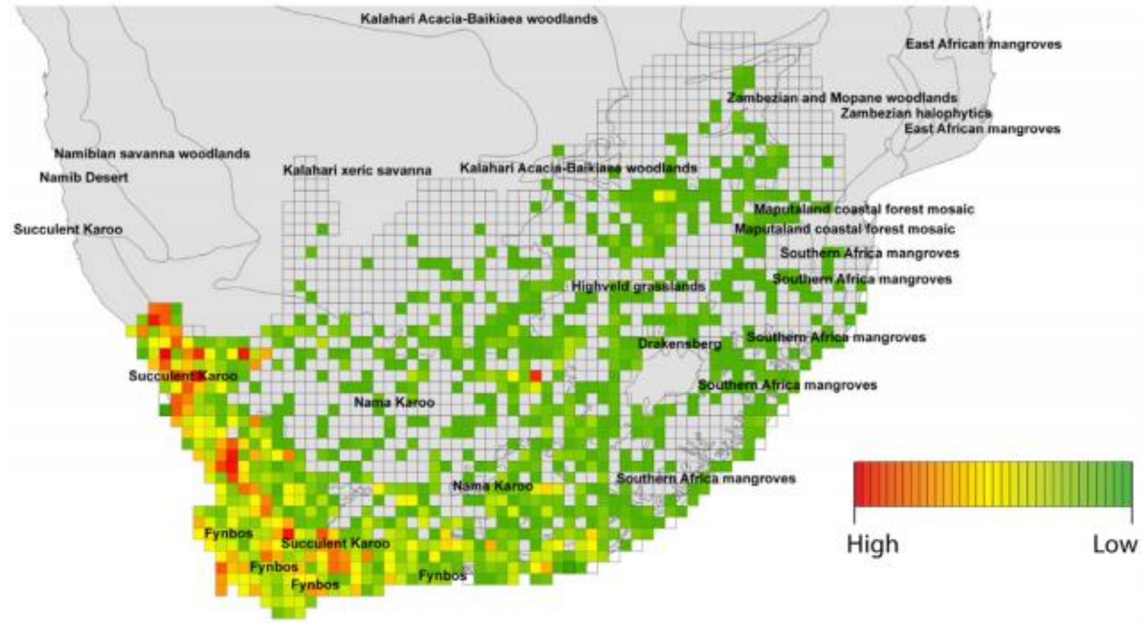

Figure 2.1 The map showing the distribution of ice plant family (Aizoaceae) (Source: Tembo-Phiri, 2019)

2.3.1 The genus *Tetragonia* (Mill)

Tetragonia decumbens Mill. is the only species that is decumbent, as it is characterized by stems, woody at the base, and rather rigid, long roots and runners with hairy leaves and yellow flowers survive dry summer months and re-sprouts when exposed to water (Forrester, 2004; Tembo-Phiri, 2019). It is indigenous to the coastline of South Africa receiving winter rainfall, stretching from the borders on the West Coast to the Kei River on the East. Though this plant is not at risk of extinction, it is a greatly under-utilized vegetable that shows great promise as an undemanding resilient winter crop (Forrester, 2004). It has never been cultivated but is being piloted for possible commercial cultivation at a community garden in Khayelitsha, Cape Town, along with other potential winter rainfall crops. The species can be found in a variety of habitats such as dunes and on both light and heavy-textured soils from red sands to grey cracking clays, particularly in areas subject to periodic inundation e.g. floodplains, creek and stream banks, gilgais and, claypans (Hoare *et al.,* 2006; Tembo-Phiri, 2019). It is recorded as having been searched historically, though there is little evidence of it is still being eaten as a leafy green vegetable traditionally. There is however a growing group of chefs, food innovators, gardens, community farmers, and local knowledge holders who are re-kindling interest in the culinary use of Cape wild food plants. The species is recognized for its high nutritional value and drought-resistant traits (Forrester, 2004; Van Wyk, 2011).

Figure 2.2 *T. decumbens* growing close to the sea spray in its natural habitat on the south-western Cape coast (Source: Laubscher).

Figure 2.3 A closer look at the tinny yellow flowers of *T. decumbens* (African Plants - A Photo Guide, 2020)

2.4 Challenges associated with food security

The perception of food security has been on the international agenda since 1948, when the Universal Declaration of Human Rights affirmed that everyone has the right to a standard of living sufficient for their health and well-being, including their families, including food (Amar-Klemesu, 2000). Food security is generally designed to be based on three pillars: availability, access, and use. These concepts are hierarchical, with availability necessary but not sufficient to ensure access, which in turn is necessary but not sufficient for effective use (Barett, 2010). In the past few years the world has produced enough food to feed the world's population, and while a new green revolution is still being called for, understand why people don't have access to sufficient safe and nutritious food has become the focus of research and policy (Hadley & Crooks, 2012). A new finding by Arnold *et al.* (2011) and Wiggins *et al*. (2009) affirms that food security exists when people have physical, social, and economic access at all times to adequate food, safe and nutritious, that meets their nutritional needs and preferences for active and healthy lives. Duncan (2002) contends that food security achievements are ultimately measured in terms of human health indicators such as child mortality and life expectancy, because, without food security, advances in human wellbeing, hygiene, and disease control cannot be made even with reasonable other contributions such as water, hygiene and disease control. Measuring improvements in food security at a national or global level is therefore a matter of measuring improvements in human well-being. According to Ericksen *et al*. (2009) Global Environmental Change (GEC), including soil degradation, loss of biodiversity, changes in hydrology, and changes in climate patterns as a result of increased anthropogenic greenhouse gas emissions, will have serious consequences for food security, especially for more vulnerable groups. The FAO estimated that 1.02 billion people went hungry in 2009, the highest world hunger ever, mainly due to declining investment in agriculture.

It has been estimated that land degradation, urban expansion, and the conversion of crops and arable land for non-food production will reduce total global acreage by 8-20% by 2050. This fact, combined with water scarcity, is already a daunting challenge to increase food production by 50% to meet the projected needs of the world population by 2050 (Nellemann & MacDevette, 2009; Chakraborty, 2011). According to a 2004 report by the Food and Agriculture Organization (FAO) of the United Nations, more than 814 million people in developing countries suffer from malnutrition. Despite the dramatic increase in food production and availability, nutrition, and food insecurity remain at unacceptable levels (Premanandh, 2011).

The rise in food prices urged policymakers to place food security on the political agenda. With, food security as a long-standing concern, an in-depth FAO (2006) project study shows that food production must be increased by 70 percent in the year 2050 to feed the world population. More recently, this number has been reduced to 60% with the investigation of the report (Van Dijk & Meijerink, 2014). Developing countries have significantly fewer agricultural researchers compared to the economically active population in agriculture or agricultural land (Pinstrup-Andersen & Pandya-Lorch, 1998).

In South Africa, about 4 million people are smallholder farmers for various reasons, but mostly from traditional regions. The most common reason for choosing agriculture is to find an additional food source that can be developed over time (Baiphethi & Jacobs, 2009; Mango *et al*., 2017). In recent years, special attention has been paid to access to food and measure constant supply. This stems from the recognition that although food is available in markets, it may not be accessible to some households. According to Labadarios *et al*. (2011), after ten years of democracy, a large proportion of South African's still consider themselves as low-income earners and unable to provide for the needs of their household. Empirical research on food security in South Africa is very limited. The lack of comparative studies and time-series data prevents an accurate assessment of food security and food security trends in South Africa. Limited national representative surveys have focused on the food security of the South African population with limited monitoring system for food security (Hendriks, 2005). Developing cultivation methods for *T. decumbens* in hydroponics can greatly support food security challenges with increasing production of the leafy green wild species.

2.5 Challenges associated with climate change

Problems with the reliability of fresh water supply due to climate change variability, increasing costs for water such as well as high costs of pumping groundwater have affected the income of many farmers (Mushtag *et al*., 2009). Cosgrove and Loucks (2015) stated that increasing public awareness of global climate change has raised serious concerns about its potential impact and its consequences. Although there are different results on the specific effects of climate change on water sources, many scientists suspect that climate change can increase and the severity of extreme weather events such as droughts may occur (Schwartz & Randal, 2003; Ding, 2011). In addition to the risk of future water supply due to population growth, urbanization, and environmental protection in many regions have called for local water supply to with intensified competition for scarce water resources (Cosgrove & Loucks, 2015).

According to Brody *et al*. (2008), climate change refers to the global climate change and physical geography associated with global warming with challenges such as snow and ice caps are melting, rising sea levels, increasing droughts which are likely to continue. Climate change is not new, which have serious consequences, such as the appearance of leaves about 400 million years ago in response to a dramatic reduction in CO2 stress as well as its emergence after the end of the ice age, and about 11,000 years ago (Ceccarelli *et al*., 2010). Global climate models predict an increase in the speed and intensity of extreme weather as well as global warming. Abiotic stresses such as heat and drought often reduce the barrier to the production of key crops such as wheat. Rising temperatures around low development phases affect yields, with longer periods of heat exposure leading to greater losses (Sultan *et al*., 2010). Combined with the stress of drought, the negative impact on agricultural production may be even greater. Annual precipitation rates remain the most important natural resource to replace fresh water supplies for many of the 48 countries in continental Africa (Wiley, 2018).

The variability of rainfall between and within a year is perhaps the most important climatic element that determines the success of agriculture in many regions where the availability of soil water is climatically controlled by precipitation and evaporation (Cooper *et al*., 2008). Weather patterns are very predicable with droughts which can occur in low-precipitation years and flooding in years with heavy rainfall or even for a short time in years with low rainfall. While severe droughts have hit Africa within a succession of six episodes, the global impact of the drought on African economies can be significant for example, 8 to 9% of GDP in Zimbabwe and Zambia in 1992, 4 to 6% of GDP in Nigeria, and Niger in 1984 (Sivakumar *et al*., 2005).

Drought is recognised as an on-going global climate event characterized by less than normal precipitation over several months to several years (Mishra & Singh; 2010; Dai, 2011). The effects of drought are largely unstructured and difficult to predict compared to the effects of other hazards. While the effects of the drought are also very diverse, ranging from agriculture to water supply, industry, energy production, human and marine health, forests, and other sectors it could be disastrous (Wilhite *et al*., 2007). As drought can be divided into three categories: Agricultural and hydrological periods are associated with the two main water sources. Agricultural drought occurs only when the available soil moisture is not sufficient to meet the crop's production requirements

(Komuscu *et al*., 1998). On the other hand, hydrological drought refers to periods below normal water flow while poor storage has linked the two types of drought to the extreme degree of drought. Another global initiative to counteract drought depends on irrigation or rapid evaporation of ice (Olukayode, 1985; Kiem & Verdon-kidd, 2011; Rangecroft *et al*., 2019). Drought stress or water pressures are often words by farmers to describe the effects of dry weather on plants. Indicators such as soil water content, groundwater and or environmental conditions are often used to calculate drought stress. Alternatively, soil water levels is used as a measure of evaluate drought stress in plants with less groundwater available to simplify complex physical plant growth processes (Laio *et al*., 2001).

Consequently, the magnitude of the effects of the drought depends on the sector concerned and the magnitude of the impacts directly or indirectly and possibly included (Soltys-Kalina *et al*., 2016; Rangecroft, *et al*., 2019). Drought and flooding alone have caused 80% of deaths and up to 70% of economic losses in sub-Saharan Africa. Frequent droughts have also slowed and successfully threatened GDP growth in many African countries. Additionally, drought has direct and indirect consequences that impact productivity, livelihood, health, lifestyle, assets, and resources that contribute to food insecurity and poverty (Berry *et al*., 2009). However, the indirect impact of drought on environmental degradation and domestic well-being due to its impact on crop prices may be greater than its direct impact (Shiferaw *et al*., 2014).

Drought in South Africa has affected the economy and local communities by putting increasing pressure on the country's economic system, including increased unemployment, adverse effects on growth in economic activity, for example, lower purchasing power and higher costs of servicing farmers' debt (Benson & Clay, 1998; Shiferaw *et al*., 2014; Baudoin *et al*., 2017). Growing a drought-resilient species such *T. decumbens* using hydroponics could greatly contribute to the sustainable production of food crops for communities and farmers where water has become scarce.

2.6 Challenges and importance of growing wild leafy green vegetables

Dogan (2016) said that many edible wild plants are rich in nutrients and vitamins, making them especially valuable for a balanced diet in resource-poor communities (Table 2.1). Food that comes from nature is always important to the poor and becomes vital in times of conflict or famine. Wild plants contain vitamins, minerals and trace elements. They supplement the basic food for a balanced diet, even under normal living conditions (Figures 2.4 & 2.5). Over the past ten years, there has been an increasing demand for leafy vegetables and their ready-to-eat salads (RTE) because people have changed their eating habits because of their interest in a healthier lifestyle. Nevertheless, fresh leafy vegetables and their RTE salads are recognized in many parts of the world as a source of food poisoning outbreaks. However, this increased percentage of epidemics cannot be fully explained by increased consumption and increased monitoring of these epidemics (Taban & Halkman, 2011). Leafy green vegetables (LGV) are rich in phenolic compounds with a wide range of biological functions, including antioxidants and antimicrobial activities.

Scientists, public health officials, and consumers recognize that fresh fruits and vegetables play an important role in healthy eating and provide essential vitamins, minerals, and nutrients. Increased consumer demand for healthy foods and the availability of these products during the year have increased the consumption of fresh products in the US and Europe. Plants can therefore be more important vectors for enteric pathogens than previously thought. Leafy vegetables eaten raw, such as lettuce, spinach, and endive, are the products most commonly implicated in foodborne disease outbreaks, especially those caused by *E*. *coli* O157: H7 and salmonella infection (Franz *et al*., 2010). The cultivation of undocumented edible wild plants such *T. decumbens* could provide an added value product to traditional vegetable crops if cultivated under strict control of hydroponic practices.

Figure 2.4 Green leaves and tinny white flowers of *Alternanthera sessilis* a reported leafy green vegetable (Source: PhytoImages.siu.edu).

Figure 2.5 Green leaves and tinny white flowers of *Amaranthus hybridus* (Source: http://www.weedscience.org/Details/Case.aspx?ResistID=18184

Table 2.1 Diversity, consumption of wild edible plants consumed in South Africa (Adapted from Dweba & Mearns, 2011).

Species name	Family	Edible parts	Habitat
Alternanthera sessilis (L.) DC.	Amaranthaceae	L	C, FR, G, SL, S
Amaranthus hybridus L.	Amaranthaceae	L, ST	C, FR, G, SL, S
Asystaca schimper T.	Acanthaceae	L	C, FR
Bidens pilosa L.	Asteraceae	L, ST	C, FR, G
Brassica carinatta A.	Brassicaceae	L	C, G
Chenopodium murale L.	Chenopodiaceae	L, ST	C, FR
Corchrus olitorius L.	Tilliceae	L	C, G
Sonchus oleraceus L.	Asteraceae	L	C, G
Tetragonia decumbens Mil.	Aizoaceae	L	C, G
Tetragonia tetragonioides (Pallos)	Aizoaceae	L, ST	C

Note: L – Leaves; ST - Shoot tips; Habitat: C – Cultivated land; FR – Forest; G – Grassland; SL - Shrubland

2.7 Hydroponics Technology

Increasing water productivity requires not only better water management practices and the shift of gravity irrigation to pressurized systems, but also a major dependence on other inputs such as energy-intensive and labour-saving fertilizers, pesticides, and agricultural machinery. However, modern production practices rely heavily on these inputs, which have led to a dramatic increase in fossil fuel consumption and raised many concerns about the sustainable use of energy resources (Mushtaq *et al*., 2009).

In production ecology, the most successful scientific efforts have been made to increase food production. A fundamental scientific approach, especially in the fields of plant ecophysiology, plant selection, plant nutrition and plant protection, supported by technological development for mechanization, has made it possible to significantly increase the efficient use of water and nutrients (Brussaard *et al*., 2010). Benton (2005) reported that the term “hydroponics” was first introduced in the late 1920s and early 1930s being drawn from Hellenic term hydroponos or working with water. The word was derived from two Greek words hydro (“water”) and ponos (“labor”). Kaewwiset and Yooyativog (2017) documented that hydroponics is a technique of growing plants without soil using nutrient solutions that are optimal for plants. The first published work on soilless culture was the book, Sylva Sylvarum, published by Francis Bacon in 1627.

By 1699, John Woodward published his experiments on soilless culture with mint. In the years 1859-65, the discovery of the German bottle Julius von Sachs and Wilhelm Knop led to the development of the cultivation technique. It has rapidly been developed into standard research and teaching technology and is still widely used today and is now considered a form of hydroponics (Hussain *et al*., 2014). According to the Digital Report, "the value of hydroponics is expected to reach $ 27.29 billion in 2015 to 2020 with a CAGR of 6.39% in 2022". In addition to this growth adopted in the hydroponics market, there is also a need for an area that only requires low travel costs (Gould, 2019).

According to Reshmika *et al*. (2016) the above-ground plant is used as a way to replace the soil system with a solution that has no air or molten soil and is chemically incorporated into the nutrient solution. Depending on the type of propagation used, hydroponic systems are divided into hydroponics (culture in solution), the whole system (culture in solid-state), and aeroponics. The basic requirements are nutritional media, nutritional solution, fresh air, water, minerals, and light. The distribution of electrical conductivity, pH, temperature, dissolved oxygen, and nutrient contents in the nutritional solution must be properly regulated (Reshmika *et al*., 2016).

Plants are planted in containers containing a growth substrate of sand, perlite, peat, LECA, and gravel. Water is mixed with a measured amount of nutrients, and the solution is pumped into the system flowing through into the containers. Nutrient levels, pH, EC, and water levels are tested regularly. Hydroponics has various advantages over traditional land farming which include water use efficiency, control of the growing environment with an improved yield (Agung & Yuliando, 2015; Roberts, 2000).

Hydroponics has proved to be an excellent alternative to soil sterilization, especially because the use of chemical soil sterilizers, such as methyl bromide, are or will be soon forbidden in many countries, due to their high toxicity and their adverse effects on the environment (Savvas, 2003). There is no physical difference between plants grown in hydroponics and those growing on the ground. On earth, living things and organisms must be made of materials before they can be found in the plant. It adheres to the soil particles and is transferred to the soil solution in which the plants are placed. In hydroponics, the roots of a plant are soft and a nutrient solution containing substances (Shrestha & Dunn, 2010). There are many types of hydroponic systems, such as deep culture, aeroponics, drip system, flood and drain, a navigation system, N.F.T. (Feed film technology), and Deepwater culture (DWC) (Manisha *et al*., 2016). An aeroponic process - is the process of growing plants in an atmosphere without the use of soil or water. This method promotes suspended plants in a closed or closed space (room) by spraying the suspended roots and lower stems of the plant with a rich nutrient solution. Under these conditions, a controlled environment has great potential to improve the stages of development, health, and plant growth (Idris & Sani, 2012). Considering the advances and importance of hydroponics, experimenting with *T. decumbens* in hydroponics could be a viable option to move away from traditional soil culture systems and add important value to increase production outputs and save water.

2.7.1 Types of hydroponics system

Graham et al., (2011) state that drip irrigation systems apply the solution directly to the growth substrate resulting in very little exposure of the solution to the aerial environment. Furthermore, these systems tend to have large drop sizes that do not increase the surface area of the solution to the same degree as overhead irrigation systems this can be done continuously or at appropriate times.

Flood and drain the system works by periodically pumping nutrient solution to the plant roots once, or more often several times of the day. His flooding meets the nutritional needs of the plant by saturating the growing medium with a solution (HTG supply, 2017). Nutritional film technique (NFT) – is a popular and versatile hydroponic system. It is similar to Ebb and flow in that the system uses a pump to deliver fertilized water to the grow tray and a drainpipe to recycle the unused nutrient solution. The difference is that the NFT the nutrient is continuously flowing over the roots. Wick system **-** is by far the simplest type of hydroponic system. This is a passive system, which means there are no moving parts. The nutrient solution is drawn into the growing medium from the reservoir with a wick. Deep-water Culture (DWC) - A water tank acts as a container for storing nutrient solution. Oxygen, water, and nutrients are provided by drying plant roots in this solution (Bakhtar *et al*., 2018).

Hydroponic systems have been developed as one of the standard methods for plant natural science research and are also used in commercial production for several crops, including lettuce and tomato. Within the plant research community, various hydroponic systems have been designed to study plant responses to biotic and abiotic stresses (Nguyen *et al*., 2016). Mandizvidza (2017) documented that over recent years one of the most significant scientific revolutionary achieved is the research to grow any crop at any given time of the year without restrictions of weather, soil, and landform through hydroponics. This technique is now extensively and frequently used which has certified more research of which results have been incorporated into protected crop production systems such as hydroponics. Hydroponics provides an extensive degree of control of the essential environment surrounding the plant roots and allows the growing of plants without soil (Mandizvidza, 2017). As little documentation of hydroponics cultivation exists for coastal edible species such as *T. decumbens*, future research studies in hydroponics can support communities and farmers with scarce water resources.

2.8 Discussion and conclusion

Of the earth's half-million plant species, only about 3,000 species have been used as crops and only 150 species have been cultivated on a large scale. However, while the development of genetically modified crops may play an important role in achieving enhanced productivity that is essential for human survival, developing new crops by domesticating currently wild edible species offers considerable potential (Ali-Shtayeh *et al*., 2008). In a country such as South Africa where a large part of the rural population exists below the poverty line, there is a great need to create new opportunities for the disadvantaged small-scale farmer (Van Wyk, 2011). Given the fact that many wild coastal species are not utilized to their full potential or their habitat is threatened with overharvesting, there exists an urgent need in South Africa for more research into the commercial cultivation of these valuable species to advance their optimal propagation and growth requirements. *T. decumbens* is recorded as having been used historically, though there is little evidence of this species used as commercial leafy green vegetable. There is however a growing group of chefs, food innovators, gardens, community farmers, and local knowledge holders who are re-kindling an interest in the culinary use of Cape wild food plants. Several species are recognized for its high nutritional value and drought-resistant traits (Forrester, 2004; Van Wyk, 2011 ;) and therefore, it has become important to advance future studies on the cultivation of these species to enhance their commercial potential.

2.9 Acknowledgments

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2.10 References

African Plants - A Photo Guide. 2020. *Tetragonia decumbens* Mill. http://www.africanplants.senckenberg.de/root/index.php?page_id=78&id=5853 29 November 2020.

Agung, P.P. & Yuliando, H. 2015. Soilless Culture System to Support Water Use Efficiency and Product Quality: A Review. *Agriculture and Agricultural Science Procedia*, 3: 283–288. http://dx.doi.org/10.1016/j.aaspro.2015.01.054.

Alexandratos, N. 1999. World food and agriculture: Outlook for the medium and longer term. *Proceedings of the National Academy of Sciences of the United States of America*, 96(11): 5908–5914.

Ali-Shtayeh, M.S., Jamous, R.M., Al-Shafie, J.H., Wafa'A, E., Kherfan, F.A., Qarariah, K.H., Isra'S, K., Soos, I.M., Musleh, A.A., Isa, B.A., & Herzallah, H.M. 2008. Traditional knowledge of wild edible plants used in Palestine (Northern West Bank): a comparative study. *Journal of Ethnobiology and Ethnomedicine*, 4(1):13.

