EFFECTS OF IRRIGATION INTERVAL AND PLANTING DENSITY ON BIOMASS YIELD AND CHEMICAL COMPOSITION OF NIGHTSHADE (*SOLANUM RETROFLEXUM*) IN LIMPOPO PROVINCE, SOUTH AFRICA

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF AGRICULTURAL MANAGEMENT (PLANT PRODUCTION), DEPARTMENT OF PLANT PRODUCTION, SOIL SCIENCE AND AGRICULTURAL ENGINEERING, SCHOOL OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES, FACULTY OF SCIENCE AND AGRICULTURE, UNIVERSITY OF LIMPOPO, SOUTH AFRICA

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DECLARATION

I, Thakgala Confidence Mabotja, declare that this dissertation hereby submitted to the University of Limpopo for the degree Master of Agriculture Management has not been previously submitted by me or anybody for a degree at this or any other University, that this is my work in design and in execution and that all material contained herein had been acknowledged.

Candidate: Thakgala Confidence Mabotja ________ Signature ________ Date

Supervisor: Professor P.W. Mashela ________ Signature ________ Date

DEDICATION

To my loving mother: Eunice Kwena Mabotja

My son: Kutullo Thebe Mabotja

My brother: Mosa Mabotja

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ABSTRACT

Nightshade (*Solanum retroflexum* Dun.) is among the most important indigenous leafy vegetables in Vhembe District, Limpopo Province, South Africa, due to its high values of beta-carotene, vitamin E, folic acid, ascorbic acid, calcium, iron and protein. Vhembe District occurs in the tropical regions of Limpopo Province and the production of vegetables is dependent upon the availability of irrigation water. An Integrated Drip Irrigation System (IDIS) and a 3S planter were developed to save water by planting several plants/hole of drip irrigation system. The subsystems in IDIS allow for the production of different crops with different water requirements, whereas the 3S planter can be used for planting from one to nine plants/hole of drip irrigation system. Also, the subsystems could be used in assessing irrigation interval for crops under various planting densities. The interaction of irrigation interval and planting density of *S. retroflexum* had not been documented. The objective of this study, therefore, was to determine the interactive effects of irrigation interval and planting density on biomass yield and chemical nutrient elements (summer harvest only) of *S. retroflexum* under field conditions. The irrigation interval and planting density/hole were arranged in a split-plot experimental design, with eight replications. The main plot was irrigation interval and the subplot was the planting densities. Harvesting was done twice for both summer and winter experiments. The first harvest (H1) was done at 6 weeks after transplanting, with the second harvest (H2) being done at six weeks after the first harvest. Fresh shoots were oven-dried at 60°C for 72 h for the determination of dry matter. Mature leaves were powdered and analysed for mineral content (Ca, P, K, Mg, Na, Fe, Zn, Mn and Cu) using the ICPE-9000. Data were subjected to analysis of variance using SAS software. In the summer experiment, the interaction was significant ($P \leq 0.05$) for dry shoot mass at H1 and H2. However, the contribution of the interaction in the total treatment variation (TTV) of the variable was negligent and therefore, only single factors were reported. Irrigation interval and planting density had highly significant ($P \leq 0.01$) effects on plant variables during H1 and H2 in summer and winter. However, irrigation interval effects for dry shoot mass were not significant for summer H2. Interaction effects were significant for Ca, P, K, Mg, Mn and Cu in leaf tissues during summer H1, but were not significant for Na, Fe and Zn. Also, irrigation interval was significant for Ca, Mg, P, K, Na, Fe, Zn, Mn and Cu during summer H1, whereas planting density had no significant effects for all chemical nutrients except for Ca, P and K during summer H1. Dry shoot mass of *S. retroflexum* increased linearly with increasing irrigation interval and planting density. Results suggested that most nutrient elements increased with deficit irrigation water and higher planting density, whilst P decreased under high planting density. The study showed that there is a high potential for saving water through longer irrigation intervals and produce good high yields at a higher planting density. In conclusion, the use of IDIS and 3S planter to promote growth and accumulation of essential nutrient elements on *S. retroflexum* demonstrated that longer irrigation interval and higher plant density per drip irrigation hole could be suitable for cultivation of this indigenous vegetable. The recommendation of this study is that higher planting density and longer irrigation intervals are key determinants of higher biomass yield and water saving strategies for large-scale production of the crop. Further, the mineral composition of the crop was under the influence of higher planting density and irrigation intervals.

CHAPTER 1

GENERAL INTRODUCTION

1. Research problem

1.1 Background

1.1.1 Description of the research problem

An Integrated Irrigation System (IIS) intended to produce high crop yield per drop of irrigation water was researched and developed at the Green Biotechnologies Research Centre for Excellence (GBRCE), University of Limpopo, South Africa in the context of climate-smart agriculture (Mashela, 2015). Climate change is adding pressure to the already stressed ecosystem for agricultural productions. Climate change projections suggested future decreases in yields of maize (5%), wheat (22%) and rice (2%) due to increases of drought in South Africa (Mabhaudhi and Modi, 2016). Many agricultural production systems are now being affected by climate change which had since increased uncertainty and exacerbate drought incidents, land loss due to salinity and water scarcity (IFAD, 2011). On the other hand, a wild vegetable species such as nightshade (*Solanum retroflexum* Dun.), which is indigenous to South Africa, is drought-tolerant and has the potential to produce high vegetative yield in areas where most exotic crops might perform poorly (Van Averbeke and Juma, 2006).

Worldwide, there is a growing need for developing resilient agricultural systems and new strategies that could be adaptable to climate change (Chivenge *et al*., 2015). The new strategies should ideally involve promotion and cultivation of indigenous vegetables, which could therefore, be essential in the future development of appropriate water-saving management tactics and increase in the efficiency of water use for agricultural production and processing (Mashela, 2015).

Inland South Africa temperature is projected to increase by 6°C and rainfall decrease by 5-10% by 2030. Worldwide, water scarcity is already affecting 2.8 billion people during at least one month of every year (IPCC, 2014). Increased demand for food security, mineral nutrition security and water security from the growing populations and the effects of climate change, had been escalating the impact of food insecurities and nutrition insecurities with water scarcity experienced in arid- and semi-arid areas of South Africa (Wenhold *et al*., 2007).

Water security can be defined as the reliable availability of an acceptance quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks (Muller *et al*., 2009). Efficient water use by IIS is, therefore, becoming increasingly, important especially in arid- and semi-arid regions with limited water sources (Mashela, 2015). Climate change has a negative impact in agriculture by increasing water demand (Reid *et al*., 2005), where the world is expected to produce more nutritious food to meet the demand of rapidly growing populations by 70% in developing countries (FAO, 2013). Therefore, cultivation of drought-tolerant plants coupled with appropriate water saving systems like the Integrated Drip Irrigation System (IDIS) and 3S planter would be able to increase the capacity of agricultural productions as dictated by extremes of climate change (Mashela, 2015).

Worldwide, water scarcity is a major threat to food and nutrition security (Besada and Werner, 2015). However, there is a low intake of vegetables, which had been among the top ten risks factors intensifying mortality (Shiundu, 2005). Indigenous vegetables are known to be drought-tolerant and rich sources of various micronutrients. In the year 2000, South Africa had11.1 million males and 12.5 million females who were over 15 years with a low intake of vegetables (Schneider *et al*., 2007). In order to address the situation, there had been a necessity to increase the cultivation of indigenous vegetables and to promote their utilisation. However, modernisation of South African communities, affordability and availability of vegetables due to their seasonality, have had a negative impact on consumption of indigenous vegetables (Faber and Wenhold, 2007). Among various adaptation mechanisms, selection and promotion of indigenous vegetables with low fertiliser and water requirements might also contribute to improve food, nutrition and water security in marginal communities (Steyn *et al*., 2001).

S*olanum retroflexum* is a biannual herbaceous indigenous plant and could sometimes behave as a perennial due to its deep root system (Akubugwo *et al*., 2007; Njume *et al*., 2014; Van Rensburg *et al*., 2014). *Solanum retroflexum* belongs to the family *Solanaceae*, a cosmopolitan family containing most essential vegetables and fruits that includes tomatoes, chilies, green and red peppers (Edmonds and Cheweya, 1997). This plant is among the most important indigenous leafy vegetables in Vhembe District, Limpopo Province, containing high beta-carotene, vitamin A and E, folic acid, ascorbic acid, calcium, iron, fibre and proteins (Van Averbeke and Juma, 2006). Therefore, this plant could be suitable for cultivation in most arid- and semi-arid rural regions of South Africa (Van Jaarsveld *et al*., 2014). The plant also has some medicinal properties and is widely used in treating cancerous sores, leucoderma and wounds (Edmonds and Cheweya, 1997; Maanda and Bhat, 2010). The purple or black berries are extensively consumed either as fresh or as preserves, but green fruit berries contain solanine ($C_{45}H_{73}NO_{15}$), which could cause some degree of human poisoning (Van Rensburg *et al*., 2007).

Currently, there is scant information on interactive effects of irrigation interval and planting densities on growth of *S. retroflexum* as well as the mineral nutrient in leaf tissues. This indigenous vegetable is one of the most underutilised crops intended for use in context of climate-smart agriculture. Climate-smart agriculture (CSA) is an integrative approach for developing agricultural strategies by adapting and building resilience in agricultural production system for food security under climate change and also by reducing greenhouse gas emissions from agricultural production system (World Bank, 2008). Indigenous vegetables can grow on soil with low fertility, and most are relatively drought-tolerant, are well-adapted to harsh environmental conditions and require limited synthetic chemicals protection against pest (Van Averbeke and Juma, 2006). Increase in water use efficiency holds the key to mitigating water scarcity and food or nutrition insecurity issues (Costa *et al*., 2007). The 3S planter can improve water use efficiency by improving soil coverages, therefore, supplying more crops with one drop of water. The IDIS is a water-saving irrigation system which could mitigate the negative impact of climate change on limited available water sources for agricultural purposes.

1.1.2 Impact of the research problem

Agriculture alone contributes 14% of the greenhouse gas emissions to global emission scales (IPCC, 2007). The drawbacks of climate change are generally felt through a series of impacts that cover all aspects of socio-economic impacts in terms of economic opportunities and political stability (IFAD, 2011). Globally hot temperatures are expected to increase by 2°C to 5°C between 2010 and 2050, with the estimated cost to adapt to climatic fluctuations being approximately US$75 billion to US$100 billion a year (Benhin, 2006). Approximately, 7.4 million people in South Africa suffer from hunger every day, which is a direct negative effect on food and nutrition security (Stats SA, 2016). Global climate change introduces more uncertainty regarding future water supplies, with water scarcity threatening food and nutrition security (FAO, 2013). Achieving food, nutrition and water security and to produce high crop yields under such conditions, depends on many factors, including the proper irrigation intervals and the use of optimum planting densities.

1.1.3 Possible causes of the research problem

Previously, indigenous vegetables played a major role in contributing to food and nutrition security for poor communities in the rural areas of South Africa (Oelefse and Van Averbeke, 2012). However, the utilisation of these crops had been relegated to the status of weeds (Mashela and Mollel, 2001) by promoting exotic crops, which resulted in declining consumption and cultivation of former crops (Van Rensburg *et al*., 2004). Due to their nutritional content, there is immediate need in improvement of dietary intake of leafy indigenous vegetables, especially in marginalised households. Usually, the indigenous leafy vegetables are easier to produce and require limited cultural practices such as irrigation, fertilisation and pest management with respect to weed, insect, and pathogens (Slabbert, 2007; Van Rensburg *et al*., 2007; Van Vuuren, 2006).

In 2015, Limpopo Province was declared a disaster area due to continuous droughts, which were last experienced in 1983 (SAHNS, 2016). The current exotic crop yield, quality and quantity were reduced and could be hardly sustained in terms of production under such harsh environmental conditions. Therefore, it is urgent to promote the production and utilisation of indigenous leafy vegetables in order to provide food and nutrition security to marginalised households (Van Jaarsveld *et al*., 2014). The planting density and the quantity of water are important on yield production and growth of crops, but these are difficult by inherently being plant-specific. *Solanum retroflexum* is an essential indigenous leafy vegetable to South Africa (Schippers, 2002), but is mostly harvested from the wild, with limited cultivated areas by small-scale farmers in rural communities in Vhembe District, Limpopo Province (Van Averbeke and Juma, 2006). This vegetable could play an important role in food security, job creation and wealth creation as outlined in the Presidential Outcomes set aside for the agricultural sector (NDP, 2012).

Water scarcity is one of the leading challenges affecting more than 1.1 billion of people globally (WWF, 2014). Over 40% of the world population lives in regions with water scarce challenges and the situation could worsen if current population growth trends continue. Climate change is generally the primary determinant of agricultural productivity (Bouwer, 2000). Future climate change would also worsen the current stressors such as drought conditions and flooding events that would severely affect the agricultural potential of many regions, which would subsequently place food security at dire risk. Strategies and new innovations should therefore, be implemented to improve water use efficiency (WUE), starting with the choice of irrigation system and optimal planting densities followed by the application of the proper irrigation intervals in terms of both timing and quantity of water. Due to repeated incidents of drought coupled with increasing water scarcity the IDIS and 3S planter would be ideal to improve crop WUE. These systems are being researched and developed by the GBRCE, University of Limpopo (Mashela, 2015).

South Africa is fundamentally a semi-arid and water-scarce country with a mean annual rainfall of 500 mm, which is half the world average, with 9% rainfall converted to river runoff (Tapela, 2008). Prospects of climate change, low and irregular rainfall, along with continued population growth and industrialisation in Limpopo Province, due to increased mining activities, have intensified the search for measures to conserve water in irrigated agriculture (IPCC, 2014). Competition for water resources is one of the greatest concerns when viewed within the context of the impacts this would have on exotic crops and the vulnerability of marginal communities and the urban poor, regarding food and nutrition security, because the incidents of crop failures would likely increase (Sisulu and Scaramella, 2012).

1.1.4 Proposed solutions

Indigenous future crops, particularly the neglected underutilised crops, have high nutritional levels of micro-nutrients and are mostly drought-tolerant (Shiundu, 2005). Therefore, such crops could significantly contribute to nutrition security if eaten as part of the daily diets (Makobo *et al*., 2010). *Solanum retroflexum* is considered as a wild species, and thus, has never been considered for large-scale commercial production in South Africa, with limited information on its agronomics (Van Averbeke and Juma, 2006). Given the challenges that Limpopo Province is rated as one of the poorest provinces in South Africa, with high level of water scarcity, unlimited population growth and restricted food and nutrition security (Machete *et al*., 2004; Oelefse and Van

Averbeke, 2012), alternative crops should be sought and further researched and developed to enhance their entering the main stream agricultural production systems.

Indigenous leafy vegetables had been identified as holding the key to contributing towards food and nutrition security (NDP, 2012). Such plants have the potential to adapt from the underutilised status to commercial production status, thereby, contributing to income generation for subsistence farmers. Consequently, there is need to generate empirically-based information on water requirement and agronomic practices for these vegetables (Maseko *et al*., 2015). Water requirement could include amount of water per irrigation and irrigation interval, which plant- specific. Agronomic practices in indigenous vegetables would among other things, include optimum irrigation interval as well as the planting density per hole of drip irrigation system and mineral content of *S. retroflexum*.

Generally, the production of indigenous vegetables in South Africa does not meet the market demands due to inappropriate production technologies and the exclusive focus on exotic vegetables (Schippers, 2006). Education on health benefits of indigenous leafy vegetables would be essential. Also, most indigenous leafy vegetables are adaptable to low rainfall in semi-arid areas of Southern Africa, where water scarcity for crop production is one of the major limiting factors (Machete *et al*., 2004; Oelefse and Van Averbeke, 2012).

Irrigation in South Africa accounts for nearly 63% of arable agriculture, with some estimates being as high as 70% (Gerbens-Leenes and Nonhebel, 2004). Therefore, irrigation water management in context of climate-smart agriculture would have to be carried out efficiently and effectively with the aim of saving water, while maximising crop productivity (Niederwieser, 2001). Concerns on future increasing water demands inland South Africa have led to the introduction of new technologies and strategies for improving water use efficiency, while improving underutilised indigenous future crops which could have the capability to ameliorate the effects of drought on food security.

