Cape Peninsula
University of Technology

GERMINATION AND GROWTH RESPONSES OF HORDEUM VULGARE SV13 CULTIVATED AS A GREEN FODDER CROP FOR AFRICAN CONDITIONS.

by

Ryan Anthony Smith

Thesis submitted in fulfilment of the requirements for the degree

Master of Horticultural Science

in the Faculty of Applied Sciences

at the Cape Peninsula University of Technology

Cape Town

Supervisor: Prof CP Laubscher

DECLARATION

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

Signed **Date**

ABSTRACT

This study evaluated the effects of 5 different soaking treatments in conjunction with 5 varying irrigation intervals on the germination, growth and nutritional values of seed of *Hordeum vulgare* Sv13. The 5 different soaking times consisted of 1, 3, 8, 16 and 24 hours. The barley seed was first cleaned and then placed in a vessel containing 500 ml of distilled water with a 20 % solution of sodium hypochlorite (bleach) at room temperature. Thereafter the pre-soaked seeds were transferred to a perforated container, containing no medium and placed into a growing chamber equipped with drip irrigation. The seed was then irrigated with 1245 ml of water at 5 different intervals namely every 2, 4, 8 10 and 12 hours. The temperature of the hydroponic growing room was kept at a constant 23 °C using a photoperiod of 16-hour day/ 8-hour darkness. The seed was allowed to germinate and grow for a period of 8 days before being harvested.

The objectives of this study were to determine the most beneficial combination of soaking treatment in conjunction with the most beneficial irrigation interval on the germination rate of the seed allowing for radicle emergence and coleoptile production. It was also used to determine which combination of treatments was most beneficial to the growth and nutritional values of the seed post-harvest. Another objective was to ascertain the shortest soaking time for application in a small-scale, hydroponic growing unit as well as the frequency of irrigation required to grow seedlings, thereby determining the amount of water required to produce a seedling mat for a small-scale, subsistence farmer, with the emphasis being on water reduction.

Each treatment was replicated 10 times and consisted of 500 grams of seed, which when placed into its container measured 2 centimetres in depth, totalling 25 treatments in all. Germination was measured by observing radicle emergence in the first 2 days of the growing period first after a 24-hour cycle and again after 48 hours. The numbers of leaves present at harvest after an 8-day growing period were also counted to determine germination rate of the seeds. Growth was determined by average leaf height as well as the tallest leaf on day 8 of the growing cycle. Root mat expansion was also measured, post-harvest, which was compared to the initial 2 cm planting depth of seed. Wet and dry weights of the plant material were measured post-harvest. Samples of the harvested material were also sent for nitrogen and protein analysis.

It was discovered that most of the results favoured a shorter soaking time and an increase in irrigation frequency, bar a few exceptions. Most favoured a pre-soaking time of only 1 hour

together with an irrigation frequency of between 2 and 4 hours. This shows that small-scale farmers would be able to reduce the time spent on soaking of their seed. Although the frequency of the irrigation interval remained high further testing would be required to determine if the amount of water applied at each irrigation interval could be reduced and still produce favourable results. It would also remain to be seen if no irrigation during the 8-hour dark photoperiod would have any negative impact on germination, growth and nutritional values of the seedlings.

ACKNOWLEDGEMENTS

I wish to thank:

- To my parents for their support and encouragement throughout the process of completing this study.
- To Prof. Charles Laubscher, for his guidance, invaluable knowledge and support which lead to the completion of this thesis.
- Cape Peninsula University of Technology for providing funding for my research.
- The National Student Financial Aid Scheme (NSFAS) for granting me further funding towards the completion of my studies.
- My gratitude is extended to the Agrifood Technology Station in particular Mr L. Dolley and Mr N Mchicileli for their contributions to this this study.

TABLE OF CONTENTS

	Declaration	**ii**
	Abstract	**iii**
	Acknowledgements	**v**

CHAPTER ONE