Armar-Klemesu, M. 2000. Urban agriculture and food security, nutrition and health. *Growing cities, growing food. Urban agriculture on the policy agenda*, 99–118.

Arnold, M., Powell, B., Shanley, P. & Sunderland, T.C.H. 2011. Forests, biodiversity, and food security. *The International Forestry Review*, 13(3):259–264.

Baiphethi, M.N. & Jacobs, P.T. 2009. The contribution of subsistence farming to food security in South Africa. *Agrekon,* 48(4): 459–482.

Bakhtar, N., Chhabria V., Cohougle, I., Vidhrani, H. & Hande, R. 2018. Based on a hydroponic farm. International conference on smart system and inventive technology. 205–209.

Barrett, C.B. 2010. Measuring food insecurity. *Science*, 327(5967): 825–828.

Baudoin, M.A., Vogel, C., Nortje, K. & Naik, M. 2017. Living with drought in South Africa: lessons learnt from the recent El Niño drought period. *International Journal of Disaster Risk Reduction*, 23: 128–137.

Benson, C. & Clay, C. 1998. The impact of drought Sub-Saharan African economies. The World Bank technical paper, 401.

Benton, J. 2005. *Complete Guide for Growing Plants Hydroponically* - J. Benton Jones, Jr. - Google Books.

Berry, H. L., Bowen, K. & Kjellstrom, T. 2010. Climate change and mental: A causal pathway farm. *International Journal Public Health,* 55: 123–132.

Born, J., Linder, H.P. & Desmet, P. 2007. The Greater Cape Floristic Region. *Journal of Biogeography*, 34(1): 147–162.

Brody, S.D. 2008. Examining the relationship between physical vulnerability and public perception of global climate change in the United States. *Environment and Behaviour,* 40(1): 72–95.

Brussaard, L., Caron, P., Campbell, B., Lipper, L., Mainka, S., Rabbinge, R., Babin, D. & Pulleman, M., 2010. Reconciling biodiversity conservation and food security: Scientific challenges for a new agriculture. *Current opinion in Environmental sustainability*, *2*(1-2): 34-42.

Ceccarelli, S., Grando, S., Maatougui, M., Michael, M., Slash, M., Haghparast, R., Rahmanian, M., Taheri, A., Al-Yassin, A., Benbelkacem, A. & Labdi, M. 2010. Plant breeding and climate changes. *The Journal of Agricultural Science,* 148(6): 627–637.

Chakraborty, S. & Newton, A.C. 2011. Climate change, plant diseases, and food security: an overview. *Plant Pathology*, 60(1): 2–14.

Charles, H., Godfray, H. & Garnett, T. 2014. Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639): 6–11.

Cooper, P.J.M., Shiferaw, B., Rao, K.P.C., Shapiro, B., Dimes, J. & Twomlow, S. 2008. Coping better with current climate variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to the future climate change. *Agriculture, Ecosystems and Environment,* 126: 24–35.

Cosgrove, W.J. & Loucks, D.P. 2015. Water management: Current and future challenges and research directions. *Advanced Earth and Space Sciences,* 51(6). 4823-4839

Dai, A. 2011. Drought under global warming: a review. Wiley Interdisciplinary Reviews. [Date accessed: 14/02/2020].

Ding, Y. 2011. Measuring economic impacts of drought: a review and discussion. *Disaster Prevention and Management,* 20(4): 434–446. DOI 10.1108/09653561111161752

Dogan, Y., Baslar, S., Ay, G. & Mert, H.H. 2016. The use of wild edible plants in western and central Anatolia (Turkey). *Economic Botany*, *58*(4): 684–690.

Duncan, R.C. 2002. Food security and the world food situation. *Handbook of Agricultural Economics*, *2*: 2191-2213.

Ericksen, P.J., Ingram, J.S. & Liverman, D.M. 2009. Food security and global environmental change: emerging challenges. *Environmental Science & Policy*, 12, 373-377.

Dweba, T.P. & Mearns, M.A. 2011. Conservation indigenous knowledge as the key to the current and future use of traditional vegetables. *International Journal of Information Management,* 31(6): 564–571.

Fischer, T., Byerlee, D. & Edmeades, G. 2014. Crop yields and global food security: will copyright Act 1968 yield increase continue to feed the world? Australian Centre for International Agricultural Research. Pp 634.

Forrester, J. 2004. *Tetragonia decumbens* | *Plantz Africa*. http://pza.sanbi.org/tetragonia-decumbens [Date accessed: 29/11/2020].

Franz, E., Tromp, S.O., Rijgersberg, H. & Van Der Fels-Klerx, H.J. 2010. Quantitative microbial risk assessment for Escherichia coli O157: H7, Salmonella, and Listeria monocytogenes in leafy green vegetables consumed at salad bars. *Journal of Food Protection*, *73*(2): 274–285.

Gould, S. 2019*. Internal design of a hydroponics greenhouse for tri cycle farms*. Biological and Agricultural Engineering Department, College of Engineering. Undergraduate Honours Thesis University of Arkansas.

Graham, T., Zhang, P., Woyzbun, E. & Dixon, M. 2011. Response of hydroponic tomato to daily applications of aqueous ozone via drip irrigation. *Scientia Horticulturae,* 129: 464– 471.

Gray, M. 1997. A new species of *Tetragonia* (Aizoaceae) from arid Australia. *Telopea*, *7*(2): 119–127.

Gregory, P.J., Ingram, J.S. & Brklacich, M. 2005. Climate change and food security. Philosophical Transactions of the Royal Botanical Society. *Biological Sciences*, *360*(1463): 2139–2148.

Grivetti, L.E. & Ogle, B.M. 2000. Value of traditional foods in meeting macro and micronutrient needs: *The Wild Plant Connection*, 13: 31–46.

Hadley, C. & Crooks, D.L. 2012. Coping and the biosocial consequences of food insecurity in the 21st century. *American Journal of Physical Anthropology*, *149*(55):72–94.

Hendriks, S.L. 2005. The challenges facing empirical estimation of household food (in) security in South Africa. *Development Southern Africa*, *22*(1):103–123.

Hoare, D.B., Mucina, L., Rutherford, M.C., Vlok, J.H., Euston-Brown, D.I., Palmer, A.R., Powrie, L.W., Lechmere-Oertel, R.G., Proches, S.M., Dold, A.P. & Ward, R.A., 2006. Albany thicket biome. The vegetation of South Africa, Lesotho and Swaziland*.* *Strelitzia*, 541–567.

Hussain, A., Iqbal, K., Aziem, S., Mahato, P. & Negi, A. 2014. A review on the science of growing crops without soil (Soilless Culture) – A Novel Alternative for Growing Crops. *International Journal of Agriculture and Crop Sciences,* 7(11): 833–842.

Idris, I. & Sani, M.I. 2012. Monitoring and control of aeroponic growing system for potato production. In *2012 IEEE Conference on Control, Systems & Industrial Informatics* (pp. 120-125). IEEE.

Kaewwiset, T. & Yooyativong, T. 2017. Electrical conductivity and pH adjusting system for hydroponics by using linear regression. ECTI-CON 2017 - 2017 14th International Conference on Electrical Engineering/Electronics, Computer. *Telecommunications and Information Technology*, 761–764.

Kellner, A., Ritz, C.M., Schlittenhardt, P. & Hellwig, F.H. 2011. Genetic differentiation in the genus Lithops L. (Ruschioideae, Aizoaceae) reveals a high level of convergent evolution and reflects geographic distribution. *Plant Biology*, 13(2): 368–380.

Kiem, A. & Verdon-Kidd, D. 2011. Steps toward “useful” hydroclimatic scenarios for water resource management in the Murray-Darling Basin. *Water Resources Research*, 47(12).

Klak, C., Hanáček, P. & Bruyns, P.V. 2017. Out of southern Africa: Origin, biogeography and age of the Aizooideae (Aizoaceae). *Molecular Phylogenetics and Evolution*, 109: 203–216.

Komuscu, A.U., Erkan, A. & Sukriye, O.Z. 1998. *Possible impacts of climate change on soil moisture availability in the southeast Anatolia development project region (Gap): An analysis an agricultural drought perceptive.* Kulwer Academic Publishers*,* 40: 519–545.

Labadarios, D., Mchiza, Z.J.R., Steyn, N.P., Gericke, G., Maunder, E.M.W., Davids, Y.D. & Parker, W.A. 2011. Food security in South Africa: a review of national surveys. *Bulletin of the World Health Organization*, *89*: 891-899.

Laio, F., Porporato, A., Ridofi, L. & Rodriguez-Iturbe, I. 2001. Plants in water-controlled ecosystems: active role in hydrologic process and response to water stress II. Probabilistic soil moisture. *Advanced in Water Resources,* 24: 707–723.

Mandizvidza, T. 2017. Influence of nutrient and light management on postharvest quality of lettuce (*Lactuca sativa* L.) in soilless production systems. *Master's Thesis*, University of Stellenbosch.

Mango, N., Siziba, S. & Makate, C. 2017. The impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa. *Agriculture & Food Security*, 6(1): 4–11.

Manisha, N., Raghavendrarao, S., Vandna, R. & Ajay, J. (2016). Deciphering phosphate deficiency –mediated root traits in effects on different root traits in rice grown in a modified hydroponic system. *Frontiers in Plant Science,* 7(550).

Maseko, I., Mabhaudhi, T., Tesfay, S., Araya, H.T., Fezzehazion, M. & Plooy, C.P.D. 2018. African leafy vegetables: A review of status, production, and utilization in South Africa. *Hydrological Sciences Journal,* 64(3): 276–287.

Mishra, A.K. & Singh, V.P. 2010. A review of drought concepts. *Journal of Hydrology, 391*(1-2): 202-216.

Misselhorn, A., Aggarwal, P., Ericksen, P., Gregory, P., Horn-Phathanothai, L., Ingram, J. & Wiebe, K. 2012. A vision for attaining food security. *Current Opinion in Environmental Sustainability*, 4(1): 7–17.

Misselhorn, A.A. 2005. What drives food insecurity in southern Africa? a meta-analysis of household economy studies. *Global Environmental Change*, 15: 33–43.

Mugambiwa, S.S. & Tirivangasi, H.M. 2017. Climate change: A threat towards achieving 'sustainable development goal number two' (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. *Jamba: Journal of Disaster Risk Studies*, 9(1): 1–6.

Mulder, C.H. 2003. AIZOACEAE. *Review of Palaeobotany and Palynology,* 123: 41– 45.

Mushtaq, S., Maraseni, T.N., Maroulis, J. & Hafeez, M. 2009. Energy and water tradeoffs in enhancing. food security: A selective international assessment. *Energy Policy*, *37*(9): 3635–3644.

Nellemann, C. & MacDevette, M. 2009. *The environmental food crisis: the environment's role in averting future food crises: a UNEP rapid response assessment*. UNEP/Earthprint.

Nguyen, N., McInturf, S. & Mendoza-Cózatl, D. 2016. Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements. *Journal of Visualized Experiments,* 113: e54317.

Olukayode, O.E. 1985. A comparative performance analysis of three meteorological drought indices. *Journal of Climatology,* 5(6): 655–664.

Pinstrup-Andersen, P. & Pandya-Lorch, R. 1998. Food security and sustainable use of natural resources: a 2020 vision. *Ecological Economics*, *26*(1):1–10.

Rangecroft, S., Van Loon, A.F., Maureira, H., Verbist, K. & Hannah, D.M. 2019. An observation-based method to quantify the human influence on hydrological drought: Upstream–downstream comparison. *Hydrological Sciences Journal*, 64(3): 276-287.

Rasul, G. 2016. Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environmental Development*, 18: 14–25. http://dx.doi.org/10.1016/j.envdev.2015.12.001.

Reshmika, P.K., Reshma, M.R. & Gayakawad, P.S. 2016. Expansion of green areas in cities through soilless cultivation of vegetables. *International Journal of Agricultural Science and Research,* 6(2): 209–214.

Roberts, L. 2000. Biotechnology: Hydroponics part 1. *Tech Directions* 60(4): 12.

Ronquest-Ross, L., Gunnar, N. & Sigg, O. 2015. Food consumption changes in South Africa since 1994. *South African Journal of Science,* 111: 9–10.

Rosegrant, M.W. & Cline, S.A. 2003. Global food security: challenges and policies. *Science*, *302*(5652): 1917–1919.

Rundel, P.W., Esler, K.J. & Cowling, R.M. 1999. Ecological and phylogenetic patterns of carbon isotope discrimination in the winter-rainfall flora of the Richtersveld, South Africa. *Plant Ecology*, 142(1–2): 133–148.

Savvas, D., Karagianni, V., Kotsiras, A., Demopoulos, V., Karkamisi, I. & Pakou, P. 2003. Interactions between ammonium and pH of the nutrient solution supplied to gerbera (*Gerbera jamesonii*) grown in pumice. *Journal of Plant Nutrition*, 393 – 402.

Schwartz, P. & Randall, D. 2003. An Abrupt Climate change scenario and its possible for the United States national security. California Inst of Tech Pasadena Jet Propulsion Lab.

Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. & Menkir, A. 2014. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes,* 3: 67–79.

Shrestha, A. & Dunn, B. 2010. Hydroponics. Oklahoma Cooperative Extension Service.

Sivakumar, M.V.K., Das, H.P. & Brunini, O. 2005. Impact of present and future climate variability and change on agriculture and forest in the arid and semi-arid tropics. In *Increasing climate variability and change*. Springer, Dordrecht. Pp 31-72.

Soliman, M.I., Zaghloul, M.S. & Heikal, Y.M. 2017. Comparative karyotype of Three Mesembryanthemum (Aizoaceae) Species in Egypt. *Journal of Modern Science & Engineering,* 1(3): 72–89.

Soltys-Kalina, D., Plich, J., Strzelczyk-Żyta, D., Śliwka, J. & Marczewski, W. 2016. The effect of drought stress on the leaf relative water content and tuber yield of a half-sub family of ‘Katahdin’-derived potato cultivars. *Breeding Science,* 66(2): 328-331.

Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., Ciais, P., Guimberteau, M., Traore, S. & Baron, C. 2013. Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. *Environmental Research Letters*, 8(1):014040.

Taban, B.M. & Halkman, A.K. 2011. Do leafy green vegetables and their ready-to-eat [RTE] salads carry a risk of foodborne pathogens? *Anaerobe*, *17*(6): 286-287.

Tembo-Phiri, C. 2019. *Edible Fynbos Plants: A Soil types and irrigation regime investigation on Tetragonia decumbens and Mesembryanthemum crystallinum*. Stellenbosch University. http://scholar.sun.ac.za/handle/10019.1/105974

Valente, L.M., Britton, A.W., Powell, M.P., Papadopulos, A.S.T., Burgoyne, P.M. & Savolainen, V. 2014. Correlates of hyperdiversity in southern African ice plants (Aizoaceae). *Botanical Journal of the Linnean Society*, 174(1): 110–129.

Van Rensburg W.J., Van Zijl, J.J.B. & Sonja, L.V. 2007. The importance of traditional leafy vegetables in South Africa. *African Journal of Food, Agriculture, Nutrition, and Development*, *7*(4): 1–13.

Van Wyk, B.E. 2011. ‘The potential of South African plants in the development of new medicinal products’, *South African Journal of Botany,* 77(4):812–829.

Venter, S.L., Jansen van, W.S., Vorster., van den Heeveer., E. & van Zijl, J.JB. 2007. Promotion of African leafy vegetables within the agricultural research council - vegetable and ornamental plant institute: the impact project. *African Journal of Food Agriculture Nutrition and Development,* 7(4):1–12.

Wiggins, S., Keats, S. & Vigneri, M. 2009. Impact of the global financial and economic situation on agricultural markets and food security. Overseas development institute.

Wiley, J. & Sons. 2018. Climate-resilient crops for improving global food security and safety. *Plant, Cell & Environment,* 41: 877–884.

Wilhite, D.A., Svoboda, M.D. & Hayes. 2007. Understanding the complex impact of drought: A key to enhancing drought mitigation and preparedness. *Water Resource Management,* 21: 763–774.

Willert, D.J. V., Brinekmann, E., Eller, B.M. & Scheitler, B. 1984. Oecologia (Berlin). *Oecologia*, 61: 393–397.

CHAPTER THREE:

VEGETATIVE GROWTH OF *TETRAGONIA DECUMBENS* MILL. IN RESPONSE TO FERTIGATION REGIMES IN HYDROPONICS

Vegetative growth of *Tetragonia decumbens* Mill. in response to different fertigation regimes in hydroponics

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3.1 Abstract

Tetragonia decumbens is an indigenous plant species to the Western Cape province of South Africa. The species is recognized for its high nutritional value and drought-resistant traits. This study was designed to investigate the vegetative growth of *T*. *decumbens* under different fertigation regimes in hydroponics. The research was conducted over 7 weeks in a controlled environment supported by technology installed in the greenhouse facility at the Cape Peninsula University of Technology, Bellville campus, Cape Town, South Africa. The experimental set up consisted of four treatments, each of which was made of 9 replicates of the plant species. Three treatments were grown in nutrient solutions of different concentrations (T1 = 140g/70 L; T2 = 70g/70 L; and T3 = 35g/70 L) while the control received no nutrients. Findings from this study revealed that nutrient application had significant effects on vegetative growth of *T*. *decumbens* except in the control where minimal growth was recorded. The study further revealed that a well-drained, yet less water-holding capacity soilless media in conjunction with a pH range of 5.5 to 6.5 would yield the best results in terms of vegetative growth. Therefore, hydroponic media with low water retention, high nutrient application, low electrical conductivities, and moderate pH levels had better results in terms of vegetative growth when compared to the other treatments. It can be also suggested that a nutrient application is much needed to enhance a quality edible plant in hydroponics. A well-drained, yet less water-holding capacity soilless media in conjunction with a pH range of 5.5 to 6.5 is therefore recommended for the best yield in *T*. *decumbens* in terms of vegetative growth.

Keywords: Aizoaceae; Dune spinach; electrical conductivities; hydroponics; nutrient application; soilless media

3.2 Introduction

Among *Tetragonia* species of Aizoaceae family, *Tetragonia decumbens* is the only one that is decumbent, which is characterized by woody stems at the base, and rather rigid, long roots and runners with hairy leaves and yellow flowers that survive dry summer months and re-sprouts when exposed to water (Tembo-Phiri, 2019). Also known as Dune Spinach, as it stabilizes dunes, acts as a seed trap, generates organic matter, the species continues to play a functional role in its natural habitat. Being edible it can be eaten raw in salads or cooked with other vegetables and has a salty taste with papillose wings on the ripe fruit like those of its congenator *T. tetragonioides* otherwise called New Zealand Spinach. The plant is recognized for its high nutritional value and drought-resistant traits (Forrester, 2004; van Wyk, 2011).

According to Balemie and Kebew, (2006), millions of people in many developing countries do not have enough food to meet their daily needs, additionally for health reasons people need to consume one or more green vegetable per day such as wild edible species. Therefore, for the most part, rural communities depend on wild resources, including wild edible plants, to meet their food needs in times of food crisis. The variety of nutrients in wild food ensures nutritious family diets at minimal costs and this contributes to family food safety (Kaschula, 2008). Numerous articles show knowledge about edible fauna in parts of Africa and all have shown that wild plants are an important part of many African diets, especially in times of food insecurity (Uusiku *et al*., 2010).

In previous literature, Christenhusz and Byng (2016) quoted the population of known plant species in the world as 374000, constituted by approximately 78,854 lower plants and 308,312 higher plant species. Out of this number, not less than 28,187 are used for medicinal purposes; 28000 as ornamental plants; and 7000 as crops (Khoshbakht & Hammer, 2008; Allkin, 2017). A careful look into this number suggests that despite the rising demand for food owing to the increasing human population, less attention is given to edible species. Although genetically modified plants can play an important role in producing a significant increase in human survival production, the growth of new plants through the introduction of wild edible plant species provides significant energy (Chivenge *et al*., 2015).

Despite the opportunities inherent in the cultivation of wild plant species, about 1.02 billion people worldwide are undernourished (Gonzalez, 2010). Although it has been widely reported that hundreds of millions of indigenous people especially in developing worlds regularly collect plant resources to provide for their daily needs, wild edible plants also serve as a supplement to non-indigenous people and provide an alternative source of rich nutrients (Konsam *et al*., 2016). Apart from reducing the vulnerability of local communities to food insecurity and provide a buffer in times of food shortage, un-patronized edible vegetables also make these communities less prone to health risks (Bharucha & Jules, 2009). Similarly, wild plant species also have great potential for evolving new plants through domestication and enlarge the pool of genetic resources for breeding and selection (Achary & Acharya, 2010; Uprety *et al*., 2012).

To achieve sustainable agriculture, there is the need to complement existing agricultural practices with the use of a hydroponic system (Snow *et al*., 2008; Jordan *et al*., 2018; Faber *et al*., 2020). Hydroponics (or soilless cultivation) is a broad term that encompasses all methods of growing plants in a solid base medium (growing on a substrate) or a nutrient solution (aqueous culture). Also, in hydroponic plants, absorption is usually proportional to the concentration of nutrients in the solution near the roots and is heavily influenced by environmental factors such as salinity, oxygenation, temperature, pH, and conductivity of the nutrient solution, light intensity, photoperiod, and humidity (Nxawe *et al*., 2010; Jordan *et al*., 2018). Some benefits of hydroponic growing systems are limitation of water waste (recirculation), crops grown in controlled environments (control of pests, nutrients, and attributes required for optimal plant growth), and the ability to manipulate conditions to maximize production in limited space vertical gardens (Savvas, 2003; Domingues *et al*., 2012; Treftz & Omaye, 2016). The type of hydroponic system chosen for use is important and is based on the condition of the plant and its valuable properties desired. For example, swelling of potato roots will require sufficient substrate to improve, and the growth pattern of butternuts will require more space to reproduce. For this reason, the hydroponic system needs to be improved to encourage the growth of valuable plant traits. (Lefever, 2013).

Although the pH of the soil can be manipulated by adding some products like sulfur to lower the pH or lime to raise the pH, it is often not practical for the smallholder farmer (Domingues *et al*., 2012). Dordas, (2008) reported that pH is a critical variable in plant growth as well as affecting the availability of various elements to the plant. Research has further indicated that pH can have a significant influence on the growth and essential oil yield of various plants. However, it has been proven that pH can harm plant growth, particularly those that are being cultivated in hydroponic cultures (Koehorst *et al*., 2010). The pH of the nutrient solution is a major determinant of nutrient uptake by the plants. It affects the solubility of nutrients thus controlling the availability of nutrients to the plant. At low pH, cation absorption decreases, and anion absorption increases, and vice versa. (Saparamadu *et al*., 2010). Through hydroponic cropping, the pH of the nutrient solution can be manipulated via the application of certain products at the most suitable pH range 5.8 - 6.5 depending on crops (Nxawe *et al*., 2010). Leafy vegetables grown in soilless culture require careful regulation of pH and fertilizer management because of the limited root substrate and high density of seedlings; also, the concentrations of essential plant nutrients in such a medium are frequently insufficient to sustain plant growth (Pardossi *et al*., 2011). Therefore, optimization of the nutrient solution concentration is required by farmers to maximize yield and quality (Fallovo *et al*., 2009).