1.1.5 General focus of the study

The overview of smallholder farming in South Africa suggested that indigenous vegetable farming has an important role in human nutrition in the rural areas of the country (Oelofse and Van Averbeke, 2012). *Solanum retroflexum* is a drought- tolerant indigenous leafy vegetable, rich in protein, fibers, vitamins and amino acids. This makes *S. retroflexum* an indigenous leafy vegetable of choice for inclusion in food-based approaches that have the potential to ameliorate malnutrition, which is an important type of under nutrition among the marginal communities of South Africa (Van Averbeke *et al*., 2007). However, information on the irrigation interval and planting density for this plant had not been documented. Therefore, the production of multiple seedlings and irrigation interval through the water-saving IDIS and the use of 3S planter would provide information on the optimum irrigation interval and the optimum planting density for this vegetable.

1.2 Problem statement

Solanum retroflexum is an essential leafy vegetable indigenous to Limpopo Province, South Africa, with medicinal and nutritional properties for serving as a future crop. However, information on the interactive effects of irrigation interval and planting density on vegetative yield and mineral nutrients of *S. retroflexum* is not documented.

Selection and promotion of indigenous nutritious food crops with low water requirement for smallholder farmers and home gardeners would improve food security, nutritional and health status. The researcher intends to establish multiple planting densities of *S. retroflexum* through the use of IDIS and 3S planter to optimise the productivity of this leafy vegetable under different irrigation interval.

1.3 Rationale of the study

Solanum retroflexum is a drought-tolerant indigenous crop with the potential to serve as a future crop under the context of climate change inland South Africa, where predictions such as harsher climatic conditions for most exotic crops by 2030 had been made (Sisulu and Scaramella, 2012). It is expected that good management, adoption of new strategies and innovations together with suitable practice will improve water conservation and intake of underutilised indigenous vegetable and result in more efficient crop production under irrigated conditions (Mashela, 2015). The establishment of *S. retroflexum* under irrigation interval and planting density would provide essential growth, yield and mineral content information with respect to the potential usefulness of this plant as a future crop. A better understanding of the effects of irrigation and planting densities on indigenous vegetable can help to determine optimal irrigation scheduling.

1.4 Purpose of the study

1.4.1 Aim

Developed sustainable cropping systems for *S. retroflexum* in semi-arid regions of Limpopo Province.

1.4 2 Objectives

1. To determine interactive effects of different irrigation interval and planting density per drip hole on vegetative growth and mineral nutrients of *S. retroflexum* during summer.
2. To investigate the interactive effects of different irrigation interval and planting density per drip hole on vegetative growth of *S. retroflexum* during winter.

1.5 Hypotheses

1. The interactive effects of different irrigation interval and planting density per drip hole would have an effect on vegetative growth and nutritional elements of *S. retroflexum* during summer*.*
2. The interactive effects of different irrigation interval and planting densities per drip hole would have an effect on vegetative growth of *S. retroflexum* during winter.

1.6 Reliability, validity and objectivity

In this study, reliability of data were based on statistical analysis of data at the 5% probability level, validity would be achieved through repeating the experiments in time, while objectivity would be achieved by ensuring that the findings are discussed on the basis of empirical evidence, in order to eliminate all forms of subjectivity (Leedy and Ormrod, 2005).

1.7 Bias

Bias would be minimised by ensuring that the experimental error in each experiment was reduced through replications, and by assigning treatments randomly within the selected research designs (Leedy and Ormrod, 2005).

1.8 Ethical considerations

In the current study, IIS in under review for patent registration by the University of Limpopo. The researcher would ensure that moral or legal rights of any potential claimants are respected. The University policies, appropriate legal framework and ethical considerations as outlined here, would endure beyond the completion of this study.

1.9 Scientific contribution

Findings of the study would provide empirically-based information on interactive effects of irrigation interval and planting density on growth and chemical composition of *S. retroflexum* under Limpopo Province. The information would help in decision-making as to whether the plant could be embraced as a future alternate crop for the semi-arid regions of Limpopo Province.

1.10 Structure of dissertation

Chapter 1 focused on Research Problem, followed by Literature Review (Chapter 2). Chapter 3 focused on addressing both Objective 1 and Objective 2. In Chapter 4, the findings were summarised and then integrated to provide the significance of the findings and the recommendations with respect to future research, which were followed by conclusions. Citations in text and reference-listing adopted the Harvard style using author-alphabet as approved by the Senate of the University of Limpopo.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Indigenous vegetables are the most important source of food, mainly in the rural areas of South Africa (Modi *et al*., 2006; Van Rensburg *et al*., 2007; Vorster *et al*., 2007; Vorster *et al*., 2008). These vegetables had formed part of human diet since the time of Khoisanoid people, who lived in Southern Africa over 120 000 years and survived by collecting plants from the wild (Fox and Norwood Young,1982; Parsons, 1993). Collecting and cultivating vegetables continued over the years to be a predominant cultural practice among Africans in South Africa (Bhat and Rubuluza, 2002; Husselman and Sizane, 2 006; Modi *et al*., 2006; Van Rensburg *et al*., 2004). Most indigenous vegetables are both heat-tolerant and drought-tolerant, and therefore, require minimum resources, which make them suitable for smallholder farmers and home gardeners (Dovie *et al*., 2002; Shackleton *et al*., 1999; Shackleton, 2003; Van Rensburg *et al*., 2007). Indigenous vegetables were reported to be resistant to certain pests and pathogens (DAFF, 2013). Therefore, the basic assumption had been that they could grow better and produce higher yields when proper agronomic management factors such as irrigation interval and planting density were optimised

Indigenous vegetables form part of the daily staple diet of South Africans and are rich in nutrients such as vitamin A and iron (Faber *et al*., 2010), which are commonly associated with malnutrition diseases. The inclusion of these vegetables in human diets had been identified as a major means of promoting balanced diet across populations in marginal areas, however their level of utilisation had been decreasing (Mauyo *et al*., 2008; Modi *et al*., 2006). Most South African rural communities were observed to be consuming less indigenous vegetables, which contributed to poor quality diets and increased incidents of nutritional deficiencies (DAFF, 2013; Medisa and Tshamekang, 1995; Modi *et al*., 2006; Shackleton 2003; Steyn *et al*., 2001; Van Rensburg *et al*., 2007). The decreased level of utilisation is characterised by limited information on agronomic practices that describe production systems such as the amount of irrigation and optimum planting density (Van Rensburg *et al*., 2007).

Most indigenous vegetables are often described as drought-tolerant and have the potential to ameliorate poverty, hunger and malnutrition when different strategies are applied and could, therefore, prove vital in fighting food insecurities (Mabhaudhi, 2009; Zeven, 1998). Strategies based on health benefits and nutrient-rich foods like indigenous vegetables are considered essential. Studies conducted on wild African vegetables in South Africa also highlighted their significant contribution as sources of micronutrients (Lewu and Mavenghama, 2010; Nesamvuni *et al*., 2001). Generally, most indigenous vegetables contain micronutrient levels as high as or even much higher than those found in exotic vegetables (Ndlovu and Afolayan, 2008; Odhav *et al*., 2007; Steyn *et al*., 2001).

Other studies (Faber *et al*., 2007; Flyman and Afolayan, 2006; Odhav *et al*., 2007 Uusiki *et al*., 2010) reported that nutritional composition of indigenous leafy vegetables have high levels of vitamin A and minerals when compared to those in cultivated vegetables. However, most indigenous knowledge systems for these vegetables had been lost over decades and this had been attributed to people’s negligence to learn about such culture due to limited information on agronomic and cultivation practices, exacerbated by much reliance on exotic vegetables (Vorster *et al*., 2008). Lost knowledge included other less known edible vegetable species, preservation methods, indigenous seed collection, and storage systems. The decline in indigenous vegetable knowledge systems coupled with limited information on nutritional values had been cited among reasons for the decline in the consumption of indigenous vegetables (Mnzava, 1997). Lack of improved cultivars constraints the production of these vegetables. On the other hand, seed companies do not consider the production and marketing of indigenous vegetable seeds to be a profitable business. In addition, *S. retroflexum* is an open-pollinated plant species, which allows farmers to save their own seeds. This further reduces marketing opportunities for private companies (Afari-Sefa *et al*., 2012).

2.2 Work done on the problem statement

2.2.1 Crop yield response to planting density

Optimum planting density is a key to achieving maximum crop production, especially when water is a limiting factor (Bell *et al*., 1991). The ideal planting densities could lead to optimum yields, whereas too high or too low planting densities could result in relatively lower yields and quality (Maseko *et al*., 2015). Currently, most farmers aim at producing the highest yield per production area by resorting to the highest possible planting density. One of the possible ways to achieve this is to increase planting density by decreasing row spacing (Rana and Rana, 2014). The plant number per unit area could be easily increased and also the potential yield loss of individual plants can be compensated by the higher plant density (ARC-GCI, 2002). However, higher planting densities intensify competition for nutrients, physical space and water. Under drought conditions, competition could be high resulting in extreme plant water stress (Law-Ogbomo and Eghaverba, 2009). Increasing plant density might decrease the individual production of plants, but the overall yield per unit area might increase in accordance to density-dependent growth patterns (Egli, 1988). Plant population management is generally poor in many smallholder farming systems under irrigation, with under populations being prevalent (Moswetsi *et al*., 2017).

Changes in planting densities might necessitate changes in cultural practices. For instance, *Amaranthus* planting densities from 100 to 200 plants/m^2 could be practiced for the increased yield if the uprooting method at harvest was to be used (Mamadi *et al*., 2009). The yield could be from 1.2 to 2.25 kg/m^2. The planting density for onions when using the 3S planter ranged from of 25 plants/m^2 to 225 plants/m^2 (Mabotja, 2015), with bulb yield from 44g/m^2 to 215g/m^2. For leafy vegetables that can be harvested more than once, 20 to 25 plants/m^2 could be highly recommended and the expected yield could range from 1.0 to 1.5 kg/m^2 (Mabotja, 2015).

However, too high or too low planting density could have positive or negative impact on most crop traits. As planting density increases, there is an increase in interference for available water, nutrients and light, the competition results in reduced yield (Law-Ogbomo and Egharevba, 2009). Water stress, nutrient deficiency and less light penetration are induced by higher plant density (Yarnia, 2010). Increased competition for available nutrients in the soil at higher plant densities might lead to reduced chlorophyll content due to shading (Kamel *et al*., 1983). Lower plant densities might result in higher chlorophyll content due to less competition for nutrients and less shading. Aminifard *et al*. (2012) reported no variations in chlorophyll content of sweet pepper (*Capsicum annuum L.*) due to increased plant densities, suggesting that variations could be plant-specific.

The study conducted at the Green Biotechnologies Research Centre for Excellence (Mabotja, 2015), on exotic crops such as onion (*Allium cepa* L.), Swiss chard (*Beta vulgaris* subsp. *vulgaris*) and beetroot (*Beta vulgaris* L.) under the use of IIS irrigation system and a 3S planter had linear relations for plant growth variables and planting density, suggesting that the system could be suitable for 9 plants per hole of drip irrigation. The highest yield was observed at 8 and 9 plants per hole of drip irrigation. More crop yields per one drop of water were being practiced on exotic vegetable crops.

2.2.2 Planting density of crops

The ideal planting density depends on several factors such as availability of water, soil fertility, type of crop and row spacing (Rana and Rana, 2014). High plant density can significantly increase yield per unit area, however high planting density than the required can results in additional stress to the plants which in turn could have adverse effects on yield, whereas lower planting density could lead to unnecessary sacrificing of crop yield (ARC-GCI, 2002). Higher planting density increases leaf area index (LAI) and consequently, water consumption. Therefore, the use of higher planting density under limited water supply may increase plant water stress and dramatically reduce yield (Tetio-kagho and Gardner, 1988). The use of IDIS and 3S planter can therefore help in improving water use efficiency by planting multiple seedlings of *S. retroflexum* per hole of drip irrigation.

2.2.3 Crop yield response to irrigation interval

Successful vegetable production depends on adequate water for plant growth and good yields. However, due to shortage of water in South Africa, most vegetable producers experience high crop yield losses (DWAF, 2002). Water shortage in crop production interferes with the normal functioning of plant cells such as elongation and expansion, resulting in reduced plant height, leaf number and leaf area and, generally, reduced plant growth (Kaya *et al*., 2006; Nonami, 1998). Limpopo Province had been declared as a disaster area due to continuous drought spells in 2015 (SAHNS, 2016). Therefore, application of water through irrigation systems became a necessity for vegetable farmers to produce target crop yields.

Water-saving strategies could be achieved by practicing irrigation interval, where vegetable plants are irrigated less than the crop water requirement. The concept had been defined as deficit irrigation (Pereira *et al*., 2002). Irrigation is affected by the structure and texture of the soil, depth of effective root-zone of the soil, type of the crop and developmental stage of the crop (Scherer, 2000). Proper irrigation plays a major role in increasing the water use efficiency and productivity by applying the required amount of water when it is needed. Studies have shown that increased water productivity and water use efficiency through proper irrigation intervals in crop production holds the key to future water scarcity challenges (UN-Water, 2007).

The relation between irrigation interval and water use efficiency is another issue when dealing with irrigation management practices in vegetable production. Water use efficiency increases of up to over 60% or 70% without harming crop yield or quality have been recorded in best case scenarios (Costa *et al*., 2007). The study conducted by Nkgapele and Mphosi (2014) on indigenous leafy vegetable, wild cucumber (*Cucumis myriocarpus* Naudin), revealed that an irrigation interval of 4 days could produce the highest crop fresh and dry biomass yields. Khazaie *et al*., (2007) reported that high potential for water saving could be achieved through the longest irrigation of 14 days on certain medicinal and herbaceous plants such as thyme (*Thymus vulguris*) and hyssop (*Hyssopus officinalis*).

2.2.4 Crop yield response to irrigation interval and planting densities interaction

Yield of vegetables is a complex variable that depends on the interaction between environmental factors and management practices. Achieving high crop yield under water scarce regions depends on various factors, including proper irrigation interval together with optimum planting densities (Mashela, 2015). A better understanding of the effects of irrigation interval and planting densities can help to determine optimal irrigation scheduling and planting densities (Wang and Tian, 2004). Therefore, there is a need to improve irrigation water management for indigenous vegetables in smallholder farming systems. Due to limited information on agronomics of indigenous vegetables (Nesamvuni *et al*., 2001), there is need to establish interaction effects of irrigation interval and planting density for crops such as *S. retroflexum*.

2.2.5 Contribution of indigenous vegetables in Limpopo Province

Limpopo Province is known to be one of the poorest provinces in South Africa, with 89% of the provincial population living in rural areas and 11% in urban/peri-urban areas with a very high rate (38.9%) of unemployment (Stats SA, 2012). Therefore, there is a need to encourage and promote the consumption of affordable food such as traditional food crops. Indigenous vegetables are rich in mineral nutrient elements and play a major role in contributing to food security, especially to poor family households (Oelefse and Van Averbeke, 2012). Limpopo Province was reported to have higher consumption of traditional food crops and these crops have the potential to combat hidden hunger, more especially among low income earners and the rural population (Steyn *et al*., 2001).

2.2.6 Irrigation systems in Limpopo Province for smallholder farmers

South Africa has invested substantially in smallholder farmer irrigation systems, particularly in the former homelands. Irrigation need to be designed for production of multiple crops in order to enhance holistic livelihoods (Mapedza *et al*., 2015). In Limpopo Province alone, there had been 171 irrigation schemes with assets valued at R4 billion (Botha *et al*., 2003). However, most of the irrigation schemes never performed optimally (Botha *et al*., 2003) and had been abandoned. In these areas, irrigated farming has the potential to contribute significantly to food security and income and create employment for the homestead participating in the irrigation schemes (Bembridge, 2000; Letsoalo and Van Averbeke, 2004). Limpopo Province is one of the driest and the poorest province in South Africa, with over 18 500 ha of smallholder irrigation (Machete et *al*., 2004). However, productivity is generally low and the farmer’s income is often below subsistence levels (Machete *et al*., 2004). According to the White Paper on Agriculture (NDA, 1995), water in South Africa is a limited natural resource that is essential for life in both rural and urban areas. Coupled with the intensity of mining sectors in the region, water is bound to continue to be a source of conflict among various stakeholders.