The electrical conductivity (EC) measured using the EC meter is an indirect indication of the strength of the nutrient solution. For a hydroponic system, the ideal EC range is between 1.5 to 2.5 ds m^{-1} and a higher EC hinders nutrient absorption due to an increase in osmotic pressure whereas lower EC may severely affect plant health and yield (Samarakoon *et al*., 2006; Yadav *et al*., 2011). The study, therefore, aimed to determine how different fertigation regimes would affect the vegetative growth of *T. decumbens* to assist in establishing an optimal protocol for cultivating the plant in hydroponics.

3.3 Materials and methods

3.3.1 Greenhouse Experiment

This investigation was conducted over 7 weeks in the research greenhouse facility at the Cape Peninsula University of Technology, Bellville Campus, Cape Town, South Africa; GPS co-ordinates - 33º 55'45.53S, 18º 38' 31. 16E. the nature of the structure and the technology installed ensured full control of the environment within the greenhouse.

3.3.2 Plant preparation

The plant sample consisted of *T. decumbens* stock plants obtained from Assegaaibosch nursery on the South Western Cape coast. Two hundred uniform cuttings were made with a length of approximately 3 cm using the stock material and placed in cutting square trays containing washed and sterilized coarse river sand. The cuttings were dipped into a rooting hormone number 1; the cutting trays were then placed in the main greenhouse on the Bellville campus of the Cape Peninsula University of Technology on heated propagation beds. After 12 days rooting period, the cuttings were move under 40% shade cloth for one week to harden off before being planted out into the experimental site (Figure 3.3). The cuttings were then planted out to 15 cm pots and placed in a randomized block design onto galvanized steel tables covered in black plastic sheeting with ten replicates of each treatment.

3.3.3 Hydroponic experiment

The hydroponic structure was built from white plastic gutters (3 m long) which were purchased from Builders Warehouse Cape Town. A hack saw was used to cut the gutters into (1.36 m long). A stop end was put on each end of the gutter to prevent water from pouring over at the end silicon was applied to keep the two parts firm. The gutters were then placed on steel tables (2.5 × 1 m) which was used a flat surface. The silicon was left to dry up for two days before the experiment could run. On the second day the silicon was dry the gutters were mounted onto the tables using cable tires this was to prevent the gutters from tilting over. The gutters were wrapped with black plastic polyethylene sheets to avoid algae build-up and nine holes were cut for placing (12.5 cm) plastic pots. The plastic pots were lined with a shade net to prevent Consol® silica sand from leaching into the system. A 20 ml black irrigation pipe was used for recirculating the nutrient solution from the reservoir into the NFT system. Beneath each table were reservoir tank (70 L) with a submersible water pump (1400l/h) - HJ1542. The reservoirs were filled with water and left to run for two days. After two days the plastic pots with planted *T. decumbens* were placed on each hole of the gutter and left for three days to run only with water. Nutrifeed fertilizer supplied by Starke Ayres, Cape Town containing the following ingredients: 65 g/kg N, 27 g/kg P, 130 g/kg K, 70 mg/kg Ca, 20 mg/kg Cu, 1500 mg/kg Fe, 10 mg/kg Mo, 22 mg/kg Mg, 240 mg/kg Mn, 75 mg/kg S, 240 mg/kg B and mg/kg Zn. Fertilizer group 1 Reg No: K2025 (Act 36/ 1947) was applied. There were three treatments which were as follows: 140g/70L, 75g/70L and 35g/70L the nutrient solution was controlled at a rate of 2 L/h. The pH and electrical conductivity (EC) were maintained at 4.5, 5.5, 6.5, and 3.38, 2.34, 1.10 ds m^{-1}(S) respectively. pH levels of aqueous nutrient solution were monitored using a Martini Instruments PH55 pH probe and for adjusting the pH hydrochloric acid (HCl) was used to lower the pH, sodium hydroxide (NaOH) was used for raising the pH. EC levels of the aqueous nutrient solutions were monitored with a calibrated hand-held digital EC meter (Hanna Instruments®™ HI 98312). The nutrient solutions were refreshed every 2 weeks to minimize the build-up of salts in the growing media. As the water drained out of the pots it drained back into the reservoirs and was reused. The experiment was arranged in a randomized block design (Kumar, & Cho, 2014; Teto *et al*., 2016; Faber *et al*., 2020).

3.3.4 Treatment preparation and application

Soilless medium treatments were prepared using 100% silica sand medium. All silica sand used was thoroughly rinsed with tap water until water poured through the sand ran clear. Fertigation regimes were achieved by installing identical pumps to all hydroponic systems. The amount of aqueous nutrient solution delivered to each growing bed was controlled by adjusting all output valves.

3.3.5 Experimental treatments

All treatments contained 100% silica sand growing media and a mid-frequent fertigation regime. Each treatment was numbered, as presented in Table 3.1 below.

Table 3.1 Experimental treatments

Treatments	Composition
Control	100% Silica sand with no nutrients per minute for 2 hours every week
Treatment 1	100% Silica with 140g/70 L per minute for 2 hours every week
Treatment 2	100% Silica with 70g/70 L per minute for 2 hours every week
Treatment 3	100% Silica with 35g/70 L per minute for 2 hours every week

3.4 Data collection

3.4.1 Roots and shoot growth

Root and shoot lengths were measured before transplanting into the hydroponic systems and again at the end of the experiment. Measurements were done in millimetres using a standard ruler and recorded.

3.4.2 Dry weight

Plants were placed in brown paper bags post-harvest and dried at 30–31 °C for 48 hours in a forced convection oven (Daihan Labtech LDO-150F) until there was no further weight loss. Plants were then weighed using an electronic balance model PS750/C/2 laboratory balance (Radwag®, Poland) with 0.001 g readability and recorded. The difference between the wet and dry weights correlates with the amount of water held within the plants‟ tissues.

3.5 Statistical analysis

Data for growth performance was analyzed using one-way analysis of variance (ANOVA) and Fisher's Least Significant Difference (Fisher's L.S.D) test used to evaluate between treatments using Statistica (StatSoft, Inc., Tulsa, OK, US). Different treatments were considered as independent variables and the significance threshold was set at $P \leq 0.05$ (Steel & Torrie, 1980).

3.6 Results

3.6.1 Number of shoots in *T. decumbens*

The results show that there was no significant difference in the number of shoots for treatments 1, 2, and 3 during the 7 weeks of the experiment except during week 6 when significant variation occurred (Figure 3.4). Similarly, the control treatment differed significantly from other treatments that were investigated (Figure 3.1, Table 3.2).

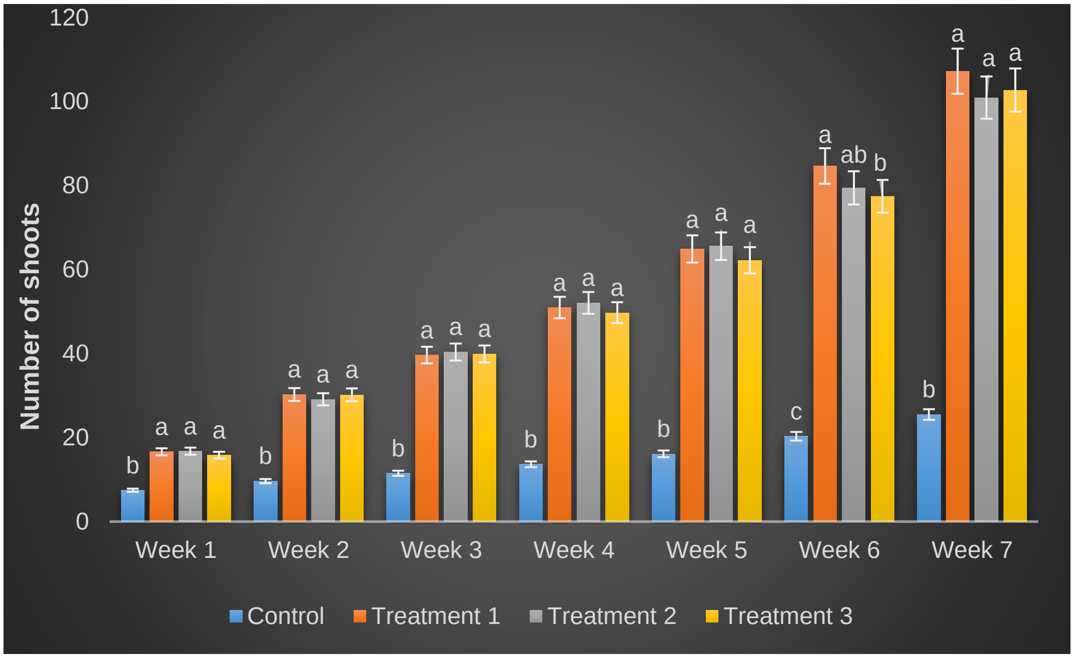

Figure 3.1 Number of shoots of *T. decumbens* with different letters which indicate means that are significantly different.

Table 3.2: Mean squares from the analysis of variance of nutrient effect on the shoot for four treatments of *Tetragonia decumbens* cuttings grown in a hydroponic culture system.

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
	Means/ SD error	Means/ SD error	Means/ SD error	Means/ SD error	Means/ SD error	Means/ SD error	Means/ SD error
Control	7.444 ± 0.565b	9.629 ± 0.501b	11.481 ±0.540b	13.629 ± 0.613b	16.074 ± 0.715b	20.296 ± 0.769c	25.481 ± 0.904b
Treatment 1	16.592 ± 0.856a	30.259 ± 1.467a	39.592 ± 1.382a	50.925 ± 1.572a	64.925 ± 1.771a	84.629 ± 2.640a	107.222 ± 3.968a
Treatment 2	16.740 ± 0.774a	29.074 ± 1.062a	40.370 ± 1.176a	52.074 ± 1.529a	65.555 ± 2.117a	79.444 ± 2.197ab	100.925 ± 2.196a
Treatment 3	15.777± 0.684a	30.1481 ± 1.134a	39.888 ± 1.318a	49.703 ± 1.422a	62.185 ± 1.449a	77.444 ± 2.197b	102.703 ± 5.566a

*** Vertical columns are mean weight values and the bars on each column are ± standard errors of the mean. The mean values represented by different letters differ significantly at $P < 0.05$ as calculated by Fisher's least significant difference

3.6.2 Fresh and dry weight of *T. decumbens*

The results show variability in the fresh and dry weight for all treatments investigated during the 7 weeks of the experiment most especially in the fresh shoot and root weights where significant differences were recorded in the mean weight values at P < 0.05. However, equivalent weight was recorded for the dry shoots obtained from treatments 2 and 3 while no significant difference was observed in the dry root weight of the samples cultivated under the control and treatment 3 conditions (Figure 3.2, Table 3.3).

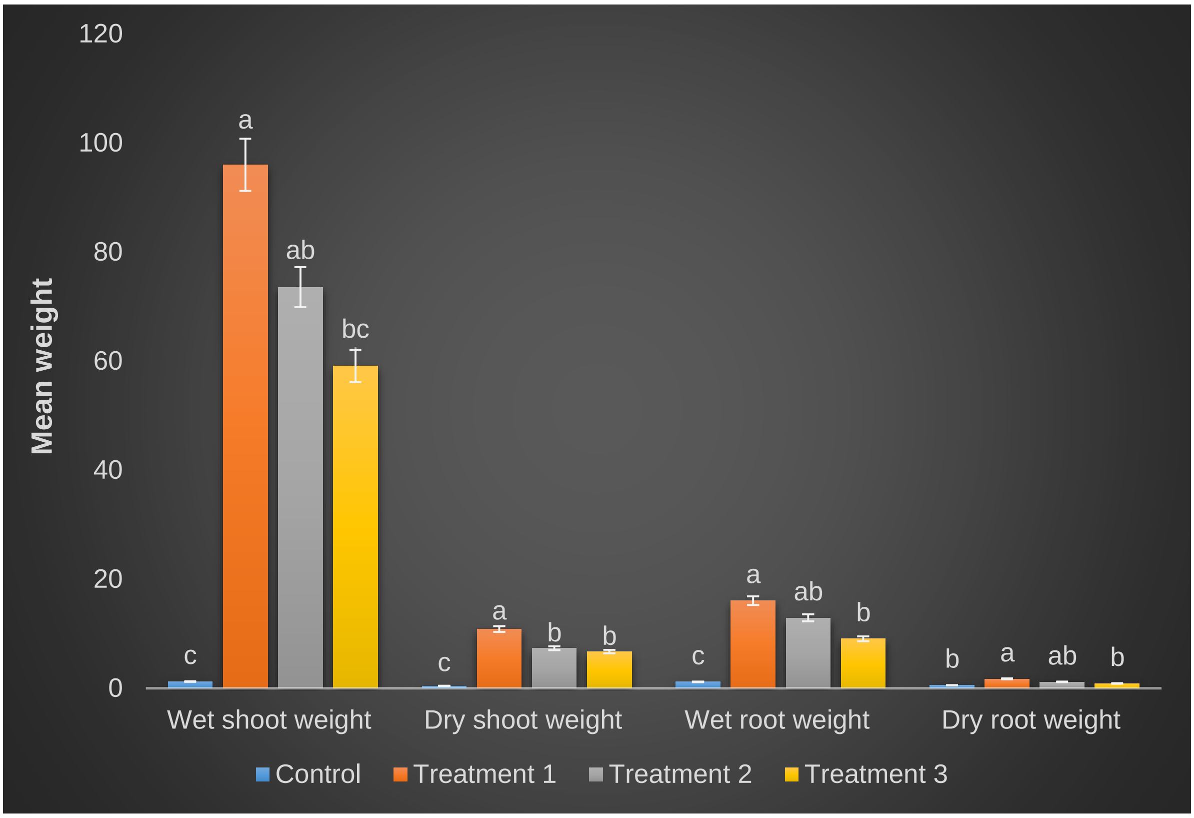

Figure 3.2 Fresh and dry weight of *T. decumbens* in response to different fertigation regimes in Hydroponics

Table 3.3 Fresh and dry weight of *T. decumbens* in Hydroponics.

Parameters	Treatments	Mean weight values	Standard Error
Wet shoot weight	Control	1.240	±0.079c
	T1	96.011	±14.167a
	T2	73.555	±13.005ab
	T3	59.103	±14.106bc
Dry shoot weight	Control	0.429	±0.023c
	T1	10.864	±1.580a
	T2	7.337	±0.761b
	T3	6.714	±1.275b
Wet root weight	Control	1.181	± 0.087c
	T1	16.081	±2.141a
	T2	12.907	±1.219 ab
	T3	9.085	±1.497b
Dry root weight	Control	0.563	±0.439b
	T1	1.709	±0.243a
	T2	1.148	±0.113ab
	T3	0.889	±0.148b

******* Vertical columns are mean weight values and the bars on each column are ± standard errors of the mean. The mean values represented by different letters differ significantly at $P < 0.05$ as calculated by Fisher's least significant difference

Figure 3.3 Rooted stem cuttings after 4 weeks ready to be planted (Picture: Nkcuknkcuka).

Figure 3.4 Shoot growth of treatment 2 at post-harvest (Picture: T. Mabela).

Figure 3.5 A picture showing root growth of *T. decumbens* (Picture: Nkcukankcuka).

3.6.3 Examining variability in the pre-planting and post-harvest shoot to root ratio of *T. decumbens* in hydroponics.

For treatments 1, 2, and 3, there was no significant difference in the ratio during the 7 weeks of the experiment, however, only control treatment exhibited variability as it differs significantly from other treatments (Table 3.4, Figures 3.4 and 3.5).

Table 3.4 Variability in the pre-planting and post-harvest shoot to root ratio of *T. decumbens*

Parameters	Treatments	Means ratio	Standard Error
Post-harvest ratio of root length to shoots	Control	1: 2	±0.830b
	T1	1: 3	±0.869a
	T2	1: 4	±0.930a
	T3	1:10	±6.488a

******* Vertical columns are mean weight values and the bars on each column are ± standard errors of the mean. The mean values represented by different letters differ significantly at $P < 0.05$ as calculated by Fisher's least significant difference

3.7 Discussion and conclusion

During plant growth, the supply of nutrients to the roots is either permanently insufficient (in the case of low soil availability) or temporarily disrupted when there is excess or scarcity of water. The regeneration of nutrients from mature leaves to areas of new growth is critical to the completion of the plant life cycle under such conditions. This behavior is common in fast-growing species, while many wild species stop growing only in unfavorable environmental conditions and therefore the redistribution of nutrients plays a slightly important role (White, 2012). Likewise, the growth rate of the plant depends primarily on the temperature around the plant, and each species has a specific temperature range represented by minimum and maximum values. These values differ in different varieties, either grains, vegetables, or fruits (Hatfield & Prueger, 2015; Jimoh *et al*., 2019).

Treatments applied in this investigation had a significant effect on the vegetative root and shoot growth of *T. decumbens*. Results obtained from this research also suggest that a well-drained medium with a high nutrient application rate yielded better results in terms of vegetative growth. This agrees with Dorais, (2008) and Blair, (1994) who reported that gas diffusion, soil activity, and fertility are optimized in a well-drained medium, giving rise to higher yield. Similarly, it was noticed plants responded better to high nutrient application overall compared to low or medium nutrient applications. These findings support that of Fallovo *et al*. (2009) who reported that the application of fertilizer is one of the most practical and effective ways of controlling and improving the yield and nutritional quality of crops for human consumption. This opportunity was availed by the fact that hydroponic systems allow easy manipulation of nutrient supply to maximize yield in a limited space (Domingues *et al*., 2012; Treftz & Omaye, 2016).

Results obtained from this research also agree with previous studies that a suitable pH and EC adjustment in hydroponics regarding plant type improved overall plant growth (Wu & Kubota, 2008; Domingues, 2012; Wortman, 2015). According to Sardare & Admane, (2013), the medium pH changes constantly as the plant grows in a hydroponic system; thus, pH control is a necessity. In this study, the pH and electrical conductivity (EC) were maintained at 4.5, 5.5, 6.5, and 3.38, 2.34, 1.10 ds m^{-1}(S) respectively. The choice of pH range may be said to be responsible for the optimal yield in *T. decumbens* since a pH range of 5.5 to 6.5 has been reported to be optimal for the availability of nutrients from most nutrient solutions for most species although some species may differ significantly (Sardare & Admane, 2013).

In conclusion, hydroponic media with low water retention and high nutrient application, low EC, and pH levels had better results in terms of vegetative growth when compared to the other treatments. It can be also suggested that a nutrient application is much needed to enhance a quality edible plant in hydroponics. Moreover, a well-drained, yet less water-holding capacity soilless media in conjunction with a pH range of 5.5 to 6.5 would yield the best results in terms of vegetative growth. Further studies would be required to investigate various growth substrates and, various fertigation regimes and how *T. decumbens* responds to these variables to further establish an optimal protocol for the cultivation of the plant in hydroponics.

3.8 Acknowledgments

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3.9 References

Acharya, K.P. & Acharya, R. 2010. Eating from the wild: indigenous knowledge on wild edible plants in Parroha VDC of Rupandehi district, Central Nepal. *International Journal of Social Forestry*, 3(1), 28–48.

Allkin, B. 2017. *Useful Plants – Medicines: At Least 28,187 Plant Species are Currently*

Recorded as Being of Medicinal Use. http://www.ncbi.nlm.nih.gov/pubmed/29144713 30 November 2020.

Balemie, K. & Kebebew, F. 2006. Ethnobotanical study of wild edible plants in Derashe and Kucha Districts, South Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, *2*(1), 53.

Bharucha, Z. & Pretty, J. 2010. The roles and values of wild foods in agricultural systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2913–2926.

Blair, G.J., Conteh, A. & Lefroy, R.D.B. 1994. Fate of organic matter and nutrients in upland agricultural systems. In *ACIAR proceedings*. 41–41. Australian Centre for International Agricultural Research.

Chivenge, P., Mabhaudhi, T., Modi, A.T. & Mafongoya, P. 2015. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, 12(6): 5685–5711.

Christenhusz, M.M.J. & Byng, J.W. 2016. The number of known plants species in the world and its annual increase. *Phytotaxa*, 261(3): 201–217.

Domingues, D. S., Takahashi, H. W., Camara, C. A. P. & Nixdorf, S.L. 2012. *Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. Computers and Electronics in Agriculture,* 84, 53–61*.*

Dorais, M. 2008. Organic production of vegetables: State of the art and challenges. *Canadian Journal of Plant Science*, 87(5): 1055–1066.

Dordas, C. 2008. Role of nutrients in controlling plant diseases in sustainable agriculture. A review. *Agronomy for sustainable development*, *28*(1): 33-46.

Faber, R.J., Laubscher, C.P., Rautenbach, F. & Jimoh, M.O. 2020. Variabilities in alkaloid concentration of Sceletium tortuosum (L .) N . E . Br in response to different soiless growing media and fertigation regimes in hydroponics. *Heliyon*, 6(11): e05479. https://doi.org/10.1016/j.heliyon.2020.e05479.

Fallovo, C., Youssef, R., Elvira, R., Alberto B. & Giuseppe C. 2009. Nutrient solution concentration and growing season affect yield and quality of *Lactuca sativa* L. var. acephala in floating raft culture. *Journal of the Science of Food and Agriculture,* 89(10): 1682–1689.

Forrester, J. 2004. Tetragonia decumbens | Plantz Africa. *South African National Biodiversity Institute (http://pza.sanbi.org/tetragonia-decumbens)*: 1–3. http://pza.sanbi.org/tetragonia-decumbens

Gonzalez, C.G. 2010. The Global Food Crisis: Law, Policy, and the Elusive Quest for Justice. *Yale Human Rights and Development Law Journal*, 13: 463–479.

Hatfield, J.L. & Prueger, J.H. 2015. Temperature extremes: Effect on plant growth and development. *Weather and climate extremes*, 10: 4–10.

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2019. Germination response of Amaranthus caudatus L. to soil types and environmental conditions. *Thaiszia- Journal of Botany*, 29(1): 085–100.

Jordan, R.A., Ribeiro, E.F., de Oliveira, F.C., Geisenhoff, L.O. & Martins, E.A.S. 2018. Yield of lettuce grown in hydroponic and aquaponic systems using different substrates. *Revista Brasileira de Engenharia Agricola e Ambiental*, 22(8): 525–529.

Kaschula, S.A. 2008. Wild foods and household food security responses to AIDS: evidence from South Africa. *Population and Environment*, 29(3–5): 162.

Khoshbakht, K. & Hammer, K. 2008. How many plant species are cultivated? *Genetic Resources and Crop Evolution*, 55(7): 925–928.

Koehorst, R., Laubscher, C.P. & Ndakidemi, P.A. 2010. Growth response of *Artemisia afra* Jacq. to different pH levels in a closed hydroponics system. *Journal of Medicinal Plants Research*, 4(16): 1617–1623.

Konsam, S., Thongam, B. & Handique, A.K. 2016. Assessment of wild leafy vegetables traditionally consumed by the ethnic communities of Manipur, northeast India. *Journal of Ethnobiology and Ethnomedicine*, 12(1): 9.

Kumar, R.R. & Cho, J.Y. 2014. Reuse of hydroponic waste solution. *Environmental Science and Pollution Research*, 21(16): 9569–9577.

Lefever, K. 2013. *Effects of pH and phosphorus concentrations on the cultivation of Salvia chamelaeagnea grown in hydroponics* (Doctoral dissertation, Cape Peninsula University of Technology).

Nxawe, S., Ndakidemi, P.A. & Laubscher, C.P. 2010. Possible effects of regulating hydroponic water temperature on plant growth, accumulation of nutrients and other metabolites. *African Journal of Biotechnology*, 9(54): 9128–9134.

Pardossi, A., Carmassi, G., Diara, C., Incrocci, L., Maggini, R. & Massa, D. 2011. Fertigation and substrate management in closed soilless culture. *EUPHOROS report (UNIPI)*.

Samarakoon, U.C., Weerasinghe, P.A. & Weerakkody, W.A.P. 2006. Effect of electrical conductivity (EC) of the nutrient solution on nutrient uptake, growth, and yield of leaf lettuce (*Lactuca sativa* L.) in stationary culture.

Saparamadu, J.S., Wijesekera, R.D., Gunawardhana, H.D. & Weerakkody, W.A.P. 2010. A low-cost nutrient formulation with a buffer for simplified hydroponics systems.

Sardare, M.D. & Admane, S.V. 2013. A review on plant without soil-hydroponics. *International Journal of Research in Engineering and Technology* 2(03): 299-304.

Savvas, D. 2003. Hydroponics: A modern technology supporting the application of integrated crop management in greenhouse. *Journal of food Agriculture and Environment*, 1:80–86.

Snow, A.M., Ghaly, A.E. & Snow, A. 2008. A comparative assessment of hydroponically grown cereal crops for the purification of aquaculture wastewater and the production of fish feed. *American Journal of Agricultural and Biological Science*, 3(1): 364–378.

Steel, R.G.D & Torrie, J.H. 1980. *Principle and procedures of statistics; a biometrical approach.* 2nd ed. New York: McGraw-Hill.

Tembo-Phiri.C. 2019. Edible fynbos plants: A soil type and irrigation regime investigation on *Tetragonia decumbens* and *Mesembryanthemum crystallinum*. Thesis on Master of Science of Conservation and Ecology Stellenbosch University.

Teto, A.A., Laubscher, C.P., Ndakidemi, P.A. & Matimati, I. 2016. Paclobutrazol retards vegetative growth in hydroponically-cultured Leonotis leonurus (L.) R.Br. Lamiaceae for a multipurpose flowering potted plant. *South African Journal of Botany*, 106: 67–70. http://dx.doi.org/10.1016/j.sajb.2016.05.012

Treftz, C. & Omaye, S.T. 2016. Hydroponics: Potential for augmenting sustainable food production in non-arable regions. *Nutrition & Food Science*, 46(5): 672-684.

Uprety, Y., Poudel, R.C., Shrestha, K.K., Rajbhandary, S., Tiwari, N.N., Shrestha, U.B. & Asselin, H. 2012. Diversity of use and local knowledge of wild edible plant resources in Nepal. *Journal of Ethnobiology and Ethnomedicine*, 8(1):16.

Uusiku, N.P., Oelofse, A., Duodu, K.G., Bester, M.J. &Faber, M. 2010. Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *Journal of Food Composition and Analysis*, 23(6): 499–509.

Van Wyk, B.E. 2011. 'The potential of South African plants in the development of new medicinal products', *South African Journal of Botany,* 77(4):812–829.

Wortman, S.E. 2015. Crop physiological response to nutrient solution electrical conductivity and pH in an ebb-and-flow hydroponic system. *Scientia Horticulturae*, 194: 34-42.

Wu, M. & Kubota, C. 2008. Effects of electrical conductivity of hydroponic nutrient solution on leaf gas exchange of five greenhouse tomato cultivars. *HortTechnology*, 18(2): 271–277.

Yadav, S., Irfan, M., Ahmad, A. & Hayat, S. 2011. Causes of salinity and plant manifestations to salt stress: a review. *Journal of Environmental Biology*, 32(5): 667.

CHAPTER FOUR:

NUTRIENT UPTAKE OF *TETRAGONIA DECUMBENS* MILL. UNDER DIFFERENT FERTIGATION REGIMES IN HYDROPONICS

Nutrient uptake of *Tetragonia decumbens* Mill. under different fertigation regimes in hydroponics

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4.1 Abstract

Tetragonia decumbens was popular among the indigenous Khoi-san people of South Africa for its high nutritional values and drought-resistant traits. However, the species became underexploited largely due to the introduction of exotic species. This study was therefore designed to profile the nutritional characteristics of *T. decumbens* cultivated under different fertigation regimes in hydroponics. The experiment was conducted for 7 weeks with a total of four treatments applied to 9 replicates of the species. The control consisted of 100% Silica sand with no nutrients; Treatment 1 (T1) - 100% Silica with 140g NPK /70 L; Treatment 2 (T2) - 100% Silica with 70g NPK/70 L; and Treatment 3 (T3) made of 100% Silica with 35g NPK /70 L, each of which was run for 2 hours every week at a pH range of 5.5 to 6.5. Post-harvest findings from the study showed that fertigation did not cause significant variability in the macronutrient concentrations of the species. However, micronutrient content was significantly affected. Furthermore, a careful comparison of the nutritional compositions of *T. decumbens* with those of certain popular vegetables showed a slightly higher concentration of nutrients in *T. decumbens*. These revelations project the species as a viable alternative source of nutrients capable of assuaging hidden hunger and malnutrition affecting a 100million population of the world.

Keywords: Diet diversity; food security; macronutrients; micronutrients; pH level; soilless farming; *Tetragonia decumbens*

4.2 Introduction

Tetragonia decumbens is a spreading shrub with shiny, sessile, dark green, and succulent leaves (Goldblatt & Manning, 2012). The species is native to the shores of Southern Africa and in Western Australia where it was first collected in 1932 near Cottesloe, a seaside suburb of Perth (Heyligers, 1999). According to Tembo-Phiri, (2019) the value of this edible species as agronomic resources has been neglected. It has never been cultivated but is being piloted for possible commercial cultivation at a community garden in Khayelitsha, Cape Town, along with other potential winter rainfall crops (Hoare *et al*., 2006).

In nature, the availability of water and nutrients can be very heterogeneous spatially and temporarily, so the root system which is in close contact with these resources must adapt to these conditions with minor or major morphological and physiological adjustment (Grasso *et al*., 2020). Plants react to environmental disturbances characteristically with a variety of physiological and developmental adaptations. Due to prolonged cultivation, the soils have undergone considerable physico-chemical and biological changes (Singh *et al*., 2019). Soil degradation, including erosion and loss of fertility, is considered the most significant environmental problem in developing countries. Even though the soils often contain adequate total amounts of the respective elements, crops grown in most soils suffer from deficiencies of one or more micronutrients (Singh, 2008). Most common of the nutrient deficiencies in crop plants is that of the macronutrients; N, P, K, Mg, Ca, and S, mostly are used in large quantities for fundamental processes such as chlorophyll production, respiration, and cell development (Cissé, 2007; Lefever, 2013).

An adaptive change in the variations in nutrient availability is an important factor limiting the distribution and productivity of plants. More so, the application of only a few nutrients namely; nitrogen, phosphorus, and potassium have been reported to cause significant changes in the absorption and availability of other nutrients (López-Bucio *et al*., 2003; Mir *et al*., 2010). Therefore, balanced fertilization is very crucial to the survival of a species, and the yield response is attributed to the native nutrient supply (Xu *et al*., 2014).

Furthermore, nutrients must be available in suitable forms and balanced quantities for optimum plant growth (López-Bucio *et al*., 2003). Soils contain natural reserves of phytonutrients in inaccessible forms to plants, however, only a small part is released each year through biological degradation and other physio-chemical processes that unlock these nutrients from the reserves (Fageria, 2016). Also, the release of these nutrients is too slow to compensate for the removal of nutrients from agricultural production and therefore needed to be supplemented to meet the physiological needs of crops. Fertilizer application comes with many benefits to crops such as manipulation of foliar nutrient stoichiometry, general growth enhancement, and improved yield quantity and quality. However, it impacts negatively on environmental quality. Hence, benefits must be integrated to get the best out of each type of fertilizer and to achieve balanced nutritional management for plant growth without compromising environmental needs (Chen, 2006; Castle & Neff, 2009).

More importantly, the latest frontier in agricultural research is to maximize crop yield and quality and to keep production costs down. To accomplish sustainable agricultural systems, the environmental impact of each field industry must be considered. Optimized agricultural production practices necessarily involve optimizing water supply and applying nutrients to maximize efficiency and minimize waste (Fernández, & Hoeft, 2009). Also, increasing demand for land for other purposes aside from agricultural needs has reduced the size of plots allocated to farming. This has seen many existing farmlands hitherto converted to schools, factories, sports centers, roads, and housing (Reed and Kleynhans, 2009; Francis *et al*., 2012; Pham *et al*., 2015).

Therefore, it is imperative to embrace soilless farming where the land requirement is minimal with maximum control over pH, electrical conductivity, and other environmental conditions. Hydroponic cultivation thus, allows easy manipulation of nutrient supply to maximize yield. It also tolerates recirculation of used water and prevents infestation of pests and diseases (Snow *et al*., 2008; Faber *et al*., 2020; Jordan *et al*., 2018). Cultivating *T. decumbens* in hydroponics is therefore in tune with contemporary realities of the need to complement existing agricultural practices in terms of efficiency and productivity. Moreover, this study is the premier research providing information about mineral analysis of *T. decumbens* cultivated in hydroponics under different fertigation regimes. Since there is a dearth of information on nutritional characteristics of the plant in existing literature, it is therefore hoped that data from this experiment will serve as a template for future researchers, households, farmers, and industrialists who may want to exploit the plant for diet diversity, food supplementation and as pharmaceutical precursors.

4.3 Materials and methods

4.3.1 Greenhouse Experiment

The cultivation experiment was conducted over 7 weeks in the research greenhouse facility at the Cape Peninsula University of Technology, Bellville, Cape Town, South Africa (GPS co-ordinates - 33º 55’45.53S, 18º 38’ 31. 16E). The nature of the structure and the technology installed ensured control of the environment within the greenhouse.

4.3.2 Experimental treatments

Treatments applied consisted of 100% Silica soilless growth media and 4 different fertigation regimes in a circulating capillary action hydroponic system. All treatments contained 100% silica sand growing media and a mid-frequent fertigation regime. Each treatment was numbered, as presented in Table 4.1 below.

Table 4.1 Experimental treatments

Treatments	Composition
Control	100% Silica sand with no nutrients per minute for 2 hours every week
Treatment 1 (T1)	100% Silica with 140g/70 L per minute for 2 hours every week
Treatment 2 (T2)	100% Silica with 70g/70 L per minute for 2 hours every week
Treatment 3 (T3)	100% Silica with 35g/70 L per minute for 2 hours every week

4.3.3 Nutrient measurements

After harvesting, replicate samples of *T. decumbens* obtained from the four treatments were dried in an oven and pulverised using an electric blender before being taken to BemLab (Pty) Ltd located at Gant's Sentrum, 16 Van Der Berg Cres, Strand, Cape Town, 7140, South Africa for proximate analysis. BemLab is a standard analytical laboratory accredited by the South African National Accreditation System (SANAS), the only National Accreditation Body that grants official recognition to Laboratories, Certification Bodies, Inspection Bodies, Proficiency Testing Scheme Providers and Good Laboratory Practice (GLP) test facilities to carry out specific tasks. At BemLab, nutritional characteristics of the plant samples vis-à-vis macronutrients (N, K, P, Ca, Mg and Na) and micronutrients (Cu, Zn, Mn, Fe, and B) were determined with the use of an Inductively Coupled Plasma- Optical Emission Spectrometer.

4.4 Statistical analysis

Data for proximate composition was analysed using one-way analysis of variance (ANOVA) and Fisher's Least Significant Difference (Fisher's L.S.D) test was used to evaluate variability between treatments using Statistica (StatSoft, Inc., Tulsa, OK, US). Different treatments were considered as independent variables and the significance threshold was set at $P \leq 0.05$ (Steel & Torrie, 1980).

4.5 Results

4.5.1 Effects of fertigation regimes on macronutrient uptake

4.5.2 The effect of nitrogen availability and uptake

It was expected to see higher readings of N with an increased nutrient application. However, the results showed that at moderate fertilizer application the N was increased. These results were measured in the control and the treatments (T1, T2 & T3). The highest N composition was recorded in treatment 2 (T2) while T1 and T3 had equivalent composition of nitrogen at $P \leq 0.05$. Of all the treatments, the control had the lowest N concentration.

4.5.3 The effect of phosphorous availability and uptake

Fertilizer application did not have significant effects on the percentage phosphorus content of the analysed plant samples regardless of treatments. This is evident in the fact that an equivalent yield of phosphorus was recorded in all the treatments except in the control sample with a lower composition of P compared with other treatments.

4.5.4 The effect of potassium availability and uptake

These results were measured in the control and the treatments (T1, T2 & T3). Variability was observed in the percentage K content of the control sample; however, there was no significant difference between T1, T2, and T3 at $P \leq 0.05$.

4.5.5 The effect of calcium availability and uptake

At $P \leq 0.05$, results showed that fertigation had no significant effect on % calcium of *T. decumbens* cultivated in hydroponics under different fertigation regimes as the control had a higher calcium content than other treatments (T1, T2 & T3) where equivalent calcium yield was recorded.

4.5.6 The effect of magnesium availability and uptake

The % magnesium content was higher in T2 than other treatments that had equivalent Mg with the control ($P \leq 0.05$).

4.5.7 The effect of sodium availability and uptake

The highest sodium composition was recorded in *T. decumbens* harvested from the control treatments suggesting that fertilization did not affect % Na content. At P ≤ 0.05, T1 had the lowest Na content while T2 and T3 had equivalent Na composition.

Table 4.2 Effects of fertigation regimes on uptake and availability of macronutrients in *T. decumbens*

	N %	P %	K %	Ca %	Mg %	Na %
Control	0.93 ± 0.06c	0.19 ± 0.05b	1.88 ± 0.13b	2.56 ± 0.18a	0.61 ± 0.04b	1.75 ± 0.21a
T1	3.13 ± 0.24b	0.55 ± 0.02a	7.02 ± 2.30a	1.06 ± 0.35b	0.60 ± 0.11b	0.59 ± 0.18c
T2	4.11 ± 0.44a	0.58 ± 0.07a	7.97 ± 0.23a	1.04 ± 0.04b	0.96 ± 0.09a	1.16 ± 0.13b
T3	3.15 ± 0.08b	0.66 ± 0.04a	6.13 ± 0.62a	0.94 ± 0.05b	0.58 ± 0.02b	1.27 ± 0.04b

*** Means that do not share a letter are significantly different.

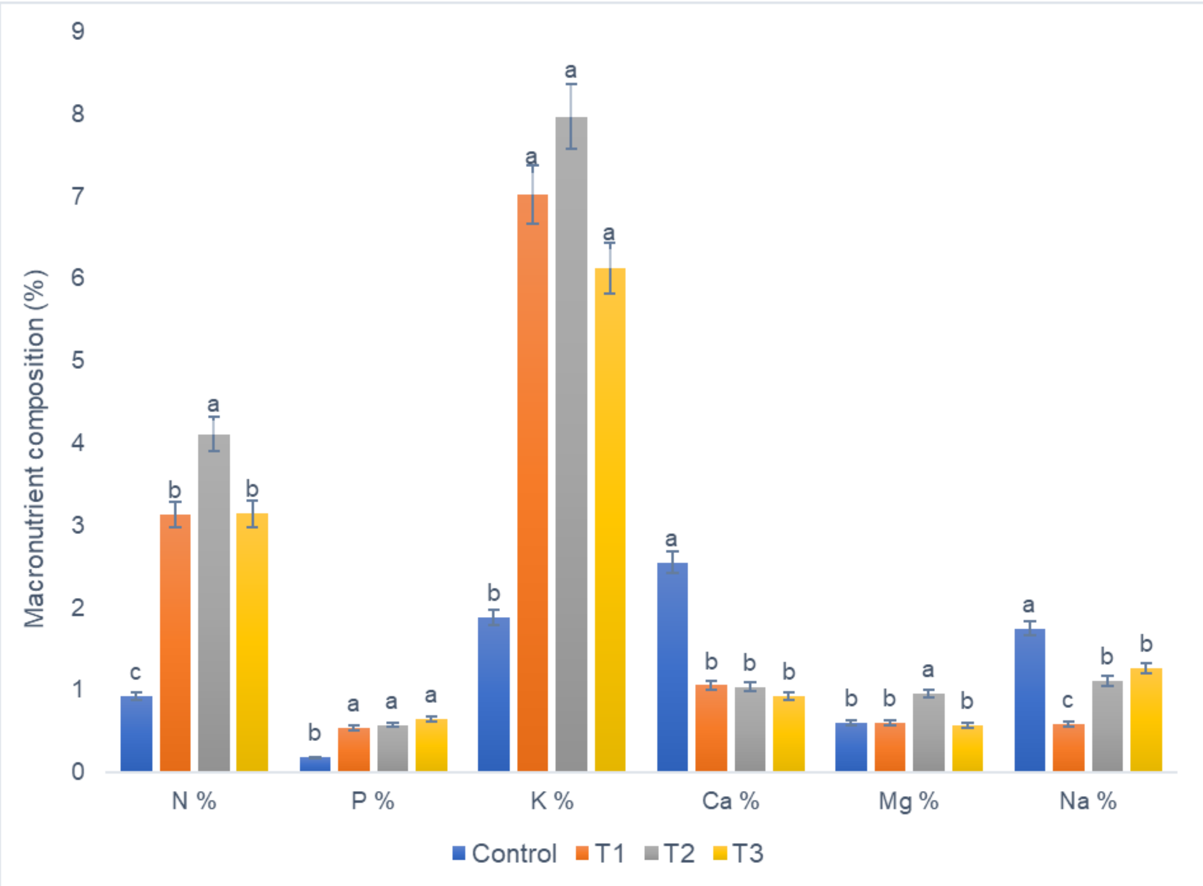

Figure 4.1 Effects of fertigation regimes on uptake and availability of macronutrients in *T. decumbens*. Means that do not share a letter are significantly different.

4.5.8 Effects of fertigation regimes on micronutrient uptake

4.5.9 The effect of manganese availability and uptake

Results show fertigation had a significant effect on Mn uptake and availability. However, an equivalent yield of Mn was recorded in all treatments including the control (Table 4.3; Figure 4.2).

4.5.10 The effect of iron availability and uptake

Fertigation had no significant effect on the iron composition of *T. decumbens*. Moreover, a higher yield in Fe was recorded in the control than other treatments. At $P \leq 0.05$, an equal yield of Fe was recorded in treatments T1, T2, and T3.

4.5.11 The effect of copper availability and uptake

Although Cu yield was low, variability occurred in the Cu composition of the tested plant samples. The control and T1 had equal and the highest Cu content while T3 had the least. A slightly higher Cu composition was recorded in T2 compared with T3.

4.5.12 The effect of zinc availability and uptake

There was significant variability in the Zn composition of the samples. Although an equivalent Zn yield was recorded in the control, T1, and T2 samples; the Zn composition of T3 was significantly high compare with other treatments (control, T1, and T2). In all treatments, however, fertigation had no significant effect on % Zn composition.

4.5.13 The effect of boron availability and uptake

Results showed that fertigation had a significant effect on % B composition. Likewise, a significant difference was observed in the B component of the tested species. At $P \leq 0.05$, T2 had the highest B yield while the lowest was recorded in the control whereas T1 and T3 had equivalent boron composition that is slightly higher than the control but lower than T2.

Table 4.3 Effects of fertigation regimes on uptake and availability of macronutrients in *T. decumbens*

	Mn (mg/Kg)	Fe (mg/Kg)	Cu (mg/Kg)	Zn (mg/Kg)	B (mg/Kg)
Control	113.50 ± 4.95a	301.00 ± 67.88a	6.00 ± 0.00a	128.50 ± 6.36b	24.00 ± 1.41b
T1	264.50 ± 198.70a	157.00 ± 48.08b	5.00 ± 1.41a	170.00 ± 100.41b	29.50 ± 0.71ab
T2	213.50 ± 64.35a	115.00 ± 1.41b	1.00 ± 0.00b	114.50 ± 21.92b	30.50 ± 4.95
T3	131.00 ± 9.90a	131.50 ± 7.78b	3.00 ± 0.00c	446.50 ± 24.75a	29.00 ± 1.41ab

*** Means that do not share a letter are significantly different.

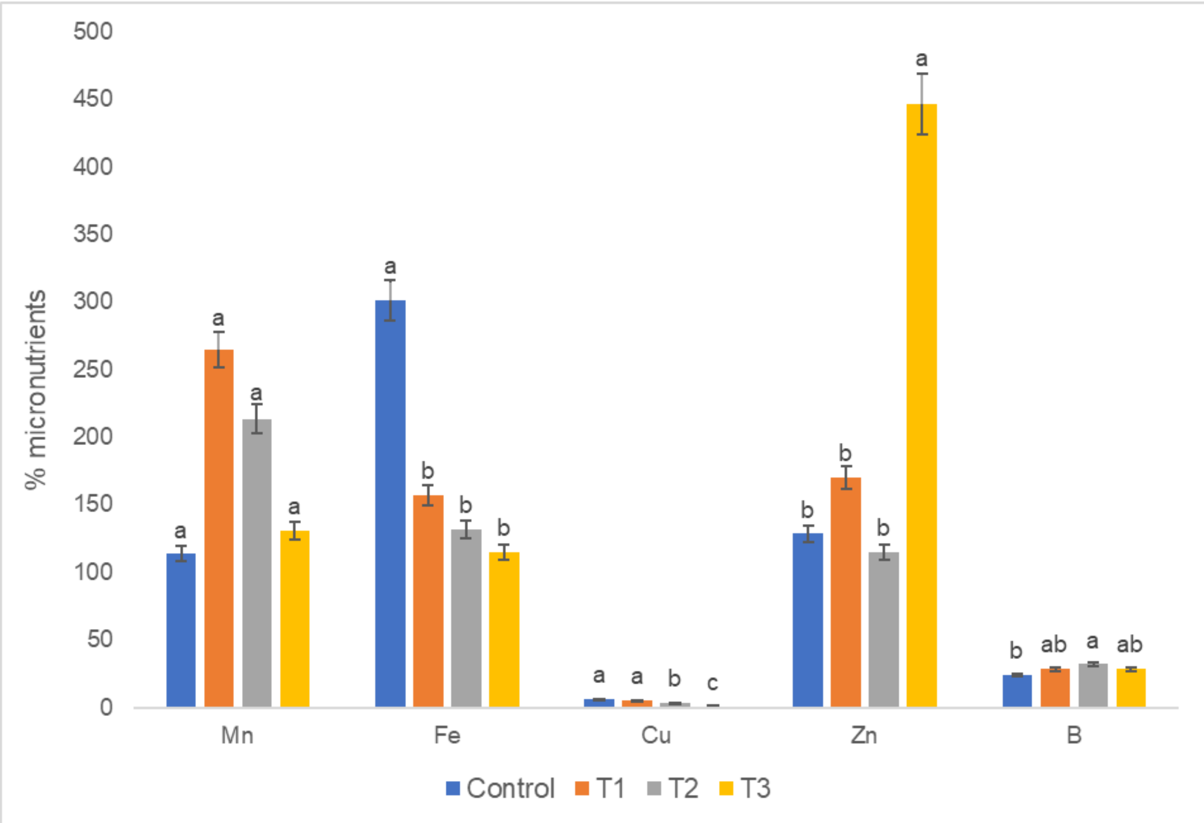

Figure 4.2 Effects of fertigation regimes on uptake and availability of micronutrients in *T. decumbens*. Means that do not share a letter are significantly different.