2.3 Work not yet done on the problem statement

2.3.1 Proposed integrated irrigation system

Integrated drip irrigation system (IDIS) is a water-saving irrigation system, with the aim to produce more crop yields per one hole of drip irrigation. The system was designed particularly for smallholder farmers and home gardeners to improve water use efficiency in rural areas of South Africa. There is a greater need for water application systems that would result in improved water use efficiency and lower evaporation losses. The IDIS structure was built out of a drip tubing pipes, control valves, various connectors, clamps, pipes thread to hose thread adapters, end caps and hose pipes for division of the main system to the subsystems (Mashela, 2015). The main system has one control valve for water supply to the subsystems, with each having its own control valve.

2.4 Addressing the identified gaps

Water scarcity in South Africa, particularly in the drought-prone Limpopo Province, had since highlighted the need to improve water use efficiency. Due to the growing population there is need to promote the utilisation of indigenous food crops in order to secure food and nutrition security at household level in poor rural areas. The promotion of water use efficiency systems like IDIS and 3S planter would be necessary for the production of indigenous leafy vegetables under water scarce areas in South Africa.

2.5 Summary of the gaps to be investigated

Currently, there is limited agronomic information on irrigation interval and planting density of *S. retroflexum* in the drought-prone Limpopo Province. Empirically-based information on the listed two gaps, could enhance the production of *S. retroflexum* in

Limpopo Province and thereby improving the consumption of indigenous leafy vegetables.

CHAPTER 3

EFFECTS OF IRRIGATION INTERVAL AND PLANTING DENSITY ON VEGETATIVE GROWTH AND CHEMICAL COMPOSITION OF NIGHTSHADE

3.1. Introduction

Integrated Irrigation Systems (IIS) for improving water use efficiency (WUE) in cropping systems is becoming increasingly important in semi-arid regions, where water deficit is a major challenge. An Integrated Drip Irrigation System (IDIS) and a 3S planter were developed to save water and increase planting densities/drip hole, respectively, in the semi-arid regions of Limpopo Province. The IDIS has a number of capabilities related to WUE since one drip hole/drip irrigation hole supplies multiple plants, whereas the 3S planter is used for planting one to nine seedlings per drip irrigation hole. The system is intended to increase planting densities and therefore, crop yields.

The system was tested for planting density in maize (*Zea mays* L.) and cowpea *(Vigna unguiculata* L.) (Mashela, 2015), onion (*Allium cepa* L.), beetroot (*Beta vulgris* L.) and Swiss chard (*Beta vulgaris var. cicla* L.) (Mabotja, 2015). In all cases, yield was increased several folds. The efficacy of the system had not been tested for use in the production of wild indigenous vegetables, most of which have attributes for use as alternative crops in semi-arid regions. Some indigenous vegetables have high nutritional levels of micronutrients and could contribute to nutritional security in marginal communities of South Africa (Makobo *et al*., 2010). *Solanum retroflexum* is one of such essential vegetable indigenous to Limpopo Province, South Africa, with both nutritional and medicinal properties for serving as a future crop.

Indigenous vegetables are also affected by low rainfall in semi-arid areas of Limpopo Province, South Africa, where water deficit for crop production is increasingly one of the major limiting factors (Machete *et al*., 2004; Oelefse and Van Averbeke, 2012). Predictive models suggested that fro 2030, due to climate change, temperatures inland South Africa, including Limpopo Province, would increase by 2°C (Steyn *et a*l., 2010). In addition, incidents of drought would increase. Generally, the availability of moisture to plants is a function of the amount of water applied (quantity) and irrigation interval. The interactive effects among irrigation interval and planting densities on yield and accumulation of mineral nutrients in indigenous vegetables had not been documented. The objectives of the study were to determine the interactive effects of irrigation interval and planting densities on yield and chemical nutrients of *S. retroflexum* during summer (October-January) 2016/2017 and during winter (May-July) 2017

3.2 Materials and methods

3.2.1 Description of the study site

The study was conducted under field conditions at the Green Biotechnologies Research Centre for Excellence (GBRCE), University of Limpopo, Limpopo Province, South Africa (23°53'10"S, 29°44'15"E). The location has hot and dry summers, with daily maximum temperature from 28 to 38°C. The average annual rainfall is less than 500 mm, which occurred mainly during summer. Two experiments were conducted during summer (October-January) 2016/2017 and winter (May-July) 2017

3.2.2 Experimental design

Seven irrigation intervals (2, 4, 6, 8, 10, 12 and 14 days), with nine planting densities (T_1 = 1 plant, T_2 = 2 plants, T_3 = 3 plants, T_4 = 4 plants, T_5 = 5 plants, T_6 = 6 plants, T_7 = 7 plants, T_8 = 8 plants and T_9 = 9 plants) per drip irrigation hole, were arranged in a split-plot experimental design, with eight replications. The main plot was irrigation interval and the subplot was the planting densities. The control treatment for irrigation interval was 2 days (Van Averbeke and Juma, 2006) and for planting density was 1 plant per drip irrigation hole.

An IDIS with seven sub-systems was used for irrigation interval with the 3S planter used to make transplanting holes/drip hole (Figure 3.1). Drip holes were 45 cm apart, with each subsystem having its own independent opening/closing valve. Each drip hole had one to nine plants throughout the IDIS with 7 irrigation intervals. All plants were irrigated using one litre in the morning, and the other litre applied in the afternoon. The irrigation interval treatment was initiated at 14 days after transplanting.

Figure 3.1 Integrated Drip Irrigation System (IDIS) at the Green Biotechnologies Research Centre for Excellence, University of Limpopo experimental field.

3.2.3 Procedures

Matured berries from *S. retroflexum* (Figure 3.2) were collected from local cultivated fields. Each day after collection, fruit were squeezed out of the carpus and the jelly-like substances that surround seeds. The jelly and seeds were placed in a small container with water to allow for fermentation. The container was loosely covered with a paper towel for 2 days and placed in an incubator (30°C) to promote the build-up of a fungal layer. The fungal layer eats the gelatinous coat that surrounds each seed, thereby preventing germination and also produces antibiotics that could possibly control seed-borne diseases. The fermentation process was done each day during fruit collection (Van Rensburg *et al*., 2007), with seeds shade-dried at a room temperature (Figure 3.3).

Figure 3.2 Matured berries of *Solanum retroflexum* after being collected from the field before fermentation process.

Figure 3.3 *Solanum retroflexum* seeds after fermentation process.

Seedlings were raised in seedling trays, with 10 g 2:1:2 (43) NPK (Multifeed) in 4 L of tapwater applied weekly after emergence and transplanted at 25 days after sowing. Generally, Multifeed (Nulandies, Johannesburg) supplies all essentials micro- and macro- nutrient elements except for Ca. At three-leaf stage, seedlings were hardened-off outside the greenhouse by withholding irrigation water, until most seedlings had wilted partially, and then water applied. A week after hardening-off, seedlings were transplanted in the field with the layout of the experiment as being illustrated in Legend 3.4 using a 3S planter (Figure 3.5). Fertilisation comprised 5 g 2:3:2 (26) NPK + 0.5% Zn + 5% S + 5% Ca to provide macro- and micro-elements and 2 g LAN at seven days after transplanting. Soon after transplanting, cutworm bait (Sodium Fluosillicate 100 g/kg) was applied around the stems of seedlings. Pests were monitored daily and controlled when more than ten were observed with the experiment. Cobalt® Advanced insecticide was used per label instruction to control aphids. Irrigation interval comprising $T_1 = 2$, $T_2 = 4$, $T_3 = 6$, $T_4 = 8$, $T_5 = 10$, $T_6 = 12$ and $T_7 = 14$ days, was initiated at 2 weeks after transplanting. Hand weeding was done when necessary.

Figure 3.4 Planting densities per drip hole under integrated drip irrigation system on growth of *Solanum retroflexum* under field conditions.

Figure 3.5 3S planting tool used for transplanting *Solanum retroflexum* seedlings.

3.2.4 Data collection

Harvesting was done twice for summer and winter experiments. The first harvest (H1) was done at 6 weeks after transplanting, when plants reached commercial maturity, with the second harvest (H2) being done at six weeks after the first harvest. At each harvest, shoots were cut-off using a pruning scissor and placed in brown paper bags, with three young branches left at the base of each plant for re-growth. At H2 all shoots were removed. At each harvest, shoots were oven-dried at 60°C for 72 h, weighed and recorded.

Dried mature leaves were ground in a Wiley mill to pass through a 0.5 mm sieve, with the fine powder stored in plastic bags. Calcium (Ca), magnesium (Mg), potassium (P), phosphorus (K), sodium (Na), zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) were quantified from 0.1 g powdered leaf samples. The powdered material was dissolved in 50 ml tubes containing 5% nitric acid (HNO_3). Materials were incubated in a waterbath at 95°C for 90 minutes, cooled at room temperature, filtered using Whatmann filter paper and covered with a foil (SW-846 EPA Method 3050B). Samples were then submitted to the Limpopo Agro-Food Technology Station (LATS) for analytical work using an Atomic Absorption Spectrophotometer ICPE-9000 (Jones and Case, 1990).

3.2.5 Data analysis

Data were subjected to analysis of variance (ANOVA) through the SAS software (SAS Institute, 2008). The degree of freedom and their mean sum of squares (MSS) were partitioned to provide the total treatment variation (TTV). In the event when the interactions were not significant ($P \leq 0.05$), mean comparisons for main and subplot factors were achieved using Waller-Duncan multiple range test at the probability level of 5%. Significant plant variables were subjected to lines of the best fit, with the generated quadratic equations used to compute optimum irrigation interval and planting density for vegetative growth and mineral nutrients. Unless stated otherwise, treatment effects were discussed at probability level of 5%.

3.3 Results

3.3.1 Plant growth variables

Treatment: The irrigation interval × planting density interaction was significant on dry shoot mass during summer H1 and H2. However, in winter H1 treatment effects were not significant, but were significant during winter H2. In all experiments, during both seasons, although the interaction effects were significant, their contribution in TTV of the variables (1-2%) was negligent (Table 3.1). Consequently, only the main factor irrigation interval and subplot factor planting density were discussed further.

In summer H1, irrigation interval contributed 22% in TTV of dry shoot mass, but had no effect during summer H2 (Table 3.1). In winter H1 and H2, irrigation interval contributed 15% and 5% in TTV of the variable during the respective harvests, respectively. In contrast, in summer H1 and H2, planting density contributed 66% and 73%, respectively, in TTV of the variable, whereas in winter H1 and H2 the treatment contributed 81% and 93%, respectively, in TTV of the variable.

Relative impact: Relative to two-day irrigation interval during summer H1, increasing irrigation interval increased dry shoot mass of *S. retroflexum*, whereas during summer H2, the variable was reduced (Table 3.2). In contrast, at low irrigation intervals, during the winter season, dry shoot mass declined during H1 and H2, but as the irrigation interval increased, the variable increased. Relative to one plant per drip irrigation hole during summer H1 and H2, increasing planting densities increased dry shoot mass of the test plant (Table 3.3). Similar results were observed in winter H1 and H2.

Table 3.1 Partitioning sources of variation on biomass of *Solanum retroflexum* in response to seven irrigation interval (days) and nine levels of planting density during two successive harvests in summer and winter months under field conditions.

		Summer 2016/2017				Winter 2016/2017			
		Harvest 1 (H1)		Harvest 2 (H2)		Harvest 1 (H1)		Harvest 2 (H2)	
Source	DF	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)
Block	7	295.87	9	86.53	19	6.87	1	4.87	1
Irrigation interval (A)	6	763.67	22**	10.43	2^{ns}	76.96	15**	23.60	5**
Error a	42	53.36	1	11.98	3	4.31	1	3.08	1
Planting density (B)	8	2308.11	66**	330.37	73**	408.48	81**	436.93	93**
A × B	48	42.71	1**	8.88	2**	2.56	1^{ns}	1.83	0**
Error b	392	26.58	1	5.09	1	2.47	1	1.30	0
TOTAL	503	3490.3	100	453.28	100	501.65		471.61	100

**Significant at P ≤ 0.01, 0.0.5, ^{ns}Not significant at P ≤ 0.05

MSS= Mean Sum of Squares

TTV= Total Treatment Variation

Table 3.2 Effects of irrigation interval (I.I) on dry shoot mass of *Solanum retroflexum* under field conditions obtained from two harvests.

	Summer 2016/2017				Winter 2017			
I.I (days)	H1[xy]	R.I. (%)[z]	H2	R.I. (%)	H1	R.I. (%)	H1	R.I. (%)
[c]2	11.10[d]	−	6.61[b]	−	5.46[d]	−	4.89[cd]	−
4	11.97[cd]	8	7.54[a]	14	4.49[e]	−18	4.57[d]	−7
6	13.92[bc]	25	6.91[ab]	5	5.47[d]	0	4.98[cd]	2
8	13.46[bcd]	21	6.37[b]	−4	6.17[c]	13	5.00[cd]	2
10	18.86[a]	70	6.75[ab]	2	6.77[bc]	24	5.47[bc]	12
12	15.21[b]	37	6.58[b]	0	6.88[ab]	26	6.14[a]	26
14	19.57[a]	76	6.57[b]	−1	7.50[a]	37	5.89[ab]	20

[x] H1 = Harvest 1, H2 = Harvest 2.

[y] Treatment means with the same letter within the column are not significantly different according to Waller-Duncan multiple range test at probability level of 5%.

[z] Relative impact (R.I.) = [(treatment/control) − 1] × 100.

[c] Control= 2 days irrigation interval.

Table 3.3 Effects of planting density on dry shoot mass of *Solanum retroflexum* under field conditions obtained from two harvests.

	Summer 2016/2017				Winter 2017			
Planting density	H 1[x,y]	R.I. (%)[z]	H2	R.I. (%)	H1	R.I. (%)	H1	R.I. (%)
[c]1	4.51^{g}	–	2.41^{f}	–	1.79^{h}	–	0.94^{i}	–
2	6.82^{f}	51	3.99^{e}	66	3.03^{g}	69	2.01^{h}	114
3	11.59^{e}	157	5.98^{d}	148	4.14^{f}	131	3.52^{g}	274
4	13.67^{d}	203	6.17^{d}	156	5.40^{e}	202	4.51^{f}	380
5	15.25^{d}	238	7.29^{c}	202	6.77^{d}	278	5.51^{e}	486
6	18.19^{c}	303	8.22^{b}	241	7.48^{c}	318	6.42^{d}	583
7	19.19^{bc}	325	8.57^{b}	256	7.80^{c}	336	7.18^{c}	664
8	20.47^{b}	354	9.03^{ab}	275	8.68^{b}	385	8.08^{b}	760
9	23.87^{a}	429	9.60^{a}	298	9.85^{a}	450	9.33^{a}	893

[x] H1 = Harvest 1, H2 = Harvest 2.

[y] Treatment means with the same letter within the column are not significantly different according to Waller-Duncan multiple range test at probability level of 5%.

[z] Relative impact (R.I.) = [(treatment/control) − 1] × 100.

[c] Control= 1 plant per drip irrigation hole.

Generated models: During summer H1, winter H1 and winter H2, dry shoot mass of *S. retroflexum* with increasing irrigation interval exhibited quadratic relations (Figure 3.1; 3.2), with the models being explained by 93, 98, and 92% associations, respectively. Dry shoot mass of *S. retroflexum* against increasing planting density during summer H1, summer H2, winter H1 and winter H2 also exhibited quadratic relations (Figure 3.3; 3.4), with the models being explained by 95, 97, 94 and 98% associations, respectively.