4.6 Discussion and conclusion

All crops require nitrogen (N) to produce a photosynthetically active canopy, whose functionality will strongly influence yield (Hawkesford, 2014). The relationship between N and chlorophyll biosynthesis cannot be overemphasized as the former forms an important precursor to the latter. That is why N status in the leaves of many crops can be simply estimated with a chlorophyll meter that ordinarily measures chlorophyll content (Von Wettstein *et al*., 1995; Zhang *et al*., 2020). In N deficient plants, there is a lack of green colour in the leaves, a decrease in leaf surface area, and a reduction in photosynthesis. Plants absorb inorganic nitrogen from the water in the root zone, therefore the destination of the nitrogen is linked to water being in the soil root zone. (Hofman, 2006; Leghari *et al*., 2016; Xing *et al.,* 2019). Thus, the presentation of the first findings regarding the response of edible *T. decumbens* to N proves to be important in the establishment of cultivation practices in hydroponics in the future.

Phosphorus is stored as phytates in plants. It is required for cell reparation, growth, and maintenance. It is an integral component of adenosine triphosphate (ATP), ribonucleic acid (RNA), and deoxyribonucleic acid (DNA) (Lewu & Mavengahama, 2010; Adegbaju *et al*., 2019). Compare to other indigenous vegetables, a higher phosphorus percent was recorded in this study for *T. decumbens* (0.66 %) which is slightly higher than earlier values recorded for *Spinacea oleracea* (spinach)- 0.0437%; *Chenopodium album* - 0.37%; and *Solanum nigrum*- 0.239% respectively reported by Ndlovu and Afolayan, (2008) and Afolayan and Jimoh, (2009). However, phosphorus content of *T. decumbens* is comparable to that of *Amaranthus*, *Rumex crispus* and *Celosia argentea* earlier reported respectively by Soriano-García *et al*. (2018), Adegbaju *et al*. (2019) and Idris *et al*. (2019).

Similarly, the % potassium composition of *T. decumbens* obtained in this experiment is positively correlated with phosphorus however, K was slightly lower than that of *S. oleracea* and *Amaranthus caudatus* respectively reported by Tang *et al*. (2019) and Jimoh *et al*. (2020). According to White and Karley, (2010) and Amtmann *et al*. (2005), potassium is the most abundant inorganic cation in plants that are needed for the activation of many enzymes that facilitate signalling and nutrient sensing. It is a vital macronutrient needed for efficient blood circulation, the transmission of nerve impulses, muscular contraction, and ionic balance (Stein, 2010; Jimoh *et al*. 2020).

Compare to earlier reports for notable vegetables, the calcium content of *T. decumbens* was higher than that of spinach (0.423%), *S. nigrum* (0.308%), and amaranth (0.159%) respectively reported by Tang *et al*. (2019), Afolayan and Jimoh, (2009) and Soriano-García *et al*. (2018). Given the fact that 1200mg of Ca is required in the human diet daily (Afolayan and Jimoh, 2009; Jimoh *et al*. 2018), a moderate serving of *T. decumbens* is sufficient to meet this dietary need. The concentration of magnesium and sodium obtained in this study is low compared to popular vegetables. This may have been influenced by a higher K^+ concentration that has been variously reported to work antagonistically against Na^+, $Ca^{2+,}$ and Mg^{2+} uptake (Voogt, 2002; Horie *et al*., 2011; Xie *et al*., 2020). Magnesium is the central atom in the chlorophyll molecule. It is a cationic element which availability aids transport mechanism and is crucial to the functionality of key photosynthetic processes (Shaul, 2002; Karley & White, 2009; Maathuis, 2009).

Results of moderate micronutrient concentration in *T. decumbens* are a pointer to the fact that the species is a good candidate for phytoremediation. However, these results are comparable with various experimental results reported by Soriano-García *et al*. (2018), Idris *et al*. 2019 and Jimoh *et al*. (2018) for other leafy vegetables like spinach, *R. crispus*, and amaranths although Lion and Olowoyo, (2013) had cautioned against health risk associated with over-consumption of vegetables containing these toxic metals.

This study highlights the importance of *T. decumbens* as an edible vegetable and its potential in bridging nutritional gaps between the rich and the poor. Marginal variability observed in the effects of fertigation regimes on nutritional characteristics of the species is an indication that the plant requires a minimal nutrient application which makes it more economical to cultivate. Apart from being the maiden research reporting macronutrient and micronutrient compositions of *T. decumbens*, the revelation that the plant has phytonutrients that compare with or higher than most popular leafy vegetables presents the plant to plant enthusiasts, marginal income households, researchers, and food processing industries as an alternative source of plant-based nutrients. To achieve diet diversity, reliable nutrient allowance, and food security, it is therefore recommended that the plant should be patronized by all and sundry.

4.7 Acknowledgments

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4.8 References

Adegbaju, O.D., Otunola, G.A. & Afolayan, A.J. 2019. Proximate , mineral , vitamin and anti-nutrient content of Celosia argentea at three stages of maturity. *South African Journal of Botany,* 124: 372–379. https://doi.org/10.1016/j.sajb.2019.05.036

Amtmann, A., Hammond, J.P., Armengaud, P. & White, P.J. 2005. Nutrient Sensing and Signalling in Plants: Potassium and Phosphorus. Advances in Botanical Research, 43: 209-257. https://doi.org/10.1016/S0065-2296(05)43005-0

Castle, S.C. & Neff, J.C. 2009. Plant response to nutrient availability across variable bedrock geologies. *Ecosystems*, 12: 101–113. https://doi.org/10.1007/s10021-008-9210-8

Chen, J.H. 2006. The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. In *International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use* 16 (20):1–11. Land Development Department Bangkok Thailand.

Cissé, L. 2007. Balanced fertilization for sustainable use of plant nutrients. *Fertilizer Best Management Practices*, 33.

Faber, R.J., Laubscher, C.P., Rautenbach, F. & Jimoh, M.O. 2020. Variabilities in alkaloid concentration of Sceletium tortuosum (L .) N . E . Br in response to different soilless growing media and fertigation regimes in hydroponics. *Heliyon*, 6: e05479. https://doi.org/10.1016/j.heliyon.2020.e05479

Fageria, N.K. 2016. *The use of nutrients in crop plants*. CRC press.

Fernández, F.G. & Hoeft, R.G. 2009. Managing soil pH and crop nutrients. *Illinois agronomy handbook*, 24:91–112.

Francis, C.A., Hansen, T.E., Fox, A.A., Hesje, P.J., Nelson, H.E., Lawseth, A.E. & English, A. 2012. Farmland conversion to non-agricultural uses in the US and Canada: Current impacts and concerns for the future. *International Journal of Agricultural Sustainability*, 10, 8–24. https://doi.org/10.1080/14735903.2012.649588

Goldblatt, P., & Manning, J. 2012. *Cape plants:* A conspectus of the Cape flora of South Africa. 703:704.

Grasso, R., de Souza, R., Peña-Fleitas, M.T., Gallardo, M., Thompson, R.B. & Padilla, F.M. 2020. Root and crop responses of sweet pepper (*Capsicum annuum*) to increasing N fertilization. *Scientia Horticulturae*, *273*: 109–645.

Heyligers, P.C. 1999. The occurrence and history of *Tetragonia decumbens* (Aizoaceae) in New South Wales. *Telopea*, *8:* 371–73.

Hoare, D.B., Mucina, L., Rutherford, M.C., Vlok, J.H., Euston-Brown, D.I., Palmer, A.R., Powrie, L.W., Lechmere-Oertel, R.G., Proches, S.M., Dold, A.P. & Ward, R.A. 2006. Albany thicket biome. *The vegetation of South Africa, Lesotho, and Swaziland. Strelitzia*, 541–567.

Hofman, G. & Van Cleemput, O. 2004. *Soil and plant nitrogen.* First version, IFA, Paris.

Horie, T., Brodsky, D.E., Costa, A., Kaneko, T., Lo Schiavo, F., Katsuhara, M. & Schroeder, J.I. 2011. K+ transport by the oshkt2;4 transporter from rice with atypical Na+transport properties and competition in permeation of K+over Mg2+and Ca2+Ions. *Plant Physiology*, 156: 1493–1507. https://doi.org/10.1104/pp.110.168047

Idris, O.A., Wintola, O.A. & Afolayan, A.J. 2019. Comparison of the Proximate Composition , Vitamins Analysis of the Essential Oil of the Root and Leaf of *Rumex crispus* L. *Plants,* 51: 1–15. https://doi.org/10.3390/plants8030051

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2020. Nutrients and Antinutrient constituents of *Amaranthus caudatus* L. cultivated on different soils. *Saudi Journal of Biological Sciences,* 27(12): 3570-3580. https://doi.org/10.1016/j.sjbs.2020.07.029

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2018. Suitability of Amaranthus species for alleviating human dietary deficiencies. *South African Journal of Botany*, 115, 65–73. https://doi.org/10.1016/j.sajb.2018.01.004

Jordan, R.A., Ribeiro, E.F., de Oliveira, F.C., Geisenhoff, L.O. & Martins, E.A.S. 2018. Yield of lettuce grown in hydroponic and aquaponic systems using different substrates. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 22: 525–529. https://doi.org/10.1590/1807-1929/agriambi.v22n8p525-529

Karley, A.J. & White, P.J. 2009. Moving cationic minerals to edible tissues: potassium, magnesium, calcium. *Current Opinion of Plant Biology,* 12(3): 291-298. https://doi.org/10.1016/j.pbi.2009.04.013

Lefever, K. 2013. *Effects of pH and phosphorus concentrations on the cultivation of Salvia chamelaeagnea grown in hydroponics* (Masters dissertation, Cape Peninsula University of Technology).

Leghari, S.J., Wahocho, N.A., Laghari, G.M., HafeezLaghari, A., MustafaBhabhan, G., HussainTalpur, K., Bhutto, T.A., Wahocho, S.A. & Lashari, A.A. 2016. Role of nitrogen for plant growth and development: A review. *Advances in Environmental Biology*, 10(9):209–219.

Lewu, F.B. & Mavengahama, S. 2010. Wild vegetables in northern kwazulu natal, south africa: Current status of production and research needs. *Scientific Research and Essays*, 5: 3044–3048.

Lion, G.N. & Olowoyo, J.O. 2013. Population health risk due to dietary intake of toxic heavy metals from Spinacia oleracea harvested from soils collected in and around Tshwane, South Africa. *South African Journal of Botany*, 88:178–182. https://doi.org/10.1016/j.sajb.2013.07.014

López-Bucio, J., Cruz-Ramírez, A. & Herrera-Estrella, L. 2003. The role of nutrient availability in regulating root architecture. *Current Opinion of Plant Biology*, 6, 280–287. https://doi.org/10.1016/S1369-5266(03)00035-9

Maathuis, F.J. 2009. Physiological functions of mineral macronutrients. *Current Opinion of Plant Biology,* 12: 250–258. https://doi.org/10.1016/j.pbi.2009.04.003

Mir, M.R., Mobin, M., Khan, N.A., Bhat, M.A., Lone, N.A., Bhat, K.A., Razvi, S.M., Wani, S.A., Wani, N., Akhter, S. & Rashid, S. 2010. Crop responses to interaction between plant growth regulators and nutrients. *Journal of Phytology,* 2(10): 09–19.

Ndlovu, J. & Afolayan, A. 2008. Nutritional analysis of the South African wild vegetable Corchorus olitorius. *Asian Journal of Plant Sciences*, 7: 615–618.

Pham, V.C., Pham, T.T.H., Tong, T.H.A., Nguyen, T.T.H. & Pham, N.H. 2015. The conversion of agricultural land in the peri-urban areas of Hanoi (Vietnam): patterns in space and time. Journal of Land Use Science, 10: 224–242. https://doi.org/10.1080/1747423X.2014.884643

Reed, L.L. & Kleynhans, T.E. 2009. Agricultural land purchases for alternative uses - Evidence from two farming areas in the Western Cape province, South Africa. *Agrekon*, 48: 332–351. https://doi.org/10.1080/03031853.2009.9523830

Shaul, O. 2002. Magnesium transport and function in plants: The tip of the iceberg. BioMetals. https://doi.org/10.1023/A:1016091118585

Singh, H., Dunn, B. & Payton, M. 2019. Hydroponic pH modifiers affect plant growth and nutrient content in leafy greens. *Journal of Horticultural Research*, *27*(1): 31–36.

Singh, M.V. 2008. Micronutrient deficiencies in crops and soils in India. In *Micronutrient deficiencies in global crop production.* Springer, Dordrecht, pp 93-125.

Snow, A.M., Ghaly, A.E. & Snow, A. 2008. A comparative assessment of hydroponically grown cereal crops for the purification of aquaculture wastewater and the production of fish feed. *Amercian Journal of Agriculture and Biological Science*, 3, 364–378. https://doi.org/10.3844/ajabssp.2008.364.378

Soriano-García, M., Ilnamiqui Arias-Olguín, I., Pablo Carrillo Montes, J., Genaro Rosas Ramírez, D., Silvestre Mendoza Figueroa, J., Flores-Valverde, E. & Rita Valladares-Rodríguez, M. 2018. Nutritional functional value and therapeutic utilization of Amaranth. *Journal of Analytical & Pharmaceutical Research*, 7: 596–600. https://doi.org/10.15406/japlr.2018.07.00288

Steel, R.G.D. & Torrie, J.H. 1980. Principle and procedures of statistics; a biometrical approach. *2nd ed.* New York: McGraw-Hill.

Stein, A.J., 2010. Global impacts of human mineral malnutrition. *Plant Soil*, 335: 133–154. https://doi.org/10.1007/s11104-009-0228-2

Tang, L., Hamid, Y., Sahito, Z.A., Gurajala, H.K., He, Z., Feng, Y. & Yang, X. 2019. Evaluation of variation in essential nutrients and hazardous materials in spinach (Spinacia oleracea L.) genotypes grown on contaminated soil for human consumption. *Journal of Food Composition and Analysis,* 79: 95–106. https://doi.org/10.1016/j.jfca.2019.03.012

Tembo-Phiri, C. 2019. Edible fynbos plants: A soil type and irrigation regime investigation on *Tetragonia decumbens* and *Mesembryanthemum crystallinum*. Thesis Master of Science of Conservation and Ecology Stellenbosch University.

Von Wettstein, D., Gough, S. & Kannangara, C.G. 1995. Chlorophyll biosynthesis. *Plant Cell*, 7: 1039–1057. https://doi.org/10.1105/tpc.7.7.1039

Voogt, W. 2002. Potassium Management of Vegetables Under Intensive Growth Conditions, in: Pasricha, N.S., Bansal, S.K. (Eds.), *Proceedings of Colloq*. International Potash Institute, Bern, Switzerland. pp. 347–362.

White, P.J. & Karley, A.J. 2010. Potassium. Plant Cell Monographs, 17: 199–224. https://doi.org/10.1007/978-3-642-10613-2_9

Xie, K., Cakmak, I., Wang, S., Zhang, F. & Guo, S. 2020. Synergistic and antagonistic interactions between potassium and magnesium in higher plants. The Crop Journal. In Press. https://doi.org/10.1016/j.cj.2020.10.005

Xing, Y., Jiang, W., He, X., Fiaz, S., Ahmad, S., Lei, X., Wang, W., Wang, Y. & Wang, X. (2019). A review of nitrogen translocation and nitrogen-use efficiency. *Journal of Plant Nutrition*, 42(19): 2624–2641.

Xu, X., He, P., Pampolino, M.F., Johnston, A.M., Qiu, S., Zhao, S., Chuan, L. & Zhou, W. 2014. Fertilizer recommendation for maize in China based on yield response and agronomic efficiency. *Field Crops Research*, 157: 27–34.

Zhang, C., Huang, Y., Xiao, Z., Yang, H., Hao, Q. & Yuan, S. 2020. (Glycine max) Regulates Chlorophyll Biosynthesis. *Plants*, 9: 1036.

CHAPTER FIVE:

ESTIMATION OF CHLOROPHYLL PRODUCTION LEVELS IN THE LEAVES OF *TETRAGONIA DECUMBENS* MILL.

Estimation of chlorophyll production levels in the leaves of *Tetragonia decumbens* Mill.

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5.1 Abstract

Plants have a wide variety of physiological and biochemical reactions at the cellular and organism levels, making them a more complex phenomenon. To fulfill these physiological functions, plants harvest energy from sunlight using chlorophylls embedded in their photosynthetic apparatus. Chlorophyll metabolism is a highly coordinated process carried out through a series of collaborative reactions catalyzed by numerous enzymes. This study was designed to estimate the chlorophyll content of the hydroponically cultivated *T. decumbens* under various fertigation regimes. A Soil Plant Analysis Development (SPAD-502) chlorophyll meter supplied by KonicaMinolta was used to measure chlorophyll. The device measures red light transmission at 650nm (the frequency at which chlorophyll absorbs light) and infrared light transmission at 940nm (at which no absorption occurs). Readings were taken from two fully formed leaves of each plant every two weeks and the numbers were averaged by the SPAD-502 counter to provide a final number. Findings from this research show that fertigation regimes had no significant effect on the chlorophyll contents of the leaves measured from Week1 to week 4 except in week 3 when slight variability occurred. At week 3, the highest chlorophyll was recorded in T1 while T2 and T3 had equivalent chlorophyll content. Similarly, the control differs significantly from other treatments as low chlorophyll yield was recorded. The research, therefore, corroborates what has been reported in earlier literature that nutrient application increases chlorophyll yield.

Keywords: Aizoaceae; dune spinach; fertigation regimes; hydroponics; nutrient solutions; photosynthesis

5.2 Introduction

One major strategy with which plants survive in a complex ecological environment is the biosynthesis of abundant chemicals. While some plant chemicals have a sharp or bitter taste (glucosinolates and pyrrolizidine alkaloids) to deter herbivores, others, such as anthocyanins and carotenoids, are colorful flower pigments that attract pollinators (Wurtzel & Kutchan, 2016). Although plant growth is determined by a wide variety of physiological, biochemical, and molecular processes, photosynthesis is an important phenomenon that contributes significantly to the growth and development of plants (Ashraf & Harris, 2013). In the process of photosynthesis, chlorophylls are essential molecules that are responsible for collecting solar energy in photosynthetic antenna systems, as well as for charge separation and electron transport in reaction centers (Ruiz-Espinoza *et al*., 2010). Chlorophyll metabolism is a highly coordinated process carried out through a series of collaborative reactions catalyzed by numerous enzymes (Masuda & Fujita, 2008; Hörtensteiner & Kräutler, 2011; Otsuki, 2018).

Moreover, several proofs from the literature indicate that chlorophyll metabolism might not only significantly influence the construction of photosynthetic apparatus but also control mechanisms such as automated cell death, the evergreen phenomenon, and intracellular communication (Tanaka & Tanaka, 2006). Additionally, photosynthesis can be said to be the most important biochemical process that takes place in plants while chlorophyll is the most important pigment. There are four types of chlorophyll: chlorophyll a, found in all higher plants, algae, and cyanobacteria; Chlorophyll b, present in higher plants and green algae; Chlorophyll c, found in diatoms, dinoflagellates, and brown algae; and chlorophyll is present only in red algae.

Wild plants contain vitamins, minerals, and trace elements. They supplement the basic food for a balanced diet, even under normal living conditions (Bvenura & Sivakumar, 2017; Jimoh *et al*., 2018). Over the past ten years, there has been an increasing demand for leafy vegetables and their ready-to-eat salads because people have changed their eating habits due to rising interest in a healthier lifestyle. Nevertheless, leafy vegetables and their salads are recognized in many parts of the world as a source of food poisoning due to microbial contamination arising from poor handling techniques (Taban & Halkman, 2011).

Among *Tetragonia* species of Aizoaceae, *T. decumbens* is the only one that is decumbent, which is characterized by woody stems at the base, and rather rigid, long roots and runners with hairy leaves and yellow flowers that survive dry summer months and re-sprouts when exposed to water (Tembo-Phiri, 2019). Dune spinach can be eaten raw in salads or cooked with other vegetables. It has a salty taste papillose wings on the ripe fruit like those of its congenator *T. tetragonioides* otherwise called New Zealand Spinach. The plant is recognized for its high nutritional value and drought-resistant traits (Forrester, 2004; van Wyk, 2011). This study aimed to establish a hydroponic protocol for the assessment of chlorophyll production levels in the leaves of *T. decumbens* under varying fertigation regimes. Findings from this research will assist to estimate the chlorophyll production capacity of the plant under hydroponics and may also be used to predict its photosynthetic efficiency.

5.3 Materials and methods

5.3.1 Greenhouse Experiment

This investigation was conducted over 7 weeks in the research greenhouse facility at the Cape Peninsula University of Technology, Bellville Campus, Cape Town, South Africa; GPS co-ordinates - 33º 55’45.53S, 18º 38’ 31. 16E. the nature of the structure and the technology installed ensured control of the environment within the greenhouse.

5.3.2 Plant preparation

The plant sample consisted of *T. decumbens* stock plants obtained from Assegaaibosch nursery on the southwestern Cape coast. Two hundred uniform cuttings were made with a length of approximately 3 cm using the stock material and placed in cutting square trays containing washed and sterilized coarse river sand. The cuttings were dipped into a rooting hormone number 1; the cutting trays were then placed in the main greenhouse on the Bellville campus of the Cape Peninsula University of Technology on heated propagation beds. The plants were then placed under 40% shade cloth for one week to harden off before being planted out into the experimental site. The plants were placed onto galvanized steel tables covered in black plastic sheeting with ten replicates of each treatment in the block design.