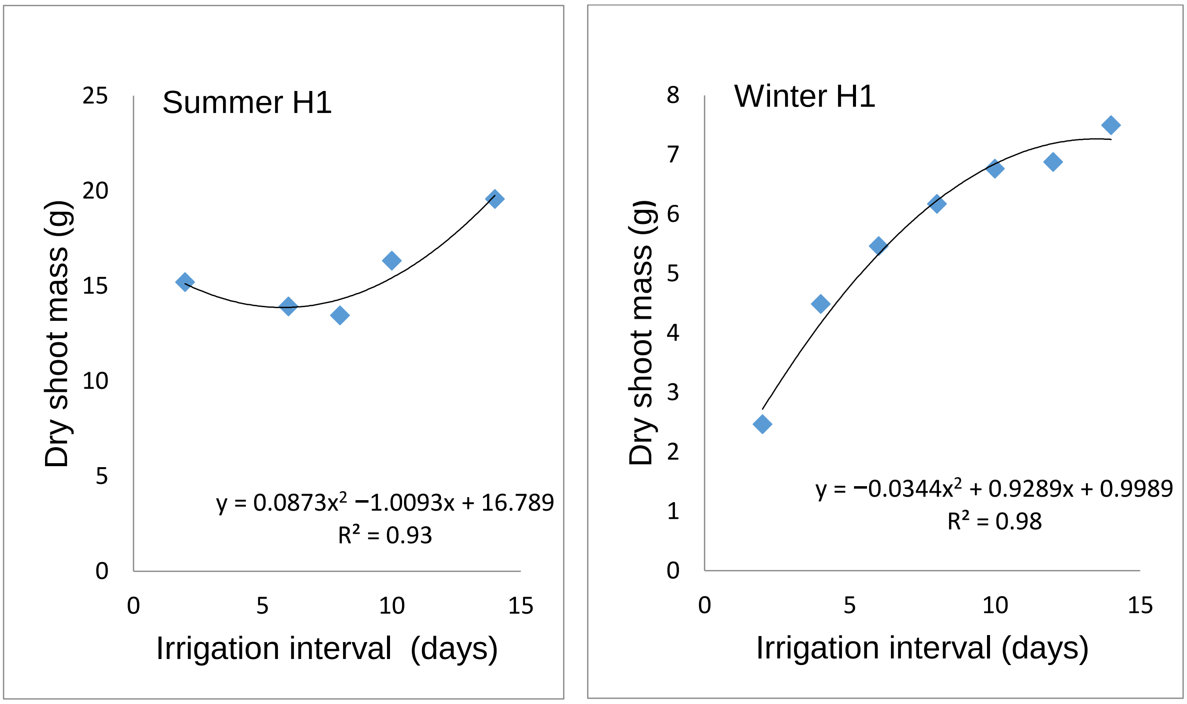

Figure 3.6 Influence of irrigation interval on dry shoot mass during summer first (H1) harvest and winter first (H1) harvest.

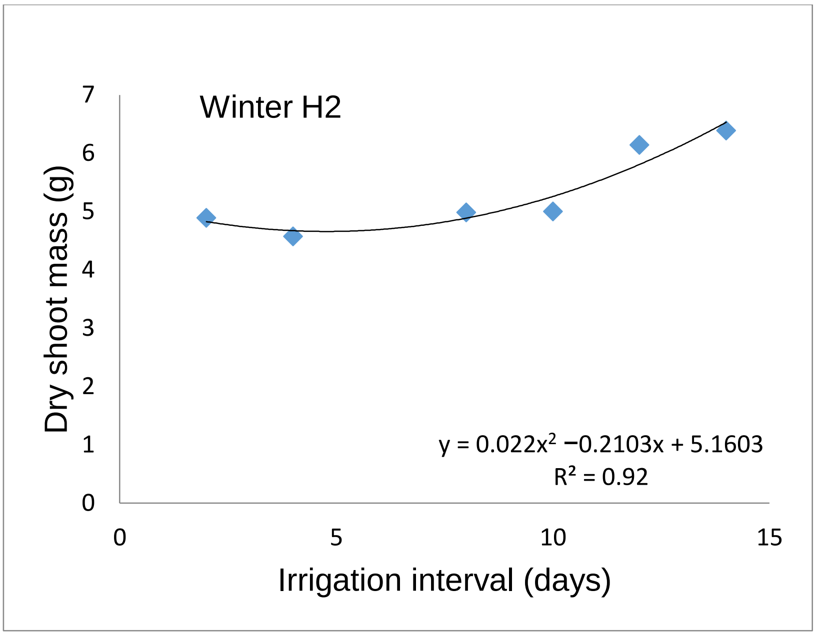

Figure 3.7 Influence of irrigation interval on dry shoot mass during winter second (H2) harvest

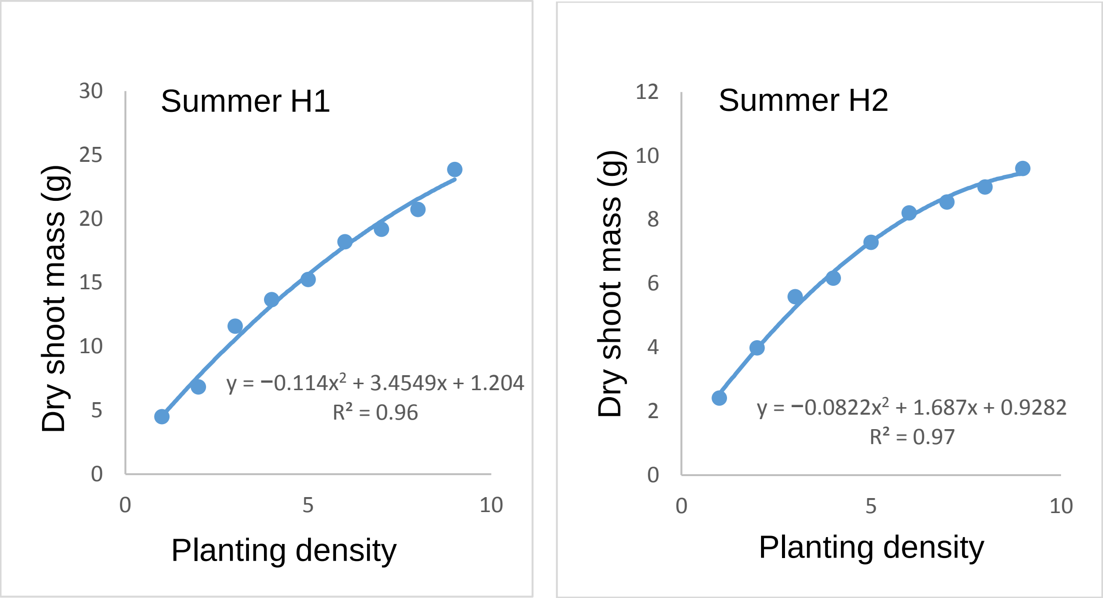

Figure 3.8 Influence of planting density on dry shoot mass during summer first (H1) and second (H2) harvests.

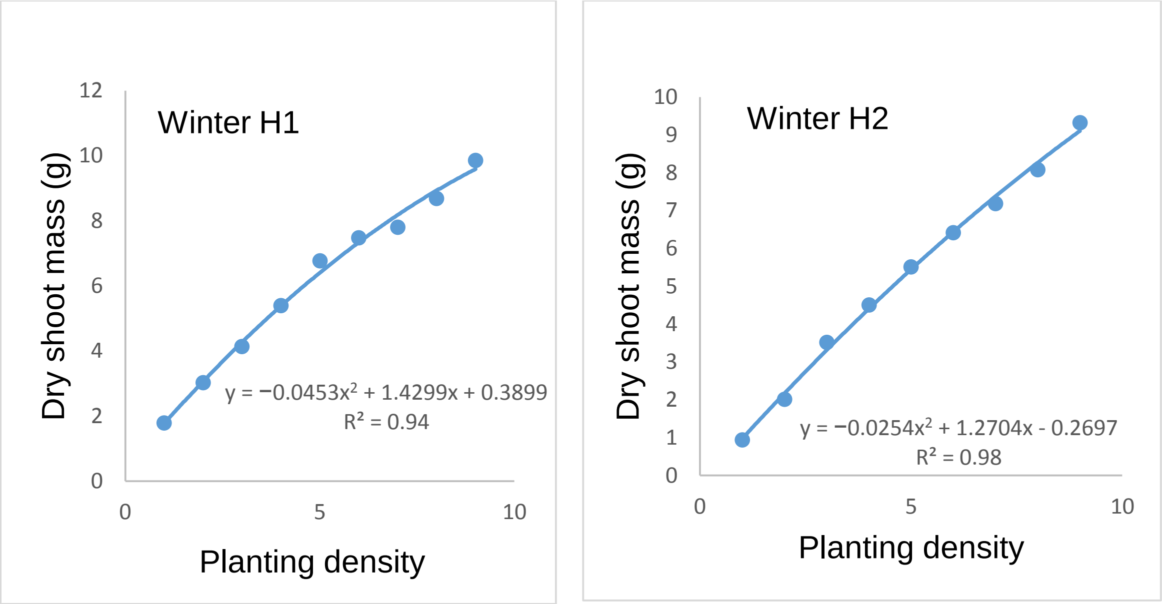

Figure 3.9 Influence of planting density on dry shoot mass during winter first (H1) and second (H2) harvests.

Optimum values: In summer H1, optimum dry shoot mass was attained at 6 days (Table 3.4). In contrast, optimum dry shoot mass in winter H1 and winter H2 were attained at 14 and 5 days, respectively. During winter H1, the optimum dry shoot mass was greater than that during summer H1, whereas those for summer H1 and winter H2 were more or less similar. In summer H1, optimum dry shoot mass was attained at 15 plants per drip irrigation hole, whereas that for summer H2 was achieved at 10 plants per drip irrigation hole (Table 3.5). In contrast, optimum dry shoot mass in winter H1 and winter H2 were extrapolated to 16 and 18 plants per drip irrigation hole, respectively (Table 3.5). During summer H1, the optimum dry shoot mass was greater than that during summer H2, whereas those for winter H1 and winter H2 were more or less similar (Table 3.5).

Table 3.4 Quadratic relationship of dry shoot mass and irrigation interval of *Solanum retroflexum* during summer first harvest (H1) and winter first and second harvests (H1 and 2).

Variable	Quadratic relation	R^2	x^z	y^z
	Summer H1			
Dry shoot mass	$y = 0.0873x^2 - 1.0093x + 16.789$	0.93	6	14
	Winter H1			
Dry shoot mass	$y = -0.0344x^2 + 0.9289x + 0.9989$	0.98	14	7
	Winter H2			
Dry shoot mass	$y = 0.022x^2 - 0.2103x + 5.1603$	0.92	5	5

^{x}Calculated optimum irrigation interval (days) $x = -b_1/2b_2$, where irrigation interval days: $b_1 = -1.0093$ and $b_2 = 0.0873$, where x was the optimum irrigation interval.

Table 3.5 Quadratic relationship of dry shoot mass and planting density of *Solanum retroflexum* during summer first and second harvests (H1 and H2) and winter first and harvests (H1 and H2).

Variable	Quadratic relation	R^2	x^z	y^z
	Summer H1			
Dry shoot mass	$y = -0.114x^2 + 3.4549x + 1.204$	0.96	15	27
	Summer H2			
Dry shoot mass	$y = -0.0822x^2 + 1.687x + 0.9282$	0.97	10	10
	Winter H1			
Dry shoot mass	$y = -0.0453x^2 + 1.4299x + 0.3899$	0.94	16	12
	Winter H2			
Dry shoot mass	$y = -0.0245x^2 + 1.2704x - 0.2697$	0.98	18	13

^{x}Calculated optimum irrigation interval (days) $x = -b_1/2b_2$, where planting density: $b_1 = 3.4549$ and $b_2 = -0.114$, where x was the optimum planting density.

^{z}Yield at optimum irrigation interval.

3.3.2 Nutrient element variables

Treatment: The irrigation interval × planting density interaction was significant for Ca, Mg, P, K, Mn and Cu during summer first harvest (H1) but not significant for Na, Fe and Zn. During summer H1, although the interaction effects were significant, their contribution (1-2%) in TTV of the variables was negligent (Table 3.6). However, for P and Cu, the two treatments alone contributed 17% and 8% in TTV of the respective variables (Table 3.6). Consequently, only the main factor irrigation interval and subplot factor planting density were discussed further.

During summer H1, major minerals: Ca, Mg, P, K and Na, irrigation interval contributed 95, 97, 68, 92 and 63% in TTV of the respective variables (Table 3.6). Irrigation interval on trace elements Fe, Zn, Mn, and Cu, contributed 90, 91, 96 and 62% in TTV of the respective variables (Table 3.7). The effect of irrigation interval on Ca concentration in leaf tissues of the test plant was low at 2 to 4 days, but starting increasing at 6 to 14 irrigation intervals. Magnesium and P increased with the increasing irrigation interval, but decreased at 10 to 14 days. Potassium also increased with the increasing irrigation interval. In contrast, Na was high at low irrigation interval, but lower at longer irrigation intervals. All trace elements concentrations (Fe, Zn, Mn, Cu) increased with the increasing irrigation interval, however the mineral concentration decreased at 10 to 14 irrigation interval days (Table 3.8, Table 3.9).

Planting density was significant only for Ca, P and K. However, the contribution in TTV of Ca and K was negligent at 1% and 3 %, respectively, whereas for P, planting density contributed 9% in TTV of the variable (Table 3.6). Planting density was not significant on all trace mineral elements. Calcium and K concentrations in leaf tissues increased with increasing planting density, whereas P was high at lower planting density and lower at higher planting density (Table 3.10).

Relative impact: Relative to two-day irrigation interval, during summer H1, increasing irrigation interval increased all major mineral and trace elements concentration in *S. retroflexum* leaf tissues, whereas Mg and Cu declined at 4 days, but as the irrigation interval increased, the variable also increased (Table 3.8, 3.9). Relative to 1 plant per drip irrigation hole, increasing plants per drip hole decreased C, starting from 2 to 5 plants per hole and started to increase at 6 to 9 plants per drip irrigation hole (Table 3.10). Phosphorus only increased at 2 plants, whereas from 3 to 9 plants the concentration decreased. Potassium only decreased at 2 and 3 plants but as the numbers of plants per drip hole were increasing, the concentration increased.

Table 3.6 Partitioning sources of variation on major minerals of *Solanum retroflexum* leaf tissues in response to seven irrigation interval (days) and nine planting densities per drip irrigation hole under field conditions obtained from summer first harvest (H1).

		Ca		Mg		P		K		Na	
Source	DF	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)
Block	7	4493.37	2	1743.95	1	247.72	2	106.50	1	2.35	7
Irrigation interval (A)	6	249338.05	95***	200677.94	97***	7658.79	68***	6905.44	92***	21.67	63***
Error a	42	1533.60	1	1104.00	1	342.32	3	77.38	1	2.36	7
Planting density (B)	8	3105.58	1***	1029.95	0^{ns}	920.72	9***	196.23	3***	2.88	8^{ns}
A × B	48	3280.59	1***	1863.67	1***	1901.44	17***	128.99	2***	2.71	8^{ns}
Error b	392	1269.56	0	1011.53	0	155.87	1	69.07	1	2.31	7
Total	503	263020.75	100	207431.04	100	11226.86	100	7483.61	100	34.28	100

***Significant at $P \leq 0.01$, ^{ns}Not significant at $P \leq 0.05$.

MSS= Mean Sum of Squares.

TTV= Total Treatment Variation.

Table 3.7 Partitioning sources of variation on trace minerals of *Solanum retroflexum* in response to seven irrigation interval (days) and nine planting densities per drip irrigation hole under field conditions obtained from summer first harvest (H1).

		Fe		Zn		Mn		Cu	
Source	DF	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)
Block	7	15.51	3	0.34	1	0.46	0	0.15	9
Irrigation interval (A)	6	459.86	90***	33.02	91***	53.98	96***	0.98	62***
Error a	42	8.44	2	0.78	2	0.41	1	0.10	6
Planting density (B)	8	6.41	1^{ns}	0.50	1^{ns}	0.47	1^{ns}	0.13	8^{ns}
A × B	48	8.51	2^{ns}	0.69	2^{ns}	0.58	1***	0.14	8***
Error b	392	8.34	2	0.82	3	0.39	1	0.09	7
Total	503	507.07	100	36.15	100	56.29	100	1.59	100

***Significant at P ≤ 0.01, ^{ns}Not significant at P ≤ 0.05.

MSS= Mean Sum of Squares. TTV= Total Treatment Variation.

Table 3.8 Macro nutrient elements as affected by irrigation interval (I.I) in leaf tissues of *Solanum retroflexum* obtained from first harvest (H1) during summer.

	Ca (%)		Mg (%)		P (%)		K (%)		Na (%)	
I.I (days)	variable[x]	R.I. (%)[z]	Variable	R.I. (%)	Variable	R.I. (%)	Variable	R.I. (%)	Variable	R.I. (%)
[c]2	1.93^{e}	−	1.50^{c}	−	2.19^{d}	−	1.92^{e}	−	0.29^{bc}	−
4	2.00^{e}	4	1.18^{c}	−21	4.43^{c}	102	2.39^{e}	24	0.33^{bc}	14
6	2.67^{e}	38	2.45^{c}	63	14.43^{b}	558	2.71^{e}	41	0.33^{bc}	14
8	42.00^{d}	2076	86.16^{b}	5644	29.75^{a}	1258	12.12^{d}	531	0.34^{c}	17
10	76.92^{c}	3885	111.04^{a}	7303	27.81^{a}	1170	15.24^{c}	694	0.58^{a}	100
12	154.25^{a}	7892	111.42^{a}	7328	26.23^{a}	1098	25.99^{a}	1254	0.38^{b}	31
14	100.42^{b}	5103	84.23^{b}	5515	20.38^{a}	831	21.61^{b}	1026	0.37^{b}	28

[x] Column means with the same letter were not different according to Waller-Duncan multiple range test at probability level of 5%.