5.3.3 Hydroponic experiment

The hydroponic structure was built from white plastic gutters (3 m long) which were purchased from Builders Warehouse Cape Town. A hack saw was used to cut the gutters into (1.36 m long). A stop end was put on each end of the gutter to prevent water from pouring over at the end silicon was applied to keep the two parts firm. The gutters were then placed on steel tables (2.5 × 1 m) which was used a flat surface. The silicon was left to dry up for two days before the experiment could run. On the second day the silicon was dry the gutters were mounted onto the tables using cable tires this was to prevent the gutters from tilting over. The gutters were wrapped with black plastic polyethylene sheets to avoid algae build-up and nine holes were cut for placing (12.5 cm) plastic pots. The plastic pots were lined with a shade net to prevent Consol® silica sand from leaching into the system. A 20 ml black irrigation pipe was used for recirculating the nutrient solution from the reservoir into the NFT system. Beneath each table was reservoir tank (70 L) with a submersible water pump (1400l/h) - HJ1542. The reservoirs were filled with water and left to run for two days. After two days the plastic pots with planted *T. decumbens* were placed on each hole of the gutter and left for three days to run only with water. Nutrifeed fertilizer supplied by Starke Ayres, Cape Town containing the following ingredients: 65 g/kg N, 27 g/kg P, 130 g/kg K, 70 mg/kg Ca, 20 mg/kg Cu, 1500 mg/kg Fe, 10 mg/kg Mo, 22 mg/kg Mg, 240 mg/kg Mn, 75 mg/kg S, 240 mg/kg B and mg/kg Zn. Fertilizer group 1 Reg No: K2025 (Act 36/ 1947) was applied. There were three treatments which were as follows: 140g/70L, 75g/70L and 35g/70L the nutrient solution was controlled at a rate of 2 L/h. The pH and electrical conductivity (EC) were maintained at 4.5, 5.5, 6.5, and 3.38, 2.34, 1.10 ds m^{-1}(S) respectively. pH levels of aqueous nutrient solution were monitored using a Martini Instruments PH55 pH probe and for adjusting the pH hydrochloric acid (HCl) was used to lower the pH, sodium hydroxide (NaOH) was used for raising the pH. EC levels of the aqueous nutrient solutions were monitored with a calibrated hand-held digital EC meter (Hanna Instruments®™ HI 98312). The nutrient solutions were refreshed every 2 weeks to minimize the build-up of salts in the growing media. As the water drained out of the pots it drained back into the reservoirs and was reused. The experiment was arranged in a randomized block design (Kumar, & Cho, 2014; Teto *et al*., 2016; Faber *et al*., 2020).

5.3.4 Chlorophyll content of leaves

The chlorophyll content was measured every two weeks using a SPAD-502 counter supplied by KonicaMinolta. This device measures red light transmission at 650 nm (the frequency at which chlorophyll absorbs light) and infrared light transmission at 940 nm (at which no absorption occurs). Using these two transmission values, the instrument calculates a Soil Plant Analysis Development (SPAD) value, which indicates the chlorophyll content. The readings were taken from two fully formed leaves of each plant and the numbers were averaged by the SPAD-502 counter to provide a final number (Butcher *et al*., 2017).

Figure 5.1 A closer picture of the chlorophyll readings on the leaves of *T. decumbens* with a SPAD-502 meter (Picture; Nkcukankcuka).

5.4 Statistical analysis

Data for growth performance was analyzed using one-way analysis of variance (ANOVA) and Fisher's Least Significant Difference (Fisher's L.S.D) test used to evaluate between treatments using Statistica (StatSoft, Inc., Tulsa, OK, US). Different treatments were considered as independent variables and the significance threshold was set at $P \leq 0.05$ (Steel & Torrie, 1980).

5.5 Results

Findings from this research show that fertigation regimes had no significant effect on the chlorophyll contents of the leaves measured from Week1 to week 4 except in week 3 when slight variability occurred. At week 3, the highest chlorophyll was recorded in T1 while T2 and T3 had equivalent chlorophyll content. Similarly, the control differs significantly from other treatments as low chlorophyll yield was recorded (Figure 5.1).

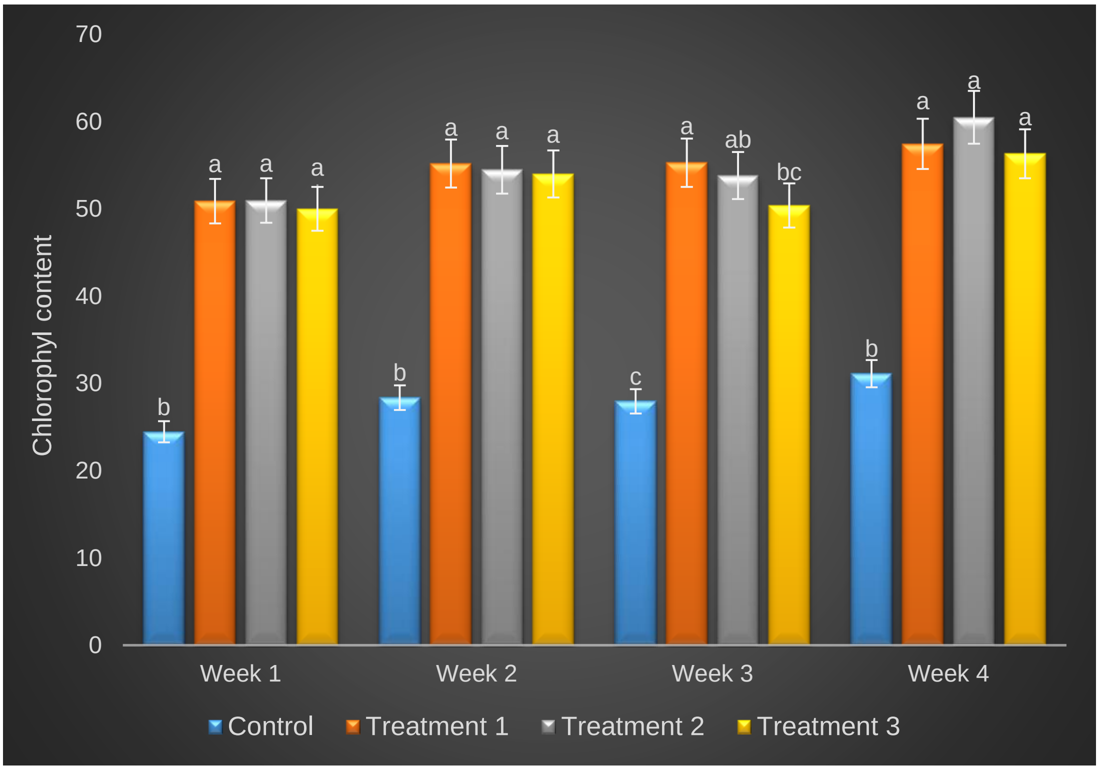

Figure 5.2 Chlorophyll content of *T. decumbens* under different fertigation regimes for 4 weeks

5.6 Discussion and conclusion

Chlorophylls are the apparatus used by plants for light-trapping and energy transduction during the anabolic process of photosynthesis. Until recently that the fifth chlorophyll was added, only four variants of chlorophyll were known. According to (Chen *et al*., 2010), the fifth chlorophyll otherwise called chlorophyll ‘f’ (C55H70O6N4Mg) is red shifted, suggesting it can absorb light from the infrared region. Chlorophyll metabolism is so important such that intracellular chloroplast-nucleus interaction depends on it (Tanaka & Tanaka, 2006). Likewise, it has been a parameter to measure the wellbeing of a plant.

In this study, different fertigation regimes applied showed no significant variability on estimated chlorophyll between treatments, however, the control varied significantly from other treatments. This implies that application nutrients affected chlorophyll content. This agrees with Liu *et al*. (2006) and Nemadodzi *et al*. (2017) who reported earlier that the rate of nitrogen and phosphorus in fertilizers affected chlorophyll content in *Spinacia oleracea*. Also, the results align with Cetin *et al*. (2015) & Otsuki, (2018) who reported no variability in chlorophyll content and the rate of photosynthesis in cotton after it was subjected to different fertigation treatments. Similarly, significant variability was observed in the chlorophyll contents of *Zea mays* and *Sorghum bicolour* cultivated in soils amended with organic and inorganic fertilizers (Amujoyegbe *et al*., 2007). Although outside the scope of this research, a combination of an air-pump, high-frequency H_2O_2 application, and vortex oxygenation was reported to have yielded the highest mean value of chlorophyll in *Pelargonium tomentosum* (Chen *et al*., 2010; Butcher *et al*., 2017) suggesting that oxygenation may drive photosynthesis through increased chlorophyll production.

This study reveals no variability in chlorophyll content between treatments under different fertigation regimes except for the control where chlorophyll yield varied significantly. Findings also corroborate what has been reported in earlier literature that nutrient application increases chlorophyll yield.

5.7 Acknowledgments

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5.8 References

Amujoyegbe, B.J., Opabode, J.T. & Olayinka, A. 2007. Effect of organic and inorganic fertilizer on yield and chlorophyll content of maize (Zea mays L.) and sorghum Sorghum bicolour (L.) Moench. *African Journal of Biotechnology*, 6(16): 1869–1873.

Ashraf, M. & Harris, P.J.C. 2013. Photosynthesis under stressful environments: An overview. *Photosynthetica*, 51(2): 163–190.

Butcher, J.D., Laubscher, C.P. & Coetzee, J.C. 2017. A study of oxygenation techniques and the chlorophyll responses of Pelargonium tomentosum grown in deep water culture hydroponics. *HortScience*, 52(7): 952–957.

Bvenura, C. & Sivakumar, D. 2017. The role of wild fruits and vegetables in delivering a balanced and healthy diet. *Food Research International*, 99: 15–30. http://dx.doi.org/10.1016/j.foodres.2017.06.046.

Cetin, O., Uzen, N. & Temiz, M.G. 2015. Effect of N-fertigation frequency on the lint yield, chlorophyll, and photosynthesis rate of cotton. *Journal of Agricultural Science and Technology*, 17(4): 909–920.

Chen, M., Schliep, M., Willows, R.D., Cai, Z.-L., Neilan, B.A. & Scheer, H. 2010. A Red-Shifted Chlorophyll. *Science*, 329(5997): 1318–1320.

Faber, R.J., Laubscher, C.P., Rautenbach, F. & Jimoh, M.O. 2020. Variabilities in alkaloid concentration of Sceletium tortuosum (L .) N . E . Br in response to different soilless growing media and fertigation regimes in hydroponics. *Heliyon*, 6: e05479. https://doi.org/10.1016/j.heliyon.2020.e05479.

Fallovo, C., Youssef, R., Elvira, R., Alberto B. & Giuseppe C. 2009. Nutrient solution concentration and growing season affect yield and quality of *Lactuca sativa* L. var. acephala in floating raft culture. *Journal of the Science of Food and Agriculture,* 89(10): 1682–1689.

Forrester, J. 2004. Tetragonia decumbens | Plantz Africa. *South African National Biodiversity Institute*: 1–3. http://pza.sanbi.org/tetragonia-decumbens.

Hörtensteiner, S. & Kräutler, B. 2011. Chlorophyll breakdown in higher plants. *Biochimica et Biophysica Acta - Bioenergetics*, 1807(8): 977–988.

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2018. Suitability of Amaranthus species for alleviating human dietary deficiencies. *South African Journal of Botany*, 115: 65–73.

https://doi.org/10.1016/j.sajb.2018.01.004.

Liu, Y.J., Tong, Y.P., Zhu, Y.G., Ding, H. & Smith, F. 2006. Leaf chlorophyll readings as an indicator for spinach yield and nutritional quality with different nitrogen fertilizer applications. *Journal of Plant Nutrition*, 29(7): 1207–1217. https://www.tandfonline.com/doi/abs/10.1080/01904160600767401 [10 December 2020].

Masuda, T. & Fujita, Y. 2008. Regulation and evolution of chlorophyll metabolism. *Photochemical and Photobiological Sciences*, 7(10): 1131–1149.

Nemadodzi, L.E., Araya, H., Nkomo, M., Ngezimana, W. & Mudau, N.F. 2017. Nitrogen, phosphorus, and potassium effects on the physiology and biomass yield of baby spinach (*Spinacia oleracea* L.). *Journal of Plant Nutrition*, 40(14): 2033–2044. https://doi.org/10.1080/01904167.2017.1346121.

Otsuki, J. 2018. Supramolecular approach towards light-harvesting materials based on porphyrins and chlorophylls. *Journal of Materials Chemistry A*, 6(16): 6710–6753. https://pubs.rsc.org/en/content/articlehtml/2018/ta/c7ta11274b [10 December 2020].

Ruiz-Espinoza, F.H., Murillo-Amador, B., Garcia-Hernandez, J.L., Fenech-Larios, L., Rueda-Puente, E.O., Troyo-Dieguez, E., Kaya, C. & Beltran-Morales, A. 2010. Field evaluation of the relationship between chlorophyll content in basil leaves and a portable chlorophyll meter (spad-502) readings. *Journal of Plant Nutrition*, 33(3): 423–438.

Steel, R.G.D & Torrie, J.H. 1980. *Principle and procedures of statistics; a biometrical approach.* 2nd ed*.* New York: McGraw-Hill.

Taban, B.M. & Halkman, A.K. 2011. Do leafy green vegetables and their ready-to-eat [RTE] salads carry a risk of foodborne pathogens? *Anaerobe*, 17(6): 286–287. http://dx.doi.org/10.1016/j.anaerobe.2011.04.004. [28 November 2020].

Tanaka, A. & Tanaka, R. 2006. Chlorophyll metabolism. *Current Opinion in Plant Biology*, 9(3): 248–255.

Tembo-Phiri, C. 2019. *Edible Fynbos Plants: A Soil types and irrigation regime investigation on Tetragonia decumbens and Mesembryanthemum crystallinum*. Stellenbosch University. http://scholar.sun.ac.za/handle/10019.1/105974.

Teto, A.A., Laubscher, C.P., Ndakidemi, P.A. & Matimati, I. 2016. Paclobutrazol retards vegetative growth in hydroponically-cultured Leonotis leonurus (L.) R.Br. Lamiaceae for a multipurpose flowering potted plant. *South African Journal of Botany*, 106: 67–70. http://dx.doi.org/10.1016/j.sajb.2016.05.012.

Van Wyk, B.E. 2011. 'The potential of South African plants in the development of new medicinal products', *South African Journal of Botany,* 77(4):812–829.

Wurtzel, E.T. & Kutchan, T.M. 2016. Plant metabolism, the diverse chemistry set of the future. *Science*, 353(6305): 1232–1236.

CHAPTER SIX:

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 General Discussion

Of the earth's half-million plant species, only about 3,000 species have been used as crops and only 150 species have been cultivated on a large scale. However, while the development of genetically modified crops may play an important role in achieving enhanced productivity that is essential for human survival, developing new crops by domesticating currently wild edible species offers considerable potential (Ali-Shtayeh *et al*., 2008). In a country such as South Africa where a large part of the rural population exists below the poverty line, there is a great need to create new opportunities for the disadvantaged small-scale farmer (Van Wyk, 2011). Given the fact that these plants are facing possible extinction due to habitat destruction and overharvesting, there exists an urgent need in South Africa for more research into the commercial cultivation of these valuable species and investigation into optimal propagation and growth requirements. *T. decumbens* is recorded as having been used historically, though there is little evidence of it is still being eaten as a leafy green vegetable. There is however a growing group of chefs, food innovators, gardens, community farmers, and local knowledge holders who are re-kindling interest in the culinary use of Cape wild food plants. The species is recognized for its high nutritional value and drought-resistant traits (Forrester, 2004; Van Wyk, 2011) and therefore, it has become important to advance future studies on the cultivation of the species to enhance its commercial potential.

During plant growth, the supply of nutrients to the roots is either permanently insufficient (in the case of low soil availability) or temporarily disrupted when there is excess or scarcity of water. The regeneration of nutrients from mature leaves to areas of new growth is critical to the completion of the plant life cycle under such conditions. This behavior is common in fast-growing species, while many wild species stop growing only in unfavorable environmental conditions and therefore the redistribution of nutrients plays a slightly important role (White, & Karley, 2010). Likewise, the growth rate of the plant depends primarily on the temperature around the plant, and each species has a specific temperature range represented by minimum and maximum values. These values differ in different varieties, either grains, vegetables, or fruits (Hatfield & Prueger, 2015; Jimoh *et al*., 2019). Treatments applied in this investigation had a significant effect on the vegetative root and shoot growth of *T decumbens*. Results obtained from this research also suggest that a well-drained medium with a high nutrient application rate yielded better results in terms of vegetative growth. This agrees with Dorais, (2008) and Blair, (1994) who reported that gas diffusion, soil activity, and fertility are optimized in a well-drained medium, giving rise to higher yield. Similarly, it was noticed plants responded better to high nutrient application overall compared to low or medium nutrient applications. These findings support that of Fallovo *et al*., (2009) who reported that application of fertilizer is one of the most practical and effective ways of controlling and improving the yield and nutritional quality of crops for human consumption. This opportunity was availed by the fact that hydroponic systems allow easy manipulation of nutrient supply to maximize yield in a limited space (Domingues *et al*., 2012; Treftz & Omaye, 2016). Results obtained from this research also agree with previous studies that a suitable pH and EC adjustment in hydroponics regarding plant type improved overall plant growth (Wu & Kubota, 2008; Domingues, 2012; Wortman, 2015). According to Sardare & Admane, (2013), the medium pH changes constantly as the plant grows in a hydroponic system; thus, pH control is a necessity. In this study, the pH and electrical conductivity (EC) were maintained at 4.5, 5.5, 6.5, and 3.38, 2.34, 1.10 ds m^{-1}(S) respectively. The choice of pH range may be said to be responsible for the optimal yield in *T. decumbens* since a pH range of 5.5 to 6.5 has been reported to be optimal for the availability of nutrients from most nutrient solutions for most species although some species may differ significantly (Sardare & Admane, 2013).

Furthermore, all crops require nitrogen (N) to produce a photosynthetically active canopy, whose functionality will strongly influence yield (Hawkesford, 2014). The relationship between N and chlorophyll biosynthesis cannot be overemphasized as the former forms an important precursor to the latter. That is why N status in the leaves of many crops can be simply estimated with a chlorophyll meter that ordinarily measures chlorophyll content (Von Wettstein *et al*., 1995; Zhang *et al*., 2020). In N deficient plants, there is a lack of green colour in the leaves, a decrease in leaf surface area, and a reduction in photosynthesis. Plants absorb inorganic nitrogen from the water in the root zone; therefore, the destination of the nitrogen is linked to water being in the soil root zone. (Hofman, 2004; Leghari *et al*., 2016; Xing *et al.,* 2019)**.** Thus, the presentation of the first findings regarding the response of edible *T. decumbens* to N proves to be important in the establishment of cultivation practices in hydroponics in the future. Phosphorus is stored as phytates in plants. It is required for cell reparation, growth, and maintenance. It is an integral component of adenosine triphosphate (ATP), ribonucleic acid (RNA), and deoxyribonucleic acid (DNA) (Lewu & Mavengahama, 2010; Adegbaju *et al*., 2019). Compare to other indigenous vegetables, a higher phosphorus percent was recorded in this study for *T. decumbens* (0.66 %) which is slightly higher than earlier values recorded for *Spinacea oleracea* (spinach)- 0.0437%; *Chenopodium album* - 0.37%; and *Solanum nigrum*- 0.239% respectively reported by Ndlovu and Afolayan, (2008) and Afolayan and Jimoh, (2009). However, the phosphorus content of *T. decumbens* is comparable to that of *Amaranthus*, *Rumex crispus* and *Celosia argentea* earlier reported respectively by Soriano-García *et al*., (2018), Adegbaju *et al*., (2019) and Idris *et al*., (2019).

Also, the % potassium composition of *T. decumbens* obtained in this experiment is positively correlated with phosphorus however, K was slightly lower than that of *S. oleracea* and *Amaranthus caudatus* respectively reported by Tang *et al*., (2019) and Jimoh *et al*., (2020).

According to Amtmann *et al*., (2005) and White and Karley, (2010), potassium is the most abundant inorganic cation in plants that are needed for the activation of many enzymes that facilitate signalling and nutrient sensing. It is a vital macronutrient needed for efficient blood circulation, the transmission of nerve impulses, muscular contraction, and ionic balance (Stein, 2010; Jimoh *et al*., 2020). Compare to earlier reports for notable vegetables, the calcium content of *T. decumbens* was higher than that of spinach (0.423%), *S. nigrum* (0.308%), and amaranth (0.159%) respectively reported by Tang *et al*., (2019), Afolayan and Jimoh, (2009) and Soriano-García *et al*., (2018). Given the fact that 1200mg of Ca is required in the human diet daily (Afolayan & Jimoh, 2009; Jimoh *et al*., 2018), a moderate serving of *T. decumbens* is sufficient to meet this dietary need. The concentration of magnesium and sodium obtained in this study is low compared to popular vegetables. This may have been influenced by a higher K^+ concentration that has been variously reported to work antagonistically against Na^+, $Ca^{2+,}$ and Mg^{2+} uptake (Voogt, 2002; Horie *et al*., 2011; Xie *et al*., 2020). Magnesium is the central atom in the chlorophyll molecule. It is a cationic element which availability aids transport mechanism and is crucial to the functionality of key photosynthetic processes (Shaul, 2002; Maathuis, 2009; Karley & White, 2009). Additionally, results of moderate micronutrient concentration in *T. decumbens* are a pointer to the fact that the species is a good candidate for phytoremediation. However, these results are comparable with various experimental results reported by Soriano-García *et al*. (2018), (Jimoh et al., 2018) and (Idris *et al*., 2019) for other leafy vegetables like spinach, *R. crispus*, and amaranths although Lion and Olowoyo, (2013) had cautioned against health risk associated with over-consumption of vegetables containing these toxic metals.

Moreover, chlorophylls are the apparatus used by plants for light-trapping and energy transduction during the anabolic process of photosynthesis. Until recently that the fifth chlorophyll was added, only four variants of chlorophyll were known. According to (Chen *et al*., 2010), the fifth chlorophyll otherwise called chlorophyll ‘f’ (C55H70O6N4Mg) is red shifted, suggesting it can absorb light from the infrared region. Chlorophyll metabolism is so important such that intracellular chloroplast-nucleus interaction depends on it (Tanaka & Tanaka, 2006). Likewise, it has been a parameter to measure the wellbeing of a plant. In this study, different fertigation regimes applied showed no significant variability on estimated chlorophyll between treatments, however, the control varied significantly from other treatments. This implies that application nutrients affected chlorophyll content. This agrees with Liu *et al*. (2006) and Nemadodzi *et al*. (2017) who reported earlier that the rate of nitrogen and phosphorus in fertilizers affected chlorophyll content in *Spinacia oleracea*. Also, the results align with Cetin *et al*. (2015) who reported no variability in chlorophyll content and the rate of photosynthesis in cotton after it was subjected to different fertigation treatments. Similarly, significant variability was observed in the chlorophyll contents of *Zea mays* and *Sorghum bicolour* cultivated in soils amended with organic and inorganic fertilizers (Amujoyegbe *et al*., 2007). Although outside the scope of this research, a combination of an air-pump, high-frequency H_2O_2 application, and vortex oxygenation was reported to have yielded the highest mean value of chlorophyll in *Pelargonium tomentosum* (Chen *et al*., 2010; Butcher *et al*., 2017) suggesting that oxygenation may drive photosynthesis through increased chlorophyll production. Findings from this research, therefore, corroborate what has been reported in earlier literature that nutrient application increases chlorophyll yield.