[z] Relative impact (R.I) = [(treatment/control) − 1] × 100. [c] Control= 2 days irrigation interval.

Table 3.9 Micro nutrient elements as affected by irrigation interval (I.I) in leaf tissues of *Solanum retroflexum* obtained from first harvest (H1) during summer.

	Fe (ppm)		Zn (ppm)		Mn (ppm)		Cu (ppm)	
I.I (days)	Variable[x]	R.I. (%)[z]	Variable	R.I. (%)	Variable	R.I. (%)	Variable	R.I. (%)
[c]2	0.88^{c}	−	0.44^{c}	−	0.21^{c}	−	0.29^{bc}	−
4	0.89^{c}	1	0.47^{c}	7	0.27^{c}	29	0.20^{c}	−31
6	0.97^{c}	10	0.55^{c}	25	0.22^{c}	5	0.33^{bc}	14
8	4.65^{b}	428	1.13^{b}	157	1.58^{b}	652	0.33^{bc}	14
10	7.32^{a}	732	1.42^{b}	223	2.07^{a}	886	0.58^{a}	100
12	4.67^{b}	431	2.33^{a}	430	2.04^{a}	871	0.38^{b}	31
14	3.63^{b}	313	1.19^{b}	170	1.55^{b}	638	0.37^{b}	28

[x] Column means with the same letter were not different according to Waller-Duncan multiple range test at probability level of 5%.

[z] Relative impact (R.I.) = [(treatment/control) − 1] × 100.

[c] Control= 2 days irrigation interval.

Table 3.10 Macro nutrient elements as affected by planting density (P.D) in leaf tissues of *Solanum retroflexum* obtained from first harvest (H1) during summer.

	Ca (%)		P (%)		K (%)	
P.D	Variable[x]	R.I. (%)[z]	Variable	R.I. (%)	Variable	R.I
[c]1	52.66^{d}	−	21.91^{b}	−	10.55^{bc}	
2	43.41^{f}	−18	22.74^{b}	4	10.77^{bc}	2
3	47.72^{e}	−9	13.31^{d}	−39	9.63^{c}	−9
4	51.12^{d}	−3	12.64^{e}	−42	11.34^{b}	7
5	58.09^{d}	10	14.73^{c}	−33	10.01^{c}	−5
6	65.53^{a}	24	14.32^{d}	−35	15.44^{a}	46
7	61.33^{b}	16	20.61^{b}	−6	13.69^{ab}	30
8	57.59^{c}	9	26.80^{a}	22	11.45^{b}	9
9	60.50^{b}	15	11.98^{f}	−45	12.24^{ab}	16

[x] Column means with the same letter were not different according to Waller-Duncan multiple range test at probability level of 5%.

[z] Relative impact (R.I.) = [(treatment/control) − 1] × 100.

[c] Control= 1 plant per drip irrigation hole.

<u>Generated models</u>: During summer H1, concentrations of Ca, Mg, P, K, Na, Fe, Cu, Zn and Mn in *S. retroflexum* leaf tissues against increasing irrigation interval exhibited quadratic relations (Figure 3.5, 3.6, 3.7), with models being explained by 98%, 92%, 97%, 97%, 86%, 88%, 83%, 88% and 87% associations, respectively. Calcium, P and K in leaf tissues of *S. retroflexum* over increasing planting density also exhibited quadratic relations (Figure 3.8) with models being explained by 91%, 59% and 59% associations, respectively.

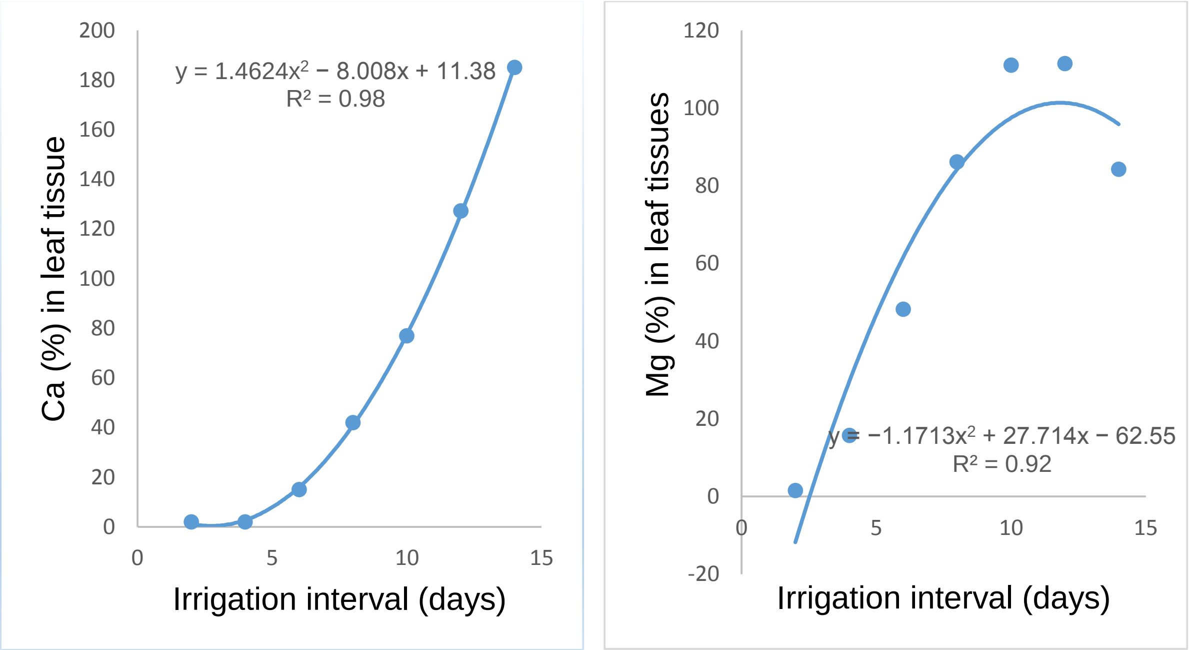

Figure 3.10 Response of Ca and Mg in leaf tissues of *Solanum retroflexum* to irrigation interval during summer first (H1) harvest

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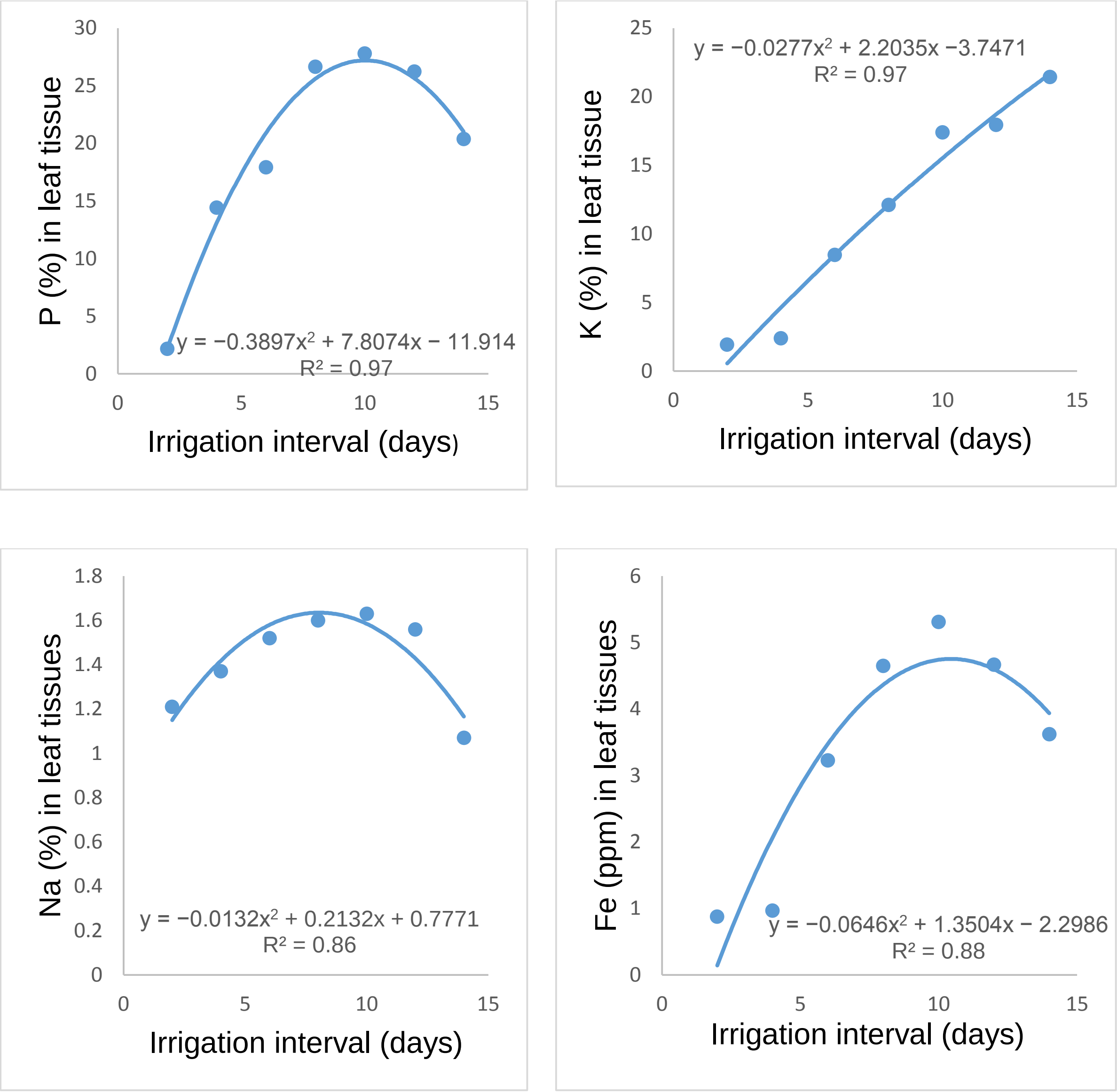

Figure 3.11 Response P, K, Na and Fe in leaf tissues of *Solanum retroflexum* to irrigation interval during summer first (H1) harvest.

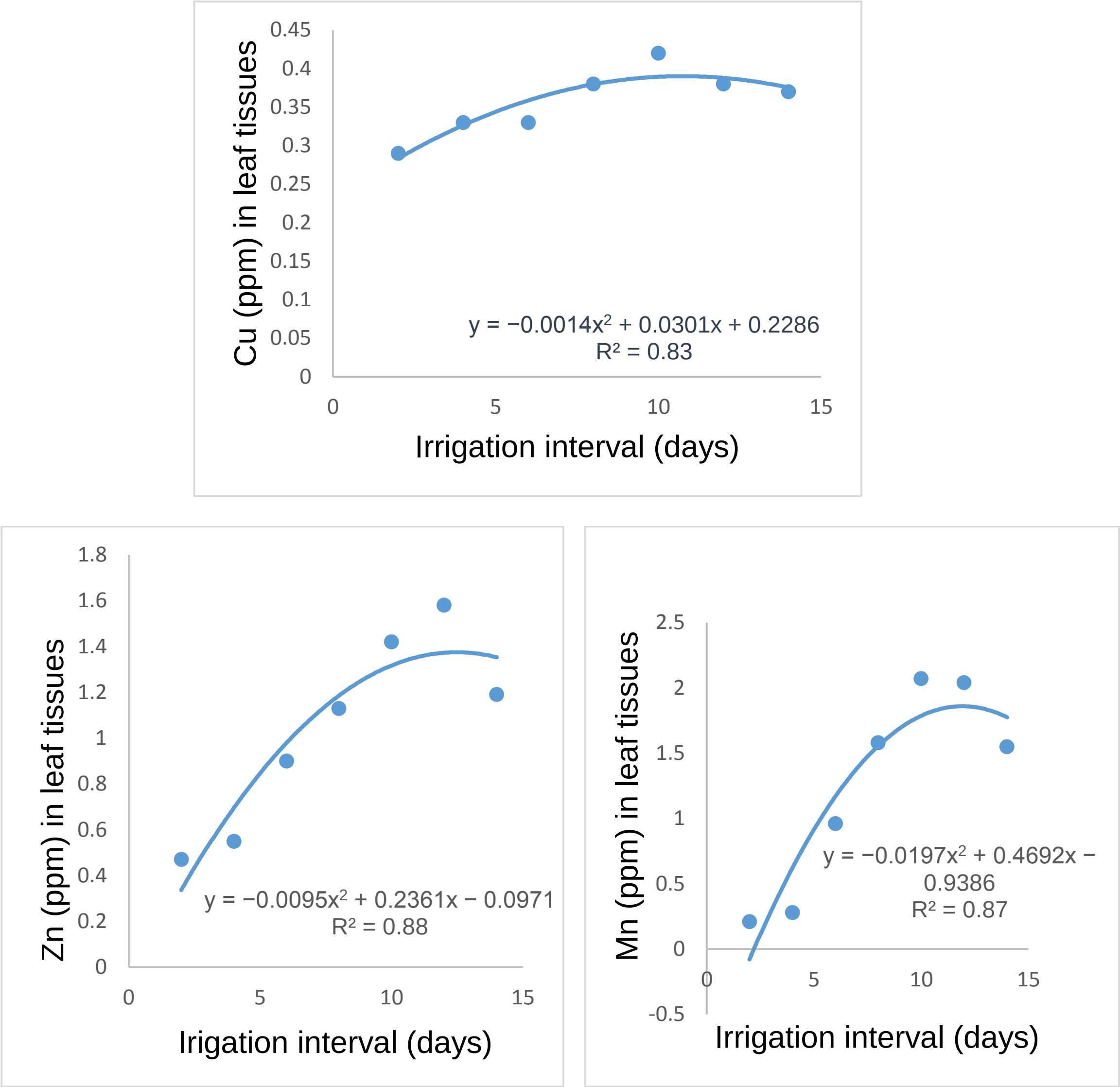

Figure 3.12 Response Cu, Zn and Mn in leaf tissues of *Solanum retroflexum* to irrigation interval during summer first (H1) harvest.

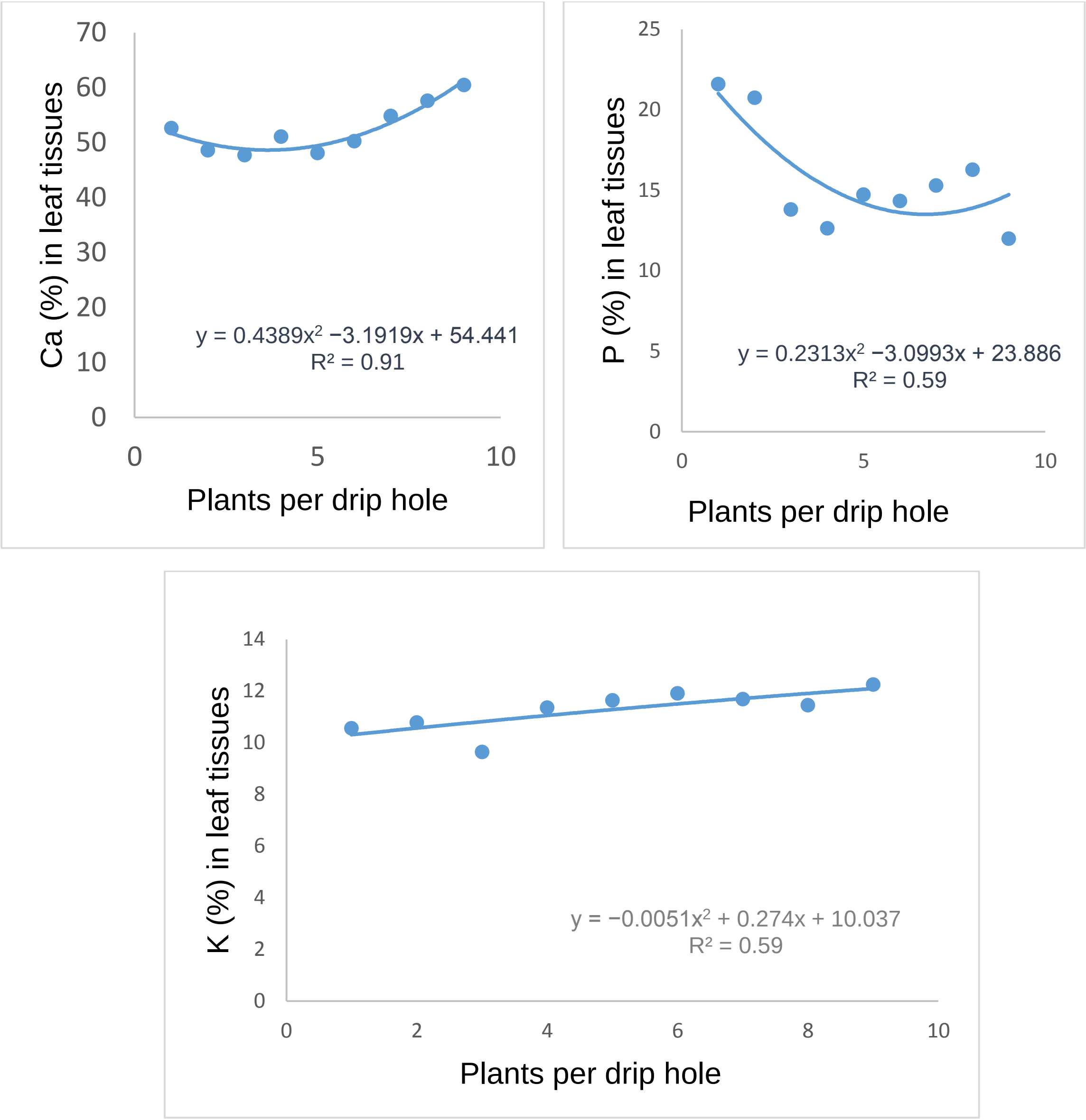

Figure 3.13 Responses of Ca, P and K in leaf tissues of *Solanum retroflexum* to planting density during summer first (H1) harvest.