6.2 General Conclusion & Recommendations

Given the fact that some plant species are facing possible extinction due to habitat destruction and overharvesting, there exists an urgent need in South Africa for more research into the commercial cultivation of these valuable species and investigation into optimal propagation and growth requirements. *T. decumbens* is recorded as having been used historically, though there is little evidence of it is still being eaten as a leafy green vegetable. There is however a growing group of chefs, food innovators, gardens, community farmers, and local knowledge holders who are re-kindling interest in the culinary use of Cape wild food plants. The species is recognized for its high nutritional value and drought-resistant traits and therefore, it has become important to advance future studies on the cultivation of the species to enhance its commercial potential. Also, hydroponic media with low water retention and high nutrient application, low EC, and pH levels had better results in terms of vegetative growth when compared to the other treatments. It can be also suggested that a nutrient application is much needed to enhance a quality edible plant in hydroponics. Moreover, a well-drained, yet less water-holding capacity soilless media in conjunction with a pH range of 5.5 to 6.5 would yield the best results in terms of vegetative growth. Also, the study reveals no variability in chlorophyll content between treatments under different fertigation regimes except for the control where chlorophyll yield varied significantly. Findings also corroborate what has been reported in earlier literature that nutrient application increases chlorophyll yield. Furthermore, findings from this study highlight the importance of *T. decumbens* as an edible vegetable and its potential in bridging nutritional gaps between the rich and the poor. Marginal variability observed in the effects of fertigation regimes on nutritional characteristics of the species is an indication that the plant requires a minimal nutrient application which makes it more economical to cultivate. Apart from being the maiden research reporting macronutrient and micronutrient compositions of *T. decumbens*, the revelation that the plant has phytonutrients that compare with or higher than most popular leafy vegetables presents the plant to plant enthusiasts, marginal income households, researchers, and food processing industries as an alternative source of plant-based nutrients. To achieve diet diversity, reliable nutrient allowance, and food security, it is therefore recommended that the plant should be patronized by all and sundry. Further studies would be required to investigate various growth substrates and, various fertigation regimes and how *T. decumbens* responds to these variables to further establish an optimal protocol for the cultivation of the plant in hydroponics.

CHAPTER SEVEN: REFERENCES

7.1 References

Acharya, K.P. & Acharya, R. 2010. Eating from the wild: indigenous knowledge on wild edible plants in Parroha VDC of Rupandehi district, Central Nepal. *International Journal of Social Forestry*, 3(1), 28–48.

Adegbaju, O.D., Otunola, G.A. & Afolayan, A.J. 2019. Proximate , mineral , vitamin and anti-nutrient content of Celosia argentea at three stages of maturity. *South African Journal of Botany,* 124: 372–379. https://doi.org/10.1016/j.sajb.2019.05.036

African Plants - A Photo Guide. 2020. *Tetragonia decumbens* Mill. http://www.africanplants.senckenberg.de/root/index.php?page_id=78&id=5853 29 November 2020. [Date accessed: 14/02/2020].

African Plants - A Photo Guide. 2020. *Tetragonia decumbens* Mill. http://www.africanplants.senckenberg.de/root/index.php?page_id=78&id=5853 29 November 2020.

Agung, P.P. & Yuliando, H. 2015. Soilless Culture System to Support Water Use Efficiency and Product Quality: A Review. *Agriculture and Agricultural Science Procedia*, 3: 283–288. http://dx.doi.org/10.1016/j.aaspro.2015.01.054.

Alexandratos, N. 1999. World food and agriculture: Outlook for the medium and longer term. *Proceedings of the National Academy of Sciences of the United States of America*, 96(11): 5908–5914.

Ali-Shtayeh, M.S., Jamous, R.M., Al-Shafie, J.H., Wafa'A, E., Kherfan, F.A., Qarariah, K.H., Isra'S, K., Soos, I.M., Musleh, A.A., Isa, B.A., & Herzallah, H.M. 2008. Traditional knowledge of wild edible plants used in Palestine (Northern West Bank): a comparative study. *Journal of Ethnobiology and Ethnomedicine*, 4(1):13.

Amtmann, A., Hammond, J.P., Armengaud, P. & White, P.J. 2005. Nutrient Sensing and Signalling in Plants: Potassium and Phosphorus. Advances in Botanical Research, 43: 209-257. https://doi.org/10.1016/S0065-2296(05)43005-0

Amujoyegbe, B.J., Opabode, J.T. & Olayinka, A. 2007. Effect of organic and inorganic fertilizer on yield and chlorophyll content of maize (Zea mays L.) and sorghum Sorghum bicolour (L.) Moench. *African Journal of Biotechnology*, 6(16): 1869–1873.

Anywar, G., Oryem-Origa, H. & Mugisha, M.K. 2014. Wild Plants Used as Nutraceuticalsfrom Nebbi District, Uganda. *European Journal of Medicinal Plants*, 4(6): 641–660.

Araya, H., Amoo, S., Laurie, R., Seetseng, K., Ibraimo, N., Masemola, C., Mamadi, N., Mndzebele, B., Ramusandiwa, T. & Lebese, J. 2020. Indigenous / Traditional African Leafy Vegetables. *Agricultural Research Council*. https://www.arc.agric.za/arc-vopi/Pages/Crop Science/Indigenous-Crops.aspx [22 November 2020].

Armar-Klemesu, M. 2000. Urban agriculture and food security, nutrition and health. *Growing cities, growing food. Urban agriculture on the policy agenda*, 99–118.

Arnold, M., Powell, B., Shanley, P. & Sunderland, T.C.H. 2011. Forests, biodiversity, and food security. *The International Forestry Review*, 13(3):259–264.

Ashraf, M. & Harris, P.J.C. 2013. Photosynthesis under stressful environments: An overview. *Photosynthetica*, 51(2): 163–190.

Baiphethi, M.N. & Jacobs, P.T. 2009. The contribution of subsistence farming to food security in South Africa. *Agrekon,* 48(4): 459–482.

Bakhtar, N., Chhabria V., Cohougle, I., Vidhrani, H. & Hande, R. 2018. Based on a hydroponic farm. International conference on smart system and inventive technology. 205–209.

Balemie, K. & Kebebew, F. 2006. Ethnobotanical study of wild edible plants in Derashe and Kucha Districts, South Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, *2*(1), 53.

Baloyi, J.K. 2010. *An analysis of constraints facing smallholder farmers in the Agribusiness value chain: A case study of farmers in the Limpopo Province* (Doctoral dissertation, University of Pretoria).

Barrett, C.B. 2010. Measuring food insecurity. *Science*, 327(5967): 825–828.

Baudoin, M.A., Vogel, C., Nortje, K. & Naik, M. 2017. Living with drought in South Africa: lessons learnt from the recent El Niño drought period. *International Journal of Disaster Risk Reduction*, 23: 128–137.

Benson, C. & Clay, C. 1998. The impact of drought Sub-Saharan African economies. The World Bank technical paper, 401.

Benton, J. 2005. *Complete Guide for Growing Plants Hydroponically* - J. Benton Jones, Jr. - Google Books.

Berry, H. L., Bowen, K. & Kjellstrom, T. 2010. Climate change and mental: A causal pathway farm. *International Journal Public Health,* 55: 123–132.

Bharucha, Z. & Pretty, J. 2010. The roles and values of wild foods in agricultural systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2913–2926.

Blair, G.J., Conteh, A. & Lefroy, R.D.B. 1994. Fate of organic matter and nutrients in upland agricultural systems. In *ACIAR proceedings*. 41–41. Australian Centre for International Agricultural Research.

Blair, G.J., Conteh, A. & Lefroy, R.D.B. 1994. Fate of organic matter and nutrients in upland agricultural systems. In *ACIAR proceedings*. 41–41. Australian Centre for International Agricultural Research.

Borelli, T., Hunter, D., Padulosi, S., Amaya, N., Meldrum, G., Beltrame, D.M.D.O., Samarasinghe, G., Wasike, V.W., Güner, B., Tan, A. & Koreissi Dembélé, Y. 2020. Local solutions for sustainable food systems: The contribution of orphan crops and wild edible species. *Agronomy*, 10(2): 231.

Born, J., Linder, H.P. & Desmet, P. 2007. The Greater Cape Floristic Region. *Journal of Biogeography*, 34(1): 147–162.

Brody, S.D. 2008. Examining the relationship between physical vulnerability and public perception of global climate change in the United States. *Environment and Behaviour,* 40(1): 72–95.

Brussaard, L., Caron, P., Campbell, B., Lipper, L., Mainka, S., Rabbinge, R., Babin, D. & Pulleman, M., 2010. Reconciling biodiversity conservation and food security: Scientific challenges for a new agriculture. *Current opinion in Environmental sustainability*, *2*(1-2): 34-42.

Butcher, J.D., Laubscher, C.P. & Coetzee, J.C. 2017. A study of oxygenation techniques and the chlorophyll responses of Pelargonium tomentosum grown in deep water culture hydroponics. *HortScience*, 52(7): 952–957.

Bvenura, C. & Sivakumar, D. 2017. The role of wild fruits and vegetables in delivering a balanced and healthy diet. *Food Research International*, 99: 15–30. http://dx.doi.org/10.1016/j.foodres.2017.06.046.
Canadian Journal of Plant Science, 87(5): 1055–1066.

Castle, S.C. & Neff, J.C. 2009. Plant response to nutrient availability across variable bedrock geologies. *Ecosystems*, 12: 101–113. https://doi.org/10.1007/s10021-008-9210-8
caudatus L. to soil types and environmental conditions. *Thaiszia- Journal of Botany*,

Ceccarelli, S., Grando, S., Maatougui, M., Michael, M., Slash, M., Haghparast, R., Rahmanian, M., Taheri, A., Al-Yassin, A., Benbelkacem, A. & Labdi, M. 2010. Plant breeding and climate changes. *The Journal of Agricultural Science,* 148(6): 627–637.

Cetin, O., Uzen, N. & Temiz, M.G. 2015. Effect of N-fertigation frequency on the lint yield, chlorophyll, and photosynthesis rate of cotton. *Journal of Agricultural Science and Technology*, 17(4): 909–920.

Chakraborty, S. & Newton, A.C. 2011. Climate change, plant diseases, and food security: an overview. *Plant Pathology*, 60(1): 2–14.

Charles, H., Godfray, H. & Garnett, T. 2014. Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639): 6–11.
Charles, H., Godfray, H. & Garnett, T. 2014. Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639): 6–11.

Chen, J.H. 2006. The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. In *International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use* 16 (20):1–11. Land Development Department Bangkok Thailand.

Chen, M., Schliep, M., Willows, R.D., Cai, Z.-L., Neilan, B.A. & Scheer, H. 2010. A Red-Shifted Chlorophyll. *Science*, 329(5997): 1318–1320.

Chivenge, P., Mabhaudhi, T., Modi, A.T. & Mafongoya, P. 2015. The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, 12(6): 5685–5711.

Cissé, L. 2007. Balanced fertilization for sustainable use of plant nutrients. *Fertilizer Best Management Practices*, 33.

Conn, S.J., Bradleigh, H., Dayod, M., Athman, A., Henderson, S., Aukett, L., Conn, V., Shearer, M. K., Fuentes, S., Tyerman, S. D. & Gilliham, M. 2013. Protocol: optimizing hydroponic growth systems for nutritional and physiological analysis of Arabidopsis thaliana and other plants. *Plant Methods* 9: 4.

Cooper, P.J.M., Shiferaw, B., Rao, K.P.C., Shapiro, B., Dimes, J. & Twomlow, S. 2008. Coping better with current climate variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to the future climate change. *Agriculture, Ecosystems and Environment,* 126: 24–35.

Cosgrove, W.J. & Loucks, D.P. 2015. Water management: Current and future challenges and research directions. *Advanced Earth and Space Sciences,* 51(6). 4823-4839

Dai, A. 2011. Drought under global warming: a review. Wiley Interdisciplinary Reviews.

Ding, Y. 2011. Measuring economic impacts of drought: a review and discussion. *Disaster Prevention and Management,* 20(4): 434–446. DOI 10.1108/09653561111161752

Dogan, Y. 2016. Wild edible plants: from the past to the future. *Austin Food Science Journal*, 1(2): 1006.

Dogan, Y., Baslar, S., Ay, G. & Mert, H.H. 2016. The use of wild edible plants in western and central Anatolia (Turkey). *Economic Botany*, *58*(4): 684–690.

Domingues, D. S., Takahashi, H. W., Camara, C. A. P. & Nixdorf, S.L. 2012. *Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. Computers and Electronics in Agriculture,* 84, 53–61.

Dordas, C. 2008. Role of nutrients in controlling plant diseases in sustainable agriculture. A review. *Agronomy for sustainable development*, *28*(1): 33-46.

Duncan, R.C. 2002. Food security and the world food situation. *Handbook of Agricultural Economics*, *2*: 2191-2213.

Dweba, T.P. & Mearns, M.A. 2011. Conservation indigenous knowledge as the key to the current and future use of traditional vegetables. *International Journal of Information Management,* 31(6): 564–571.

Ericksen, P.J., Ingram, J.S. & Liverman, D.M. 2009. Food security and global environmental change: emerging challenges. *Environmental Science & Policy*, 12, 373-377.

Faber, R.J., Laubscher, C.P., Rautenbach, F. & Jimoh, M.O. 2020. Variabilities in alkaloid concentration of Sceletium tortuosum (L .) N . E . Br in response to different soilless growing media and fertigation regimes in hydroponics. *Heliyon*, 6: e05479. https://doi.org/10.1016/j.heliyon.2020.e05479.

Fageria, N.K. 2016. *The use of nutrients in crop plants*. CRC press.

Fallovo, C., Youssef, R., Elvira, R., Alberto B. & Giuseppe C. 2009. Nutrient solution concentration and growing season affect yield and quality of *Lactuca sativa* L. var. acephala in floating raft culture. *Journal of the Science of Food and Agriculture,* 89(10): 1682–1689.

Fernández, F.G. & Hoeft, R.G. 2009. Managing soil pH and crop nutrients. *Illinois agronomy handbook*, 24:91–112.

Fischer, T., Byerlee, D. & Edmeades, G. 2014. Crop yields and global food security: will copyright Act 1968 yield increase continue to feed the world? Australian Centre for International Agricultural Research. Pp 634. fish feed. *American Journal of Agricultural and Biological Science*, 3(1): 364–378.

Forrester, J. 2004. *Tetragonia decumbens* | *Plantz Africa*. http://pza.sanbi.org/tetragonia-decumbens [Date accessed: 29/11/2020].

Francis, C.A., Hansen, T.E., Fox, A.A., Hesje, P.J., Nelson, H.E., Lawseth, A.E. & English, A. 2012. Farmland conversion to non-agricultural uses in the US and Canada: Current impacts and concerns for the future. *International Journal of Agricultural Sustainability*, 10, 8–24. https://doi.org/10.1080/14735903.2012.649588

Franz, E., Tromp, S.O., Rijgersberg, H. & Van Der Fels-Klerx, H.J. 2010. Quantitative microbial risk assessment for Escherichia coli O157: H7, Salmonella, and Listeria monocytogenes in leafy green vegetables consumed at salad bars. *Journal of Food Protection*, *73*(2): 274–285.

Gabiri, G. 2019. *Multi-scale modeling of water resources in a tropical inland valley and a tropical floodplain catchment in East Africa*. Universitäts- und Landesbibliothek Bonn. https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/7871 [22 November 2020].

Garrity, D.P., Akinnifesi, F.K., Ajayi, O.C., Weldesemayat, S.G., Mowo, J.G., Kalinganire, A., & Bayala, J. 2010. Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security,* 2(3):197–214.

Goldblatt, P., & Manning, J. 2012. *Cape plants:* A conspectus of the Cape flora of South Africa. 703:704.

Gonzalez, C.G. 2010. The Global Food Crisis: Law, Policy, and the Elusive Quest for

Gould, S. 2019*. Internal design of a hydroponics greenhouse for tri cycle farms*. Biological and Agricultural Engineering Department, College of Engineering. Undergraduate Honours Thesis University of Arkansas.

Graham, T., Zhang, P., Woyzbun, E. & Dixon, M. 2011. Response of hydroponic tomato to daily applications of aqueous ozone via drip irrigation. *Scientia Horticulturae,* 129: 464– 471.

Grasso, R., de Souza, R., Peña-Fleitas, M.T., Gallardo, M., Thompson, R.B. & Padilla, F.M. 2020. Root and crop responses of sweet pepper (*Capsicum annuum*) to increasing N fertilization. *Scientia Horticulturae*, *273*: 109–645
Gray, M. 1997. A new species of *Tetragonia* (Aizoaceae) from arid Australia. *Telopea*, *7*(2): 119–127.

Gregory, P.J., Ingram, J.S. & Brklacich, M. 2005. Climate change and food security. Philosophical Transactions of the Royal Botanical Society. *Biological Sciences*, *360*(1463): 2139–2148.

Grivetti, L.E. & Ogle, B.M. 2000. Value of traditional foods in meeting macro and micronutrient needs: *The Wild Plant Connection*, 13: 31–46.

Hadley, C. & Crooks, D.L. 2012. Coping and the biosocial consequences of food insecurity in the 21st century. *American Journal of Physical Anthropology*, *149*(55):72–94.

Hart, T., Vorster, H.J., Hart, T.G.B. & Vorster, H.J. 2007. African Indigenous Knowledge Systems in Agricultural Production. Department of Science and Technology, South Africa.

Hatfield, J.L. & Prueger, J.H. 2015. Temperature extremes: Effect on plant growth and development. *Weather and climate extremes*, 10: 4–10.

Hendriks, S.L. 2005. The challenges facing empirical estimation of household food (in) security in South Africa. *Development Southern Africa*, *22*(1):103–123.

Heyligers, P.C. 1999. The occurrence and history of *Tetragonia decumbens* (Aizoaceae) in New South Wales. *Telopea*, *8:* 371–73.

Hoare, D.B., Mucina, L., Rutherford, M.C., Vlok, J.H., Euston-Brown, D.I., Palmer, A.R., Powrie, L.W., Lechmere-Oertel, R.G., Proches, S.M., Dold, A.P. & Ward, R.A. 2006. Albany thicket biome. *The vegetation of South Africa, Lesotho, and Swaziland. Strelitzia*, 541–567.

Hofman, G. & Van Cleemput, O. 2004. *Soil and plant nitrogen.* First version, IFA, Paris.

Horie, T., Brodsky, D.E., Costa, A., Kaneko, T., Lo Schiavo, F., Katsuhara, M. & Schroeder, J.I. 2011. K+ transport by the oshkt2;4 transporter from rice with atypical Na+transport properties and competition in permeation of K+over Mg2+and Ca2+Ions. *Plant Physiology*, 156: 1493–1507. https://doi.org/10.1104/pp.110.168047

Hörtensteiner, S. & Kräutler, B. 2011. Chlorophyll breakdown in higher plants. *Biochimica et Biophysica Acta - Bioenergetics*, 1807(8): 977–988. http://dx.doi.org/10.1016/j.anaerobe.2011.04.004. [28 November 2020].

Hussain, A., Iqbal, K., Aziem, S., Mahato, P. & Negi, A. 2014. A review on the science of growing crops without soil (Soilless Culture) – A Novel Alternative for Growing Crops. *International Journal of Agriculture and Crop Sciences,* 7(11): 833–842.

Idris, I. & Sani, M.I. 2012. Monitoring and control of aeroponic growing system for potato production. In *2012 IEEE Conference on Control, Systems & Industrial Informatics* (pp. 120-125). IEEE.

Idris, O.A., Wintola, O.A. & Afolayan, A.J. 2019. Comparison of the Proximate Composition , Vitamins Analysis of the Essential Oil of the Root and Leaf of *Rumex crispus* L. *Plants,* 51: 1–15. https://doi.org/10.3390/plants8030051

Izac, A.M.N. & Sanchez, P.A. 2001. Towards a natural resource management paradigm for international agriculture: The example of agroforestry research. *Agricultural Systems*, 69(1–2): 5–25.

Jansen van Rensburg, W.S., van Averbeke, W. Slabbert, R., Faber, M., van Jaarsveld, P., van Heerden, I., Wenhold, F. & Oelofse, A. 2009. African leafy vegetables in South Africa. *Water South Africa,* 33(3): 317-326.

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2018. Suitability of Amaranthus species for alleviating human dietary deficiencies. *South African Journal of Botany*, 115, 65–73. https://doi.org/10.1016/j.sajb.2018.01.004

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2019. Germination response of Amaranthus caudatus L. to soil types and environmental conditions. *Thaiszia- Journal of Botany*, 29(1): 085–100.

Jimoh, M.O., Afolayan, A.J. & Lewu, F.B. 2020. Nutrients and Antinutrient constituents of *Amaranthus caudatus* L. cultivated on different soils. *Saudi Journal of Biological Sciences,* 27(12): 3570-3580. https://doi.org/10.1016/j.sjbs.2020.07.029

Jordan, R.A., Ribeiro, E.F., de Oliveira, F.C., Geisenhoff, L.O. & Martins, E.A.S. 2018. Yield of lettuce grown in hydroponic and aquaponic systems using different substrates. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 22: 525–529. https://doi.org/10.1590/1807-1929/agriambi.v22n8p525-529

Ju, Y., Zhuo, J., Liu, B. & Long, C. 2013. Eating from the wild: Diversity of wild edible plants used by Tibetans in Shangri-la region, Yunnan, China. *Journal of Ethnobiology and Ethnomedicine*, 9(1): 28. DOI: 10.1186/1746-4269-9-28.
Justice. *Yale Human Rights and Development Law Journal*, 13: 463–479.

Kaewwiset, T. & Yooyativong, T. 2017. Electrical conductivity and pH adjusting system for hydroponics by using linear regression. ECTI-CON 2017 - 2017 14th International Conference on Electrical Engineering/Electronics, Computer. *Telecommunications and Information Technology*, 761–764.

Karley, A.J. & White, P.J. 2009. Moving cationic minerals to edible tissues: potassium, magnesium, calcium. *Current Opinion of Plant Biology,* 12(3): 291-298. https://doi.org/10.1016/j.pbi.2009.04.013

Kaschula, S.A. 2008. Wild foods and household food security responses to AIDS: evidence from South Africa. *Population and Environment*, 29(3–5): 162.

Kellner, A., Ritz, C.M., Schlittenhardt, P. & Hellwig, F.H. 2011. Genetic differentiation in the genus Lithops L. (Ruschioideae, Aizoaceae) reveals a high level of convergent evolution and reflects geographic distribution. *Plant Biology*, 13(2): 368–380.

Khoshbakht, K. & Hammer, K. 2008. How many plant species are cultivated? Genetic Resources and Crop Evolution, 55(7): 925–928.

Kiem, A. & Verdon-Kidd, D. 2011. Steps toward "useful" hydroclimatic scenarios for water resource management in the Murray-Darling Basin. *Water Resources Research*, 47(12).

Klak, C., Hanáček, P. & Bruyns, P.V. 2017. Out of southern Africa: Origin, biogeography and age of the Aizooideae (Aizoaceae). *Molecular Phylogenetics and Evolution*, 109: 203–216.