Optimum value: The optimum irrigation interval for Ca, Mg, P, K and Na concentration was attained at 3, 12, 10, 11, 8 days, respectively (Table 3.10). The optimum irrigation interval for Fe, Zn, Mn and Cu were 10, 12, 12 and 10 days, respectively (Table 3.11).

Table 3.11 Quadratic relation of macronutrient elements in essential nutrient in *Solanum retroflexum* leaf tissues over irrigation interval from summer first (H1) harvest.

Nutrient elements	Quadratic relation	R^2	x^z	Y^z
Ca	$y = 1.4624x^2 – 8.008x + 11.38$	98	3	0
Mg	$y = −1.1713x^2 + 27.714x – 62.55$	92	12	101
P	$y = −0.3897x^2 + 7.8074x − 11.914$	97	10	27
K	$y = −0.0277x^2 + 2.2035x − 3.7471$	97	11	29
Na	$y = −0.0132x^2 + 0.2132x + 0.7771$	86	8	28

^{z}Calculated optimum irrigation interval (days) $x = −b_1/2b_2$, where irrigation interval, $b_1 = −8.008$ and $b_2 = 1.4624$, where x is the optimum irrigation interval, whereas Y is the maximum concentration of the test nutrient element.

Table 3.12 Quadratic relation micronutrient elements of irrigation interval in *Solanum retroflexum* leaf tissues over irrigation interval from summer first (H1) harvest.

Nutrient elements	Quadratic relation	R^2	x^z	y^z
Fe	$y= -0.0646x^2 + 1.3504x - 2.2986$	88	10	5
Zn	$y= -0.0095x^2 + 0.236x + 0.0971$	86	12	2
Mn	$y= -0.0197x^2 + 0.4692x - 0.9386$	87	12	2
Cu	$y= -0.014x^2 + 0.0301x + 0.2268$	83	10	4

^{z}Calculated optimum irrigation interval (days) $x = -b_1/2b_2$, where irrigation interval, $b_1 = 1.3504$ and $b_2 = -0.0646$, where x is the optimum irrigation interval.

The optimum planting density for Ca, P and K in leaf tissues of *S. retroflexum* were 4, 7 and 6 plants per hole of drip irrigation, respectively (Table 3.12)

Table 3.13 Quadratic relation of macronutrient elements in *Solanum retroflexum* leaf tissues over planting density from summer first (H1) harvest.

Nutrient elements	Quadratic relation	R^2	x^z	y^z
Ca	$y = 0.4389x^2 - 3.1919x + 54.441$	91	4	49
P	$y = 0.2313x^2 - 3.0993x + 62.55$	59	7	52
K	$y = -0.0051x^2 + 0.274x + 10.037$	59	6	52

^{z}Calculated optimum irrigation interval (days) $x = -b_1/2b_2$, where planting densities, $b_1 = -3.1919$ and $b_2 = 0.4389$, where x is the optimum planting density.

3.4 Discussion

3.4.1 Plant growth variables

The significant interactions on irrigation interval and planting density on dry shoot mass of *S. retroflexum* during summer H1 and H2 and winter H2 supported observations in herbage biomass production for *Thymus vulguris* (Khazaie *et al*., 2007). Also, the interactions which were not significant in winter H1 on dry shoot mass supported observation on vegetative growth of *Z*. *mays* when grown in winter (Sani *et al*., 2008). In other similar studies on irrigation interval × planting density interactive effects, the contribution of the source of variation in TTV of the variables could not be compared with those in the current study since partitioning of the sources of variation was not computed (Khazaie *et al*., 2007). In the current study, the partitioning of the sources of variation suggested that the TTV of the variables for the interactions were negligent since they contributed only 1-2% in TTV of the variables. Consequently, the main plot (irrigation interval) and sub-plot (planting density) factors were assessed separately as the main focus in the study.

The significant irrigation interval on dry shoot mass of *S. retroflexum* during summer H1 supported observations in biomass production of *T. vulguris* (Khazaie *et al*., 2008), leaf area of *S. retroflexum* (Slabbert *et al*., 2012) and dry shoot and root mass of chilli pepper (Ismail and Ozawa, 2009). Also, the irrigation interval that was not significant in summer H2 on dry shoot mass supported observation on pepper (*Capsicum annuum* L.) in the first year of the experiment, but no significant differences were observed during the second year of the experiment (Lawal and Rahman, 2007). In other similar studies on irrigation interval, the contribution of the source of variation in TTV of the variables could not be compared with those in the current study since partitioning of the sources of variation was not computed (Ismail and Ozawa, 2009).

In the current study, the partitioning of the sources of variation contributed (22%) to the TTV of the variable.

In the current study, increasing irrigation interval increased dry shoot mass of *S. retroflexum* during summer H1. The study conducted by Khazaie *et al*. (2007) on *T. vulguris* demonstrated a reduced herbage biomass production as irrigation increased. Slabbert *et al*. (2012), reported a decrease in leaf area of *S. retroflexum* at day 3 of water stress, Ismail and Ozawa (2009), also reported a decrease in dry shoot and root mass on chili pepper with increasing irrigation interval. In the contrary, Lawal and Rahman (2007) reported an increase in yield of pepper with increasing irrigation interval, however at a longer irrigation interval, the yield was reduced. The current observation for *S. retroflexum*, the 14-day interval gave a significantly higher dry shoot mass than at shorter irrigation interval (2 days). The results might be attributed to increased leaf area, due to the fact that leaf area development is directly related to the yield of *S. retroflexum*, since the edible part is the leaf (Jones, 1992). It is known that excessive irrigation might delay maturity, harvesting and encourage vine growth, whereas deficit irrigation decreases yield and crop quality (Ramalan and Nwokeocha, 2000). According to Van Rensburg *et al*. (2007), indigenous vegetables are reported to survive under drought conditions. The current information suggested that *S. retroflexum* is a drought-tolerant plant (Dinssa *et al*., 2016). Gulen and Eris (2004) reported that plants have the ability to avoid water stress by increasing the amount of transporters involved in water and ion uptake and transport and by rapid closing of stomata, thereby conserving as much water as possible.

The findings obtained from this study were not in agreement to those reported by Khazaie *et al*. (2008); Slabbert *et al*. (2012) and Ismail and Ozawa (2009), who found that most growth and yield components were decreased by increasing irrigation interval. This result might be attributed to studies were conducted under different environmental conditions (Muñoz *et al*., 2008). Also, Muñoz *et al*. (2008) observed that tomato plant yield (kg) grown under open field condition was greater than that for plants under greenhouse conditions with respect to utilisation of water and fertilisers. In contrast, Kanwar (2011) reported the highest yield per plant, yield/ha and number of fruits for tomato plants under greenhouse conditions.

The current study was conducted under field conditions, where irrigation was done twice, in the morning and in the afternoon to reduce evaporation effect on irrigation water. Kanton *et al*. (2008) reported irrigation time had a significant effect on yield of onion where the highest bulb yield was obtained when the plants received irrigation in the morning and evening. Leskovar (2012) pointed out that irrigation method, rate, timing and interval may influence physical and chemical properties of the soil. Result of the current study in terms of dry shoot mass might be attributed to irrigation time (Kanton *et al*., 2008). According to van Aveberke *et al*. (2007), under limited water regions, *S. retroflexum* could be irrigated at a frequency higher than once per week for optimum growth.

In the contrary, Khazaie *et al*. (2008) reported a reduced biomass production of *T. vulguris* as irrigation intervals were increasing but the reduction was not significant under field conditions. Contradiction existed when water stress had a significant effect on essential oil yield of *T. vulguris*, where the highest oil yield was observed under water stress condition (Askary *et al*., 2017). Plants under deficit water might show decrease in photosynthesis which is correlated to reduced plant growth and development (Sameen *et al.*, 2016) which in turn, led to a reduced quantity of biomass production, thereby reducing all yield components (Van Der Weijde *et al*., 2017). Slabbert *et al*. (2012) reported a reduced leaf area of *S. retroflexum* under greenhouse conditions at 3 days of water stress. Drought causes reduction of leaf area, dry matter production, decline in plant water status and transpiration (Masinde and Stutzel, 2005). According to Jones (1992), reduced leaf area is a drought mechanism, aimed at reducing plant water consumption.

Given the challenges that *S*. *retroflexum* is a wild plant that grows naturally under harsh climatic conditions, the plant might have failed to tolerate water stress under controlled environment conditions as compared to the field conditions, thereby reducing the plant leaf area (Slabbert *et al*., 2012). The current observation is in agreement with Muñoz *et al*. (2008) who reported a significant effect of greenhouse condition and open field condition on tomato yield production. Basically, the increase in dry shoot mass suggested that the plant hormone responsible for plant shoot growth was able to perform better under water shortage (Tanimoto, 2005).

Plant responses to water deficit are dependent on the amount of water loss, the rate of loss and the duration of the stressed condition (Bray, 1997). Drought-tolerant plants are able to suppress the effect of water shortage and even produce high yields under reduced irrigation events (Jones, 1992). The findings obtained in this study were in good agreement to those reported by Van Averbeke *et al*. (2007) in *Brassica rapa* L. subsp *cheninsis* and *S*. *retroflexum*, Nkgapele and Mphosi (2014) in *C*. *africanus* and

Slabbert *et al*. (2012) in *Vigna unguiculata*, who found that yield components of African leafy vegetable increased with increasing irrigation intervals or water stress condition.

The significant irrigation interval on dry shoot mass of *S. retroflexum* during winter H1 and H2 supported observations in biomass yield of okra (Sarker *et al*., 2005), vegetative growth and yield of eggplant (Hussein *et al*., 2010) and leaf growth of sweet pepper (Ismail *et al.*, 2002). In other similar studies on irrigation interval, the contribution of the source of variation in TTV of the variables could not be compared with those in the current study since partitioning of the sources of variation was not computed (Sarker *et al*., 2005). In the current study, the partitioning of the sources of variation contributed (15% and 5%) to the TTV of the variable in winter H1 and H2 respectively.

In the current study, increasing irrigation interval increased dry shoot mass of *S. retroflexum* during winter H1 and H2. The study conducted by Sarker *et al*. (2005) on okra demonstrated a decrease in biomass yield under water stress. Hussein *et al*. (2010), reported a decrease in vegetative growth and yield of eggplant as irrigation interval were increasing, Ismail *et al*. (2002) also observed inhibition of leaf growth in sweet pepper with increasing irrigation intervals. Lawal and Rahman (2007) observed similar results in okra, where 5-day irrigation intervals gave a significantly higher yield than a 15-day irrigation intervals, however the 10-day irrigation interval was not significantly different from the 15-day treatment. The current observation for *S. retroflexum*, the 14-day interval gave a significantly higher dry shoot mass than at shorter irrigation interval (2 days). The results of the current study might be attributed to increased photosynthesis rate and rapid conductance of stomata (Zain *et al*., 2014).

Schachtman and Goodger (2008) reported that chemical signals are important for plant adaptation to water stress. According to Chaves *et al*. (2002), plants strategies to cope with drought normally involve a mixture of stress avoidance and tolerance strategies that vary with genotypes.

In the contrary, Ismail and Ozawa (2009), reported a decrease in dry shoot and root mass of chill pepper as irrigation intervals were increasing. Their findings could be explained by the fact that plants were under water stress because irrigation interval has a major influence on soil moisture profile (Boamah *et al*., 2010). The decrease in dry shoot under water stress condition might be attributed to reduced leaf growth and reduced rates of photosynthesis (Jones, 1992). Under water stress condition when water deficiency level increases, transpiration rate are decreased, therefore the plant growth slows down and the total dry matter of the plants and vegetative growth is reduced (Ozenc, 2008). Contradiction existed when *C*. *annuum and C*. *fruitescens* produced higher values on leaf and root dry weight with increasing irrigation interval, however at a prolonged irrigation interval of 16 days and no water treatment, the values of the two chilli pepper cultivars decreased. The lowest values of these parameters were produced by either deficit or excess water treatments (Khan *et al*., 2009). Sánchez-Rodríguez *et al.* (2010) reported that water stress strongly affects horticultural cultivars by reducing yield and fruit quality. Also the physiological functions of the plant are altered by this stress due to the formation of reactive oxygen species and water relationships. According to Fang *et al*. (2017), yield improvement under water stress conditions has been associated with increased drought tolerance. Hutton *et al.* (2007) suggested that proper irrigation interval increases the plant water stress tolerance by developing the root in lower layers where high soil moisture content is present.

Although treatment had a significant effect on dry shoot mass, dry shoot mass during summer H1 was greater than that of winter H1 and H2. This confirms that *S. retroflexum* is a summer crop (Slabbert *et al*., 2012). During winter maximum growth and biomass production of *S. retroflexum* is obtained when the plants is exposed to full sunlight (Edmods and Chweya, 1997). Soil moisture availability and type is also considered to be one of the most important natural resource for crop production (DAFF, 2013), and these findings demonstrate plant roots were able to absorb available moisture in the soil during summer harvests due to summer rainfall hence the highest dry shoot mass of *S. retroflexum*. Most field crops begin to suffer stress when the soil water content falls below 60% (Raddatz, 1992) and winter months, rainfall is usually light or no rainfall and light rainfall is commonly considered to be ineffective due to high evaporative demand of the atmosphere (Kamara and Jackson, 1997).

The observed relative impact in the current study increased positively with increasing irrigation intervals during summer H1, ranging from the lowest to the highest relative impact. In contrast, Khazaie *et al.* (2007) observed a negative relative impact with increasing irrigation interval on *T. vulguris*, relative impact percentage was positive at the lowest irrigation interval and as the irrigation interval increased, it was reduced to a negative percentage (0.09 to −37%). The positive relative impact observation is attributed to increasing dry shoot mass with the increasing irrigation interval (Mabotja, 2015). Therefore, the results of a negative relative impact resulted from reduced biomass production under increasing irrigation interval or after plants have been exposed to deficit irrigation (Khazaie *et al*., 2007). However, the current study is in agreement with Nkgapele and Mphosi, (2014), who observed similar results where the relative impact increased with increasing irrigation interval on biomass production of *Cucumis africanus*.

During winter H1 and H2, there was a negative relative impact at the lowest irrigation interval but as the irrigation interval increased the relative impact increased positively ranging from -18 to 37 in H1 and -7 to 20 in H2. These observations might be attributed to control mean was greater than irrigation treatment mean (Mashela, 2015). The biomass production of *T. Vulgaris* was not significant in the second year of the experiment, suggesting that different irrigation interval did not have effect on biomass production (Khazaie *et al*., 2007).

Responses of irrigation interval effect on dry shoot mass were linear with 93, 98 and 92% during summer H1, winter H1 and H2, respectively. Sani *et al*. (2008) observed similar positive quadratic relation on yield of early maize cultivar with models being explained by 99%, 98% and 99% associations on cob weight, grain weight and grain weight per cob, respectively. It is clear that increasing irrigation interval affected dry shoot mass positively, thereby increasing mean values of dry shoot mass of *S. retroflexum* at a prolonged irrigation interval. The lowest values were observed at excessive water application or frequent irrigation. The study implies that in order to produce highest yields of *S. retroflexum* under drip irrigation, the crop can be irrigated at least once per week until harvest. In the present study, *S. retroflexum* growth under deficit irrigation showed a consistent increase in dry shoot mass during summer and winter harvests. Therefore, production of *S. retroflexum* might be suitable in summer and winter under field conditions.

The significant planting density on dry shoot mass of *S. retroflexum* during summer H1 and H2 supported observations in vegetative growth and yield of early maize cultivar (Sani *et al*., 2008), biomass production of *T*. *vulguris* (Khazaie *et al*., 2008), *Amaranthus cruentus*, *Corchorus olitorius* and *V*. *unguiculata* (Maseko *et al*., 2015). In other similar studies on planting density, the contribution of the source of variation in TTV of the variables could not be compared with those in the current study since partitioning of the sources of variation was not computed (Maseko *et al*., 2015). In the current study, the partitioning of the sources of variation for dry shoot mass contributed 66% and 75% in TTV of the variable during summer H1 and H2, respectively.

In the current study increasing planting density per drip irrigation hole increased dry shoot mass of *S. retroflexum* during summer H1 and H2. The study conducted by Sani *et al*. (2008) demonstrated an increase on growth and yield of early maize cultivar with increasing planting density. However, the increasing planting density did not indicate significance difference between the treatments. Khazaie *et al*. (2008) also observed an increase in herbage biomass of *T. vulguris* as planting density increased. Maseko *et al*. (2015), reported a decrease in biomass production of the three indigenous vegetables *A*. *cruentus* and *C*. *olitorius* with increasing planting density but an increase in dry mass yield for leaf and stem of *V*. *unguiculata* was observed with increasing planting density per unit area. According to Rahman and Hossain (2011), the effect of plant density on growth, plant characters and yield could vary due to varietal characters and growing seasons in the same geographical areas. The results might be attributed to the increased number of plants per unit area, which might have contributed to the production of extra dry shoot mass per unit area leading to increase in dry shoot mass or high yield (Law-ogbomo and Egharevba, 2009). Aminifard *et al.* (2010) reported a decrease in vegetative growth of pepper as planting density increased. Similar results were reported by others (Elattir, 2002; De-Viloria *et al*., 2010; Era *et al*., 2007). It is explained that as plant population density increases, competition for available water, mineral nutrients and light increases (Abubaker, 2008; Soliman *et l.*, 1995). According to Abuzar *et al*. (2011), planting density has been considered as a major factor that determines the degree of competition between plants.

The findings obtained from the current study were not in agreement to those reported by Getachew *et al*. (2012) who observed that high planting density to be associated with low dry matter content and increased dry matter with decreasing plant population. In a study conducted elsewhere, demonstrated yield of potato was not affected by population density (Masarirambi *et al*., 2012). This can be attributed to the extended amount of foliage that was produced at higher planting density population, resulting in increased dry shoot mass of *S. retroflexum* (Mabotja, 2015; Mashela, 2015). According to Mashela (2015), most smallholder farmers sow one seed or transplant one seedling per one drip hole, which results in lower crop yields. The current high crop yield results might be attributed to the increased number of plants per drip hole, which led to high dry shoot mass at the highest number of plant/hole.

Planting densities has been considered a major factor that determines the degree of competition between plants based on the observation of *Z*. *mays* (Abuzar *et al*., 2011). The results of the current study suggested that increasing planting densities per drip irrigation hole improved dry shoot mass of *S. retroflexum*. The findings obtained in this study were in good agreement to those retorted by Mamadi *et al.* (2009) and Yarnia (2010), who found that most yield components of *Amaranthus* under irrigation increased with increasing planting densities. Akintoye *et al.* (2009), reported that crop yield of watermelon per unit area tends to increase as plant density increases up to a point and then declines. Under the lowest planting density there might be too much space left between the plants, weed growth is promoted, consequently a competition of water and nutrients between crops and weeds (Rana and Rana, 2014).

The significant planting density on dry shoot mass of *S. retroflexum* during winter H1 and H2 supported observations in plant height, leaf fresh mass, leaf number and leaf area of Swiss chard and lettuce (Maboko and Du Plooy, 2013; Maboko and Du Plooy, 2009), fresh leaf and dry leaf mass of bush okra (Manuel *et al*., 1998). In other similar studies on planting density, the contribution of the source of variation in TTV of the variables could not be compared with those in the current study since partitioning of the sources of variation was not computed (Maboko and Du Plooy, 2009). In the current study, the partitioning of the sources of variation contributed 81% and 93% to the TTV of the variable during winter H1 and H2, respectively.

In the current study, increasing planting density per drip irrigation hole increased dry shoot mass of *S retroflexum* during winter H1 and H2. The study conducted by Maboko and Du Plooy (2013) demonstrated an increase in yield of Swiss chard with increasing planting density per unit area. In contrary, Maboko and Du Plooy (2009) reported a decrease in yield of lettuce with increasing planting density. Manuel *et al*. (1998) also observed similar results of increased fresh and dry leaf mass of bush okra with increasing planting density. The results of the current might be attributed to competition for photo synthetically active radiation (Maboko and Du Plooy, 2009). The findings obtained from this study were not in agreement to those reported by Masarirambi *et al*. (2012) observed that increasing planting density reduced number of branches and their leaves per plant, dry weight of leaf and stem on potato plant. According to Maboko and Du Plooy (2013) plant spacing or density plays an important role in optimising yield of vegetables. In the current study the increasing plants per drip irrigation hole increased dry shoot mass of *S. retroflexum.* Basically, when the planting density is too low, each individual plant may perform at its maximum capacity, but too low planting densities results fewer plants as a whole to reach the optimum yield (Rana and Rana, 2014). Therefore, total yield of the crop becomes a limiting factor. The findings of the study were in agreement with previous findings on Swiss chard (Maboko and Du Plooy 2013), where leaf yield per unit area increased due to increased plant density. In contrary, Shalaby and Razin (1992) reported that herbage biomass of thyme increased at the lowest planting distance. As the planting density increases, the total crop yield increases and reaches a maximum, at which point further increase in planting density results in reduced yield (Akintoye *et al*., 2009; Mueller *et al*., 2015). It is, therefore, important to use appropriate planting density. However, the observation of this study, increasing the number of plants per drip irrigation hole increased the dry shoot mass of *S. retroflexum*. According Rahman and Hossain (2011), planting densities that are either too low or too high may result in economic losses. Therefore, increasing the number of plants per drip hole through the use of 3S planter resulted in higher yields of *S. retroflexum*. The 3S planter also played a role in maintaining a uniform planting depth of the plants (Mashela, 2015).

The observed relative impact in the current study increased positively with increasing number of plants (planting density) per drip irrigation hole during summer H1and H2 and winter H1 and H2, ranging from the lowest to the highest relative impact. In contrast, Sani *et al.* (2008) observed a negative relative impact with increasing planting density on maize, relative impact percentage was negative with increasing planting density per unit area to all the treatments for cob weight (−3 to −5%), whereas grain weight had a positive relative with increasing planting density (3 to 5%). The positive relative impact observation is attributed to the increased number of plants per drip irrigation hole, where the highest number/drip hole showed the highest mean value of dry shoot mass than at lowest number/hole for *S. retroflexum* (Mabotja, 2015). Therefore, the results of a negative relative impact resulted from reduced cob weight with increasing planting density (Sani *et al*., 2008). The results of a negative relative impact might be attributed to control mean was greater than planting density treatment (Mashela, 2015). However, the current study is in agreement with Sani *et al*. (2008), who observed similar results where the relative impact increased with increasing planting density increased grain weight of maize. Good light distribution within the crop canopy increases the number of well illuminated leaves. This condition induces high rate of canopy photosynthesis that leads to high yield per crop (Liu *et al*., 2016). The increase in relative impact from the lowest planting density to the highest planting density might be attributed to the less evapotranspiration rate under the highest planting density and also light interception is improved at the highest the planting density which leads to high photosynthesis (Rahman *et al*., 2011). Previously it was shown that grain yield was greater at the lower plant population, which makes its relative impact to decrease at the highest plant population (Al-Kaisi and Yin, 2003).

Responses of planting density effect on dry shoot mass were linear with 95, 97, 94 and 98% during summer H1 and H2, winter H1 and H2, respectively. Khazaie *et al*. (2007) observed similar positive quadratic relation on herbage biomass production of *T. vulguris* with models being explained by 97% and 98% over two harvests in two years. The highest percentage suggested that a perfect positive linear relationship between independent and dependent variable existed (Costa, 2017), whereas the optimum value of number of plant per drip hole was 15 plants for summer H1, 10 plants for summer H2, 16 plants in winter H1 and 18 plants/hole in winter H2. It is clear that increasing planting density/drip hole affected dry shoot mass positively, thereby increasing mean values of dry shoot mass of *S. retroflexum* with the highest number of plants/drip hole. The lowest values were observed at 1 to 4 plants/drip hole. The study implies that in order to produce highest yields of *S. retroflexum* under drip irrigation system, the number of plants/drip hole can be increased up to 9 plants/drip hole. In the present study, *S. retroflexum* growth under IDIS showed a consistent increase in dry shoot mass at a higher planting density/drip hole during summer and winter harvests. Therefore, production of *S. retroflexum* might be suitable at a higher planting density/drip hole, suggesting that farmers should increase number of plants per drip irrigation hole to produce optimum yields per one drop of water.

3.4.2 Nutrient element variables

The significant interactions on irrigation interval and planting density on chemical nutrient elements in *S. retroflexum* leaf tissues during summer H1 in this study is the first such report and could not be compared with other studies. However, in the current study, the partitioning of the sources of variation suggested that the TTV of the variables for the interactions were negligent since they contributed only 1-2% in TTV of the variables. Consequently, the main plot (irrigation interval) and sub-plot (planting density) factors were assessed separately as the main focus in the study. Irrigation interval × planting on P alone contributed 17% in TTV of the variables.

The significant irrigation interval on macronutrient (calcium, magnesium, phosphorus, potassium and sodium) and micronutrient (iron, copper, zinc and manganese) in *S. retroflexum* leaf tissues during summer H1 supported observations in deficit irrigation on nutritional composition (Ca, Mg, K, Na, Fe, Cu and Zn) of tomato plant (Agbemafle *et al*., 2015), Ca and K in leaves of *Gongronema latifolium* (Benth), whereas water stress had no significant effect on percentage concentrations of Mg, P and Na (Osaugwu and Edeoga, 2012). In other similar studies on irrigation interval, the contribution of the source of variation in TTV of the variables could not be compared with those in the current study since partitioning of the sources of variation was not computed (Agbemafle *et al*., 2015). In the current study, the partitioning of the sources of variation contributed (95%, 97%, 68%, 92%, and 63%) on Ca, Mg, P, K and Na, respectively, to the TTV of the variable. Micronutrient elements, Fe, Zn, Mn and Cu contributed (90%, 91%, 96% and 62%), respectively, to the TTV of the variable.

In the current study, increasing irrigation interval increased mineral concentration in *S. retroflexum* leaf tissues, which contradicted earlier observation (Agbemafle *et al*., 2015) in tomato plant. In an earlier study (Agbemafle *et al*., 2015), mineral content (Ca, Mg, K, Na, Fe and Zn) decreased with increasing irrigation interval, where the highest mineral content was observed at full water application treatment, whereas in the current study, most nutrient elements increased with increasing irrigation intervals. Rouphael *et al*. (2008) reported a decrease in macronutrients of mini-watermelon fruits and leaves under water stress. Contradiction existed when irrigation application increased the content of Ca, Mg and P than that of non-irrigated plants on wild banana (Zewdie *et al*., 2008).

Previously De Carvalho and Savaria (2005) reported that water stress caused a decrease in Ca content of the plants. The reduction in Ca content of the plants might be attributed to the reduction of root activity and leaf water potential, due to water stress which restricted the plant's ability to absorb Ca through the roots (Lee *et al*., 2006). However, the results of the current, calcium content in leaf tissues of *S. retroflexum* increased linearly with the increasing irrigation intervals. According to Taylor *et al*. (2004), reduced irrigation increases evapotranspiration rate hence the reduced calcium uptake by tomato fruit. The results of the study were in agreement with Olaniyi and Akanbi (2008), who reported the highest mineral contents of cabbage increased with increasing irrigation interval. Calcium is important in the growth and maintenance of bones, teeth and muscles (Akubugwo *et al*., 2007). The reduction of Ca content was also reported by others (Ashraf *et al*.,1998; Kaya *et al*., 2006 Lee *et al*., 2006).

Magnesium content increased with the increasing irrigation interval but started to decrease at longer irrigation interval. The increase in mineral content in leaf tissues with increased amount of irrigation water might be attributed to the release of more mineral ions in solution as irrigation water increased which in turn increased the rate of absorption by plant roots (Pascale *et al*., 2001). According to Pascale *et al* (2001), the decrease in amount of water in the soil would reduce the amount of mineral absorbed by the roots and hence reduced the mineral content of the fruits. The results of this study are in agreement with Nahar and Gretzmachar (2002), who reported the uptake of Mg in tomato plants was significantly reduced by water stress.

Irrigation interval had a significant effect on P content in leaf tissues of *S. retroflexum*. The results of the current study indicated that P content increased with increasing interval. However, at a longer irrigation interval P content was significantly reduced. When plants are stressed to low interval water potential, uptake of nutrients usually decrease due to diminishing absorbing poor of the roots (Dunham and Nye, 1976). According to Nelsen and Safir, (1982), P nutrition of the plants has been implicated in the ability of plants to tolerate drought. It was reported that water deficit has a direct effect on the stomatal and enzymatic apparatus as well as a long-term influence on uptake and accumulation of P by crops (Santos *et al*., 2004), especially for common bean as a poor inorganic P (Fageria *et al*., 1997).

The current findings demonstrated high accumulation of K in leaf tissues of *S. retroflexum* at the longest irrigation interval, therefore K content increased with increasing irrigation interval. Previously it was reported that deficit irrigation in tomato fruits contain less potassium (Griffiths *et al*., 1992). The results of the study do not agree with the findings of Griffiths *et al*. (1992) who reported that regulated deficit irrigated fruits of tomato plant decreased K with water stress. Nahar and Grezmachar (2002) reported the uptake of K by tomato plant was significantly reduced by water stress. Water stress also decreased K concentration of Indian rose wood leaf tissues. The results might be attributed to translocation of K from leaf to stem of stressed seedlings (Singh and Singh 2004). Osaugwu and Edeoga (2012) also observed a decrease in K content in leaves of *Gongrolema latifolium* with decreasing water application. According to Ashraf *et al*. (1998), a decrease in K content of the plants might be attributed to mobilisation of K ions from the leaves to the roots in response to water stress to increase in the osmotic potential of the sap of the roots to help the plants to withstand the effects of water stress.

The current results demonstrated that Na in leaf tissues of *S. retroflexum* was highly affected by different irrigation interval. The results of this study indicate that sodium increased with increasing irrigation intervals and drastically reduced at the longest irrigation interval. Plant responses to water and salt stress have much in common. Salinity leads to many metabolic changes that are identical to those caused by water stress (Shawquat *et al*., 2014). According to Shawquat *et al*. (2011), the higher the accumulation of sodium in leaf tissues under water stress might be due high transpiration rate. The rate of transpiration can influence uptake and movement of some ions in plants (Weatherley, 1969). These findings confirm the decrease in Na content in tomato fruits. The results of this study is in agreement to the findings of Rahman *et al*. (1999), who reported that water stress generally favours the uptake of Na in drought tolerant maize crops. The above observations can be explained by the fact that different plant species react differently to the same environmental stress.