Koehorst, R., Laubscher, C.P. & Ndakidemi, P.A. 2010. Growth response of *Artemisia afra* Jacq. to different pH levels in a closed hydroponics system. *Journal of Medicinal Plants Research*, 4(16): 1617–1623.

Komuscu, A.U., Erkan, A. & Sukriye, O.Z. 1998. *Possible impacts of climate change on soil moisture availability in the southeast Anatolia development project region (Gap): An analysis an agricultural drought perceptive.* Kulwer Academic Publishers, 40: 519–545.

Konsam, S., Thongam, B. & Handique, A.K. 2016. Assessment of wild leafy vegetables traditionally consumed by the ethnic communities of Manipur, northeast India. *Journal of Ethnobiology and Ethnomedicine*, 12(1): 9.

Kumar, R.R. & Cho, J.Y. 2014. Reuse of hydroponic waste solution. *Environmental Science and Pollution Research*, 21(16): 9569–9577.

Labadarios, D., Mchiza, Z.J.R., Steyn, N.P., Gericke, G., Maunder, E.M.W., Davids, Y.D. & Parker, W.A. 2011. Food security in South Africa: a review of national surveys. *Bulletin of the World Health Organization*, *89*: 891-899.

Laio, F., Porporato, A., Ridofi, L. & Rodriguez-Iturbe, I. 2001. Plants in water-controlled ecosystems: active role in hydrologic process and response to water stress II. Probabilistic soil moisture. *Advanced in Water Resources,* 24: 707–723.

Lefever, K. 2013. *Effects of pH and phosphorus concentrations on the cultivation of Salvia chamelaeagnea grown in hydroponics* (Masters Dissertation, Cape Peninsula University of Technology).

Leghari, S.J., Wahocho, N.A., Laghari, G.M., HafeezLaghari, A., MustafaBhabhan, G., HussainTalpur, K., Bhutto, T.A., Wahocho, S.A. & Lashari, A.A. 2016. Role of nitrogen for plant growth and development: A review. *Advances in Environmental Biology*, 10(9):209–219.

Lewu, F.B. & Mavengahama, S. 2010. Wild vegetables in northern kwazulu natal, south africa: Current status of production and research needs. *Scientific Research and Essays*, 5: 3044–3048.

Lindow, M. 2017. Rediscovering local wild food in South Africa's Western Cape. *Re.Think*. https://rethink.earth/rediscovering-local-wild-food-in-South-Africas-Western-Cape/ [22 November 2020].

Lion, G.N. & Olowoyo, J.O. 2013. Population health risk due to dietary intake of toxic heavy metals from Spinacia oleracea harvested from soils collected in and around Tshwane, South Africa. *South African Journal of Botany*, 88:178–182. https://doi.org/10.1016/j.sajb.2013.07.014

Liu, W., Antonelli, M., Kummu, M., Zhao, X., Wu, P., Liu, J., Zhuo, L. & Yang, H. 2019. Savings and losses of global water resources in food-related virtual water trade. *Wiley Interdisciplinary Reviews: Water*, 6(1):e1320.

Liu, Y.J., Tong, Y.P., Zhu, Y.G., Ding, H. & Smith, F. 2006. Leaf chlorophyll readings as an indicator for spinach yield and nutritional quality with different nitrogen fertilizer applications. *Journal of Plant Nutrition*, 29(7): 1207–1217. https://www.tandfonline.com/doi/abs/10.1080/01904160600767401 10 December 2020.

López-Bucio, J., Cruz-Ramírez, A. & Herrera-Estrella, L. 2003. The role of nutrient availability in regulating root architecture. *Current Opinion of Plant Biology*, 6, 280–287. https://doi.org/10.1016/S1369-5266(03)00035-9

Lulekal, E., Asfaw, Z., Kelbessa, E. & Van Damme, P. 2011. Wild edible plants in Ethiopia: a review on their potential to combat food insecurity. *Afrika Focus* 24(2): 71–121.
Maathuis, F.J. 2009. Physiological functions of mineral macronutrients. *Current Opinion of Plant Biology,* 12: 250–258. https://doi.org/10.1016/j.pbi.2009.04.003

Mandizvidza, T. 2017. Influence of nutrient and light management on postharvest quality of lettuce (*Lactuca sativa* L.) in soilless production systems. *Master's Thesis*, University of Stellenbosch.

Mango, N., Siziba, S. & Makate, C. 2017. The impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa. *Agriculture & Food Security*, 6(1): 4–11.

Manisha, N., Raghavendrarao, S., Vandna, R. & Ajay, J. (2016). Deciphering phosphate deficiency –mediated root traits in effects on different root traits in rice grown in a modified hydroponic system. *Frontiers in Plant Science,* 7(550).

Maseko, I., Mabhaudhi, T., Tesfay, S., Araya, H.T., Fezzehazion, M. & Plooy, C.P.D. 2018. African leafy vegetables: A review of status, production, and utilization in South Africa. *Hydrological Sciences Journal,* 64(3): 276–287.

Masud, M.M., Azam, M.N., Mohiuddin, M., Banna, H., Akhtar, R., Alam, A.S.A.F. & Begum, H. 2017. Adaptation barriers and strategies towards climate change: Challenges in the agricultural sector. *Journal of Cleaner Production*, 156: 698–706.

Masuda, T. & Fujita, Y. 2008. Regulation and evolution of chlorophyll metabolism. *Photochemical and Photobiological Sciences*, 7(10): 1131–1149.

Maxwell, D. 1999. The Political Economy of Urban Food Security in Sub-Saharan Africa. *World Development,* 27(11): 1939 –1953. media and fertigation regimes in hydroponics. *Heliyon*, 6(11): e05479.

Mir, M.R., Mobin, M., Khan, N.A., Bhat, M.A., Lone, N.A., Bhat, K.A., Razvi, S.M., Wani, S.A., Wani, N., Akhter, S. & Rashid, S. 2010. Crop responses to interaction between plant growth regulators and nutrients. *Journal of Phytology,* 2(10): 09–19.

Mishra, A.K. & Singh, V.P. 2010. A review of drought concepts. *Journal of Hydrology, 391*(1-2): 202-216.

Misselhorn, A., Aggarwal, P., Ericksen, P., Gregory, P., Horn-Phathanothai, L., Ingram, J. & Wiebe, K. 2012. A vision for attaining food security. *Current Opinion in Environmental Sustainability*, 4(1): 7–17.

Misselhorn, A.A. 2005. What drives food insecurity in southern Africa? a meta-analysis of household economy studies. *Global Environmental Change*, 15: 33–43.

Mncwango, N.C., Mavengahama, S., Ntuli., & van Jaarsveld, C.M. 2020. Diversity, consumption dynamics, and ethnomedical claims of traditional leafy vegetables consumed by a rural community in the KwaMbonambi area, northern KwaZulu-Natal, South Africa. *Journal of Biological Diversity,* 21(3): 1201–1207.

Modi, M., Modi, A. & Hendriks, S. (2006). Potential role for wild vegetables in household food security: a preliminary case study in Kwazulu-Natal, South Africa. *African Journal of Food, Agriculture, Nutrition and Development,* 6(1): 1–13.

Mugambiwa, S.S. & Tirivangasi, H.M. 2017. Climate change: A threat towards achieving ‘sustainable development goal number two’ (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. *Jamba: Journal of Disaster Risk Studies*, 9(1): 1–6.

Mulder, C.H. 2003. AIZOACEAE. *Review of Palaeobotany and Palynology,* 123: 41– 45.

Mushtaq, S., Maraseni, T.N., Maroulis, J. & Hafeez, M. 2009. Energy and water tradeoffs in enhancing. food security: A selective international assessment. *Energy Policy*, *37*(9): 3635–3644.

Nchuchuwe, F.F. & Adejuwon, K.D. 2012. The Challenges of Agriculture and Rural Development in Africa : The case of Nigeria. *International Journal of Academic Research in Progressive Education and Development*, 1(3): 45–61.

Ndlovu, J. & Afolayan, A. 2008. Nutritional analysis of the South African wild vegetable Corchorus olitorius. *Asian Journal of Plant Sciences*, 7: 615–618.

Nellemann, C. & MacDevette, M. 2009. *The environmental food crisis: the environment's role in averting future food crises: a UNEP rapid response assessment*. UNEP/Earthprint.

Nemadodzi, L.E., Araya, H., Nkomo, M., Ngezimana, W. & Mudau, N.F. 2017. Nitrogen, phosphorus, and potassium effects on the physiology and biomass yield of baby spinach (*Spinacia oleracea* L.). *Journal of Plant Nutrition*, 40(14): 2033–2044. https://doi.org/10.1080/01904167.2017.1346121.

Nguyen, N., McInturf, S. & Mendoza-Cózatl, D. 2016. Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements. *Journal of Visualized Experiments,* 113: e54317.

Nxawe, S., Ndakidemi, P.A. & Laubscher, C.P. 2010. Possible effects of regulating hydroponic water temperature on plant growth, accumulation of nutrients and other metabolites. *African Journal of Biotechnology*, 9(54): 9128–9134.

Olukayode, O.E. 1985. A comparative performance analysis of three meteorological drought indices. *Journal of Climatology,* 5(6): 655–664.

Otsuki, J. 2018. Supramolecular approach towards light-harvesting materials based on porphyrins and chlorophylls. *Journal of Materials Chemistry A*, 6(16): 6710–6753. https://pubs.rsc.org/en/content/articlehtml/2018/ta/c7ta11274b [10 December 2020].

Pardossi, A., Carmassi, G., Diara, C., Incrocci, L., Maggini, R.& Massa, D. 2011. Fertigation and substrate management in closed soilless culture. *EUPHOROS report (UNIPI)*.

Pham, V.C., Pham, T.T.H., Tong, T.H.A., Nguyen, T.T.H. & Pham, N.H. 2015. The conversion of agricultural land in the peri-urban areas of Hanoi (Vietnam): patterns in space and time. Journal of Land Use Science, 10: 224–242. https://doi.org/10.1080/1747423X.2014.884643

Pinstrup-Andersen, P. & Pandya-Lorch, R. 1998. Food security and sustainable use of natural resources: a 2020 vision. *Ecological Economics*, *26*(1):1–10.

Rangecroft, S., Van Loon, A.F., Maureira, H., Verbist, K. & Hannah, D.M. 2019. An observation-based method to quantify the human influence on hydrological drought: Upstream–downstream comparison. *Hydrological Sciences Journal*, 64(3): 276-287.

Rasul, G. 2016. Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environmental Development*, 18: 14–25. http://dx.doi.org/10.1016/j.envdev.2015.12.001.

Reed, L.L. & Kleynhans, T.E. 2009. Agricultural land purchases for alternative uses - Evidence from two farming areas in the Western Cape province, South Africa. *Agrekon*, 48: 332–351. https://doi.org/10.1080/03031853.2009.9523830

Resh, H.J. 2013. *Hydroponic Food Production.* A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower, 7th Edition, CRC Press.

Reshmika, P.K., Reshma, M.R. & Gayakawad, P.S. 2016. Expansion of green areas in cities through soilless cultivation of vegetables. *International Journal of Agricultural Science and Research,* 6(2): 209–214.

Roberts, L. 2000. Biotechnology: Hydroponics part 1. *Tech Directions* 60(4): 12.

Ronquest-Ross, L., Gunnar, N. & Sigg, O. 2015. Food consumption changes in South Africa since 1994. *South African Journal of Science,* 111: 9–10.

Rosegrant, M.W. & Cline, S.A. 2003. Global food security: challenges and policies. *Science*, *302*(5652): 1917–1919.
Ruiz-Espinoza, F.H., Murillo-Amador, B., Garcia-Hernandez, J.L., Fenech-Larios, L., Rueda-

Puente, E.O., Troyo-Dieguez, E., Kaya, C. & Beltran-Morales, A. 2010. Field evaluation of the relationship between chlorophyll content in basil leaves and a portable chlorophyll meter (spad-502) readings. *Journal of Plant Nutrition*, 33(3): 423–438.

Rundel, P.W., Esler, K.J. & Cowling, R.M. 1999. Ecological and phylogenetic patterns of carbon isotope discrimination in the winter-rainfall flora of the Richtersveld, South Africa. *Plant Ecology*, 142(1–2): 133–148.

Samarakoon, U.C., Weerasinghe, P.A. & Weerakkody, W.A.P. 2006. Effect of electrical conductivity (EC) of the nutrient solution on nutrient uptake, growth, and yield of leaf lettuce (*Lactuca sativa* L.) in stationary culture.

Saparamadu, J.S., Wijesekera, R.D., Gunawardhana, H.D. & Weerakkody, W.A.P. 2010. A low-cost nutrient formulation with a buffer for simplified hydroponics systems.

Sardare, M.D. & Admane, S.V. 2013. A review on plant without soil-hydroponics. *International Journal of Research in Engineering and Technology* 2(03): 299-304.

Savvas, D. 2003. Hydroponics: A modern technology supporting the application of integrated crop management in greenhouse. *Journal of food Agriculture and Environment*, 1:80–86.

Savvas, D., Karagianni, V., Kotsiras, A., Demopoulos, V., Karkamisi, I. & Pakou, P. 2003. Interactions between ammonium and pH of the nutrient solution supplied to gerbera (*Gerbera jamesonii*) grown in pumice. *Journal of Plant Nutrition*, 393 – 402.

Schwartz, P. & Randall, D. 2003. An Abrupt Climate change scenario and its possible for the United States national security. California Inst of Tech Pasadena Jet Propulsion Lab.

Shaul, O. 2002. Magnesium transport and function in plants: The tip of the iceberg. BioMetals. https://doi.org/10.1023/A:1016091118585

Senyolo, G.M., Wale, E. & Ortmann, G.F. 2018. Analysing the value chain for African leafy vegetables in Limpopo Province, South Africa, *Cogent Social Sciences*, 4(1): 1509417.

Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. & Menkir, A. 2014. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes,* 3: 67–79.

Shrestha, A. & Dunn, B. 2010. Hydroponics. Oklahoma Cooperative Extension Service.

Singh, H., Dunn, B. & Payton, M. 2019. Hydroponic pH modifiers affect plant growth and nutrient content in leafy greens. *Journal of Horticultural Research*, *27*(1): 31–36.

Singh, M.V. 2008. Micronutrient deficiencies in crops and soils in India. In *Micronutrient deficiencies in global crop production.* Springer, Dordrecht, pp 93-125.

Sivakumar, M.V.K., Das, H.P. & Brunini, O. 2005. Impact of present and future climate variability and change on agriculture and forest in the arid and semi-arid tropics. In *Increasing climate variability and change*. Springer, Dordrecht. Pp 31-72.

Snow, A.M., Ghaly, A.E. & Snow, A. 2008. A comparative assessment of hydroponically grown cereal crops for the purification of aquaculture wastewater and the production of fish feed. *Amercian Journal of Agriculture and Biological Science*, 3, 364–378. https://doi.org/10.3844/ajabssp.2008.364.378

Soliman, M.I., Zaghloul, M.S. & Heikal, Y.M. 2017. Comparative karyotype of Three Mesembryanthemum (Aizoaceae) Species in Egypt. *Journal of Modern Science & Engineering,* 1(3): 72–89.

Soltys-Kalina, D., Plich, J., Strzelczyk-Żyta, D., Śliwka, J. & Marczewski, W. 2016. The effect of drought stress on the leaf relative water content and tuber yield of a half-sub family of 'Katahdin'-derived potato cultivars. *Breeding Science,* 66(2): 328-331.

Soriano-García, M., Ilnamiqui Arias-Olguín, I., Pablo Carrillo Montes, J., Genaro Rosas Ramírez, D., Silvestre Mendoza Figueroa, J., Flores-Valverde, E. & Rita Valladares-Rodríguez, M. 2018. Nutritional functional value and therapeutic utilization of Amaranth. *Journal of Analytical & Pharmaceutical Research*, 7: 596–600. https://doi.org/10.15406/japlr.2018.07.00288

Sparovek, G., Berndes, G., Barretto, A.G.D.O.P. & Klug, I.L.F. 2012. The revision of the Brazilian Forest Act: increased deforestation or a historic step towards balancing agricultural development and nature conservation? *Environmental Science & Policy*, *16*: 65–72.

Steel, R.G.D & Torrie, J.H. 1980. *Principle and procedures of statistics; a biometrical approach.* 2nd ed*.* New York: McGraw-Hill.

Stein, A.J., 2010. Global impacts of human mineral malnutrition. *Plant Soil*, 335: 133–154. https://doi.org/10.1007/s11104-009-0228-2

Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., Ciais, P., Guimberteau, M., Traore, S. & Baron, C. 2013. Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. *Environmental Research Letters*, 8(1):014040.

Taban, B.M. & Halkman, A.K. 2011. Do leafy green vegetables and their ready-to-eat [RTE] salads carry a risk of foodborne pathogens? *Anaerobe*, 17(6): 286–287.
Tanaka, A. & Tanaka, R. 2006. Chlorophyll metabolism. *Current Opinion in Plant Biology*, 9(3): 248–255.

Tang, L., Hamid, Y., Sahito, Z.A., Gurajala, H.K., He, Z., Feng, Y. & Yang, X. 2019. Evaluation of variation in essential nutrients and hazardous materials in spinach (Spinacia oleracea L.) genotypes grown on contaminated soil for human consumption. *Journal of Food Composition and Analysis,* 79: 95–106. https://doi.org/10.1016/j.jfca.2019.03.012

Tembo-Phiri, C. 2019. *Edible Fynbos Plants: A Soil types and irrigation regime investigation on Tetragonia decumbens and Mesembryanthemum crystallinum*. Stellenbosch University. http://scholar.sun.ac.za/handle/10019.1/105974.

Teto, A.A., Laubscher, C.P., Ndakidemi, P.A. & Matimati, I. 2016. Paclobutrazol retards vegetative growth in hydroponically-cultured Leonotis leonurus (L.) R.Br. Lamiaceae for a multipurpose flowering potted plant. *South African Journal of Botany*, 106: 67–70. http://dx.doi.org/10.1016/j.sajb.2016.05.012

Treftz, C. & Omaye, S.T. 2016. Hydroponics: Potential for augmenting sustainable food production in non-arable regions. *Nutrition & Food Science*, 46(5): 672-684.

Uprety, Y., Poudel, R.C., Shrestha, K.K., Rajbhandary, S., Tiwari, N.N., Shrestha, U.B. & Asselin, H. 2012. Diversity of use and local knowledge of wild edible plant resources in Nepal. *Journal of Ethnobiology and Ethnomedicine*, 8(1):16.

Uusiku, N.P., Oelofse, A., Duodu, K.G., Bester, M.J. &Faber, M. 2010. Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *Journal of Food Composition and Analysis*, 23(6): 499–509.

Valente, L.M., Britton, A.W., Powell, M.P., Papadopulos, A.S.T., Burgoyne, P.M. & Savolainen, V. 2014. Correlates of hyperdiversity in southern African ice plants (Aizoaceae). *Botanical Journal of the Linnean Society*, 174(1): 110–129.

Van Rensburg W.J., Van Zijl, J.J.B. & Sonja, L.V. 2007. The importance of traditional leafy vegetables in South Africa. *African Journal of Food, Agriculture, Nutrition, and Development*, *7*(4): 1–13.

Van Wyk, B.E. 2011. 'The potential of South African plants in the development of new medicinal products', *South African Journal of Botany,* 77(4):812–829.

Venter, S.L., Jansen van, W.S., Vorster. van den Heeveer., E. & van Zijl, J.JB. 2007. Promotion of African leafy vegetables within the agricultural research council - vegetable and ornamental plant institute: the impact project. *African Journal of Food Agriculture Nutrition and Development,* 7(4):1–12.

Von Wettstein, D., Gough, S. & Kannangara, C.G. 1995. Chlorophyll biosynthesis. *Plant Cell*, 7: 1039–1057. https://doi.org/10.1105/tpc.7.7.1039

Voogt, W. 2002. Potassium Management of Vegetables Under Intensive Growth Conditions, in: Pasricha, N.S., Bansal, S.K. (Eds.), *Proceedings of Colloq*. International Potash Institute, Bern, Switzerland. pp. 347–362.

White, P.J. & Karley, A.J. 2010. Potassium. Plant Cell Monographs, 17: 199–224. https://doi.org/10.1007/978-3-642-10613-2_9

Wiggins, S., Keats, S. & Vigneri, M. 2009. Impact of the global financial and economic situation on agricultural markets and food security. Overseas development institute.

Wiley, J. & Sons. 2018. Climate-resilient crops for improving global food security and safety. *Plant, Cell & Environment,* 41: 877–884.

Wilhite, D.A., Svoboda, M.D. & Hayes. 2007. Understanding the complex impact of drought: A key to enhancing drought mitigation and preparedness. *Water Resource Management,* 21: 763–774.

Willert, D.J. V., Brinekmann, E., Eller, B.M. & Scheitler, B. 1984. Oecologia (Berlin). *Oecologia*,. world and its annual increase. *Phytotaxa*, 261(3): 201–217.

Wortman, S.E. 2015. Crop physiological response to nutrient solution electrical conductivity and pH in an ebb-and-flow hydroponic system. *Scientia Horticulturae*, 194: 34-42.

Wu, M. & Kubota, C. 2008. Effects of electrical conductivity of hydroponic nutrient solution on leaf gas exchange of five greenhouse tomato cultivars. *HortTechnology*, 18(2): 271–277.

Wurtzel, E.T. & Kutchan, T.M. 2016. Plant metabolism, the diverse chemistry set of the future. *Science*, 353(6305): 1232–1236.

Xie, K., Cakmak, I., Wang, S., Zhang, F. & Guo, S. 2020. Synergistic and antagonistic interactions between potassium and magnesium in higher plants. The Crop Journal. In Press. https://doi.org/10.1016/j.cj.2020.10.005

Xing, Y., Jiang, W., He, X., Fiaz, S., Ahmad, S., Lei, X., Wang, W., Wang, Y. & Wang, X. (2019). A review of nitrogen translocation and nitrogen-use efficiency. *Journal of Plant Nutrition*, 42(19): 2624–2641.

Xu, X., He, P., Pampolino, M.F., Johnston, A.M., Qiu, S., Zhao, S., Chuan, L. & Zhou, W. 2014. Fertilizer recommendation for maize in China based on yield response and agronomic efficiency. *Field Crops Research*, 157: 27–34.

Yadav, S., Irfan, M., Ahmad, A. & Hayat, S. 2011. Causes of salinity and plant manifestations to salt stress: a review. *Journal of Environmental Biology*, 32(5): 667.
Yield of lettuce grown in hydroponic and aquaponic systems using different substrates.

Yang, H., Wang, L., Abbaspour, K.C. & Zehnder, A.J.B. 2006. Virtual water highway: Water use efficiency in global food trade. *Hydrology and Earth System Sciences Discussions*, 3: 1–26.

Zhang, C., Huang, Y., Xiao, Z., Yang, H., Hao, Q. & Yuan, S. 2020. (Glycine max) Regulates Chlorophyll Biosynthesis. *Plants*, 9: 1036.