Iron, Zn, Mn and Cu were significantly affected by different irrigation intervals. High accumulation levels of these micronutrient elements in leaf tissues of *S. retroflexum* increased with increasing irrigation intervals and started to decrease at the longest irrigation intervals. According to Oktem (2008), water stress reduces iron uptake in sweet corn. The decrease in concentration of Zn with increasing irrigation interval from this study was not in agreement with findings of Pirzad *et al*. (2012), whose work showed that different water application had no significant effect on Zn uptake. Manganese increased with increasing irrigation intervals. However, zinc content was reduced under longer irrigation intervals. The decrease in Mn content might be attributed to increase in soil pH. Bromfield *et al*. (1983) and Cole *et al*. (2016) reported that manganese availability for plant uptake decreases as soil pH increases. Copper was high at the lowest irrigation intervals and decreased at longer irrigation intervals. Copper was reported to decrease under increasing water stress (Singh and Singh, 2004). Transpiration and other processes of plant water loss during increasing irrigation intervals might have increased the micronutrient content in the plant (Weatherley, 1969).

The significant planting density on chemical nutrient elements in *S. retroflexum* leaf tissues during summer H1 in this study is the first such report and could not be compared with other studies H1. In the current study, the partitioning of the sources of variation contributed (1%, 9%, and 3%) on Ca, P and K, respectively, to the TTV of the variable. Results of the current study indicated that the was no significant effect of planting densities on Mg, Na, Fe, Zn, Mn and Cu in *S. retroflexum* leaf tissues, except for Ca, P and K significant difference were observed. The absence of significant effects of planting densities on Mg, Na, Fe, Zn, Mn and Cu in leaf tissues of *S. retroflexum* appears that no previous study conducted on S*. retroflexum* macro and micro nutrient in leaf tissues of the crop. However, the significant effects on P and K decreased with the increasing plants per drip irrigation hole except for Ca, Ca accumulation increased with increasing planting densities. The results of this study might be attributed to indigenous vegetables are considered to have stronger water stress adaptations mechanisms than common commercially available vegetables (Oelofse and van

Averbeke, 2012), hence number of plants per drip irrigation hole had no significant effect on essential mineral content of *S. retroflexum* leaf tissues.

The observed relative impact in the current study increased positively with increasing irrigation intervals during summer H1, ranging from the lowest to the highest relative impact on all macro and micro nutrient elements except for magnesium a negative relative impact was observed at 4 days, however a positive impact was shown as the irrigation interval was increasing. In contrast, Agbemafle *et al*. (2008) observed a negative relative impact with increasing irrigation interval on tomato plant, relative impact percentage was positive at the lowest irrigation interval and as the irrigation interval increased, it was reduced to a negative percentage. The positive relative impact observation is attributed to increase in mineral content with the increasing irrigation interval (Mashela, 2015). Therefore, the results of a negative relative impact resulted from reduced mineral concentration with increasing irrigation interval or after plants have been exposed to deficit irrigation (Agbemafle *et al*., 2008).

Responses of irrigation interval effect on mineral content were linear with 98, 92 and 97, 97, 86, 88, 88, 87 and 83% on Ca, Mg, P, K, Na, Fe, Zn Mn an Cu, respectively, during summer H1. In contrary, Agbemafle *et al*. (2015) observed a negative correlation on mineral content of tomato plants with increasing irrigation interval. It is clear that increasing irrigation interval affected nutrient elements positively, thereby increasing concentrations of minerals in leaf tissues of *S. retroflexum* at a prolonged irrigation interval. The lowest concentration of nutrient elements was observed at excessive water application or frequent irrigation on most macro and micro nutrients. Planting density did not affect most of nutrient elements, where Ca and K had linear relationship with 91 and 59%, respectively, whereas P had a negative relationship with 59% coefficient of determination. The study implies that in order to produce high concentration in leaf tissues of *S. retroflexum* under drip irrigation, the crop can be irrigated at irrigation interval of 10 days at highest planting density until harvest. In the present study, *S. retroflexum* nutrient elements under deficit irrigation showed a consistent increase in concentration during summer H1.

3.5 Conclusion

Based on the results obtained from this study, it can be concluded that irrigation interval and planting densities through the use of 3S planter and IDIS had a positive effect on growth, yield, nutritional and mineral composition of *S*. r*etroflexum*. Irrigation interval and planting densities caused increase in dry shoot mass and mineral content of *S. retroflexum*. The highest dry shoot mass was observed at longer irrigation interval and higher planting densities. Most nutrient elements were low at low irrigation interval, but highest at longest irrigation interval. Concentration of most elements were not affected by the number of plants per drip irrigation hole, implying that farmers can plant up to 9 plants without any difference in nutrient element of the crop. The study suggested that smallholder farmers stand to benefit high yields from optimising irrigation application and planting density in the production of *S. retroflexum*.

In this study, we demonstrate that drip irrigation systems being used for vegetable crops are also effective for successful indigenous vegetable production, with the combined and individual effects of drip irrigation interval and planting density being significant determinants of overall yield and nutritional composition of indigenous vegetable. The highest values of these components were obtained under highest irrigation interval (10 and 14 days) and highest planting density per drip irrigation hole (8 to 9 plants), whereas the lowest values were obtained from the lowest irrigation interval (2 and 4 days) and the lowest planting density (1 and 2 plants).

Considering that most farmers and smallholder farmers usually plant one plant per drip irrigation, the 3S planter can be used to produce more crop yields per one drop of water under IDIS to supply from one plant up to 9 plants per drip irrigation hole. Water use efficiency can be improved by optimum irrigation intervals to produce more crop yields and nutritional yields with less water. In conclusion the use of 3S planter and irrigation interval could be used in the production of *Solanum retroflexum* to produce more crop yields and save water with high level of nutrient element concentrations under deficit irrigation. In conclusion, we recommend the combination of an irrigation interval and planting density of longer irrigation interval with the high number of plants per drip hole.

CHAPTER 4

SUMMARY OF FINDINGS, SIGNIFICANCE OF FINDINGS, RECOMMENDATIONS AND CONCLUSSIONS

4.1 Summary of findings

The study focused on the influence of irrigation interval and planting density on growth yield and nutrient elements in leaf tissues of nightshade (*Solanum retroflexum*) through the use of Integrated Drip Irrigation System (IDIS) and 3S planter to produce more crop yields and nutrient elements with less water. The results of the study demonstrated that irrigation interval and planting densities improved growth and accumulation of essential nutrients. The current study confirmed that plant growth and essential nutrient elements in *S. retroflexum* were affected by irrigation interval and planting densities, particularly with deficit irrigation at higher planting densities per drip irrigation hole. The use of IDIS and 3S planter should be adopted by smallholder farmers especially in semi-arid areas where water scarcity is a major challenge. The two systems improved water use efficiency without compromising the growth yield and nutrient elements of *S. retroflexum*. Findings suggested that good yield of *S. retroflexum* could be produced from 7 to 9 plants per drip irrigation hole at 10 to 14 days irrigation interval. *Solanum retroflexum* vegetative growth and chemical composition increased under deficit irrigation, water stress caused increase in yield and essential minerals. The 3S planter function is to transplant seedlings from 1 to 9 plants per drip hole to increase crop water use efficiently, thereby supplying multiple seedlings with one drop of water. In general, there were changes in vegetative growth and mineral contents of *S. retroflexum* for all irrigation interval treatment from day 2 to day 14 and planting density. However, Mg, P, Na,Fe, Cu, Zn and Mn in *S. retroflexum* slightly decreased at day 12 to 14. Planting density had no effect on most mineral content in *S. retroflexum* leaf tissues, implying that in terms of number of plants per drip hole, the population density does not affect the mineral content of the plant. The results suggested that the IDIS and 3S planter under deficit irrigation were suitable for the production of indigenous vegetable *S. retroflexum*, with the results suggesting that the test crop could be irrigated at 14-days irrigation interval with 9 plants per drip hole, which could also increase essential nutrient elements with less water.

4.2 Significance of findings

The use of 3S planter and integrated drip irrigation system can be used to produce more crop yields and essential nutrient element with less water at higher planting densities per drip irrigation hole in areas where land availability and water scarcity is a major problem. Generally, indigenous vegetables are reported to be rich source of micro and macro nutrient elements, drought tolerant and require less water to produce optimum yields (Van Rensburg *et al*., 2007). *Solanum retroflexum* performed better at higher planting densities (7 to 9 plants per drip hole) better than at lower planting densities (1 to 3 plants) under deficit irrigation, where the highest yield was recorded at 10 to 14 days irrigation intervals. The optimum irrigation interval for dry shoot in summer first harvest was attained at 6 days and during winter first and second harvests, the optimum was attained at 14 and 5 days, respectively. Planting density for dry shoot mass, the optimum was attained at 15 and 10 plants during summer first and second harvest, respectively, and during winter first and second harvest it was attained at 16 and 18 plants, respectively. The optimum irrigation interval for macronutrients (Ca, Mg, P, K and Na) was attained at 3, 12, 10, 11 and 8 days, respectively. The optimum irrigation interval for micronutrients (Fe, Zn, Mn and Cu) were attained at 10, 12, 12 and 10, respectively. Therefore, the two systems together with the test indigenous vegetable could play a role in alleviating hunger, poverty, job creation and to improve water use efficiency of the crops.

4.3 Recommendations

Agricultural interventions should aim to increase information on agronomic practices knowledge of under-exploited natural resources such as indigenous food crops (FAO, 1997). Promoting indigenous vegetables may be difficult, since many people are not aware of the nutritional value of wild vegetables. In order to promote consumption of these vegetables, farmers, smallholder farmers and family households should have access to knowledge on how to cultivate indigenous crops in marginal communities. Also, nutritional schooling of indigenous vegetable should be promoted. Food production is linked with water; however serious challenges with water scarcity and land availability especially in Limpopo Province makes it difficult for smallholder farmers to produce food crops throughout the season. Most farmers depend on rain and with drought incidents; they fail to produce maximum crop yields. Therefore, alternatives such planting of drought tolerant plants, increase plants per drip irrigation hole on integrated drip irrigation with the use of a 3S planter system could be useful in vegetable production in rural communities of Limpopo Province.

4.4 Conclusions

Based on the results obtained from this study, it can be concluded that a prolonged irrigation interval or deficit irrigation and higher planting density had positive effects on vegetative growth and chemical composition of *S. retroflexum*. Deficit irrigation caused increases in vegetative growth and most macro and micro nutrients increased with increasing irrigation intervals. However, at a prolonged irrigation interval, mineral concentrations slightly decreased except for Ca and K, the two elements increased positively with increasing irrigation interval. Planting density caused increase in growth *of S. retroflexum* during summer and winter harvest, whereas chemical composition was not affected by planting density, therefore the IDIS and the 3S planter are suitable for increasing yields and accumulation of essential nutrient elements in *S. retroflexum*. The proper application of irrigation interval with the optimum levels of planting densities could contribute to obtain a good compromise between yield and nutrient elements, allowing saving a large amount of water and this aspect is particularly important in semi-arid areas of Limpopo Province.

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APPENDICES

Appendix 3.1 Analysis of variance for dry shoot mass of *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	2071.08	295.87	5.54	
Main factor (A)	6	4582.01	763.67	14.31	0.01
Error (A)	42	2241.20	53.36	2.01	
Subplot factor (B)	8	18464.86	2308.11	86.83	0.01
A × B	48	2049.88	42.71	1.61	0.01
Error	392	10419.69	26.58		
Total	503	39828.74	3490.3		

Appendix 3.2 Analysis of variance for dry shoot mass of *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer second (H2) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	605.71	86.53	7.22	
Main factor (A)	6	62.59	10.43	0.87	0.52
Error (A)	42	11.98	11.98	2.35	
Subplot factor (B)	8	2642.97	330.37	64.91	0.01
A × B	48	426.27	8.88	1.74	0.01
Error	392	1995.11	5.09		
Total	503	5744.63	453.28		

Appendix 3.3 Analysis of variance for dry shoot mass of *Solanum retroflexum* in response to different irrigation intervals and planting densities in winter first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	48.06	6.87	1.59	
Main factor (A)	6	461.79	76.96	17.86	0.01
Error (A)	42	180.95	4.31	1.74	
Subplot factor (B)	8	3267.85	408.48	165.21	0.01
A × B	48	122.81	2.56	1.03	0.42
Error	392	969.23	2.47		
Total	503	5050.68	501.65		

Appendix 3.4 Analysis of variance for dry shoot mass of *Solanum retroflexum* in response to different irrigation intervals and planting densities in winter second (H2) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	34.11	4.87	1.58	
Main factor (A)	6	141.57	23.60	7.67	0.01
Error (A)	42	129.17	3.08	2.31	
Subplot factor (B)	8	3495.47	436.93	337.07	0.01
A × B	48	87.76	1.83	1.41	0.05
Error	392	505.54	1.30		
Total	503	4388.49	471.61		

Appendix 3.5 Analysis of variance for calcium accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	31453.58	4493.37	3.54	
Main factor (A)	6	1496028.29	249338.05	196.40	0.01
Error (A)	42	760664.76	1533.60	2.06	
Subplot factor (B)	8	24844.66	3105.58	2.45	0.05
A × B	48	154187.56	3280.59	2.58	0.01
Error	392	550990.21	1269.56		
Total	503	3018169.06	263020.8		

Appendix 3.6 Analysis of variance for magnesium accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	12207.63	1743.95	1.72	
Main factor (A)	6	1204067.65	200677.94	198.39	0.01
Error (A)	42	847585.47	1104.00	2.01	
Subplot factor (B)	8	8239.61	1029.95	1.02	0.42
A × B	48	87592.38	1863.67	1.84	0.01
Error	392	439004.16	1011.53		
Total	503	2598696.9	207431.04		

Appendix 3.7 Analysis of variance for phosphorus accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	1734.07	247.72	1.59	
Main factor (A)	6	45952.74	7658.79	49.14	0.01
Error (A)	42	169447.31	342.32	3.09	
Subplot factor (B)	8	7365.79	920.72	5.91	0.01
A × B	48	89367.67	1901.44	12.20	0.01
Error	392	67491.08	155.87		
Total	503	207431.04	11226.86		

Appendix 3.8 Analysis of variance for potassium accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	745.49	106.50	1.54	
Main factor (A)	6	41432.62	6905.44	99.98	0.01
Error (A)	42	38378.77	77.38	2.06	
Subplot factor (B)	8	1569.83	196.23	1.87	0.01
A × B	48	6062.74	128.99		0.01
Error	392	29976.99	69.07		
Total	503	118166.4	7483.61		

Appendix 3.9 Analysis of variance for sodium accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	16.42	2.35	1.02	
Main factor (A)	6	129.99	21.67	9.39	0.01
Error (A)	42	1169.10	2.36	1.87	
Subplot factor (B)	8	23.04	2.88	1.17	0.27
A × B	48	127.27	2.71		0.21
Error	392	1001.69	2.31		
Total	503	2467.51	34.28		

Appendix 3.10 Analysis of variance for iron accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	108.55	15.51	1.86	
Main factor (A)	6	2759.18	459.86	55.15	0.05
Error (A)	42	4187.87	8.44	2.01	
Subplot factor (B)	8	51.31	6.41	0.77	0.63
A × B	48	400.19	8.51	1.02	0.44
Error	392	3619.20	8.34		
Total	503	11126.3	507.07		

Appendix 3.11 Analysis of variance for zinc accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	2.37	0.34	0.41	
Main factor (A)	6	198.12	33.02	40.14	0.05
Error (A)	42	394.04	0.78	1.09	
Subplot factor (B)	8	3.99	0.50	0.61	0.77
A × B	48	32.26	0.69	0.83	0.77
Error	392	356.98	0.82		
Total	503	987.76	36.15		

Appendix 3.12 Analysis of variance for manganese accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	3.24	0.46	1.19	
Main factor (A)	6	323.86	53.98	138.81	0.01
Error (A)	42	201.44	0.41	1.06	
Subplot factor (B)	8	3.77	0.47	1.21	0.29
A × B	48	27.41	0.58	1.50	0.05
Error	392	168.76	0.39		
Total	503	728.48	56.29		

Appendix 3.13 Analysis of variance for copper accumulation in *Solanum retroflexum* in response to different irrigation intervals and planting densities in summer first (H1) harvest.

Source	DF	SS	MSS	F	P ≤
Block	7	1.02	0.15	1.55	
Main factor (A)	6	5.90	0.98	10.46	0.01
Error (A)	42	49.28	0.10	1.65	
Subplot factor (B)	8	1.03	0.13	1.37	0.21
A × B	48	6.36	0.14	1.44	0.05
Error	392	40.80	0.09		
Total	503	104.39	1.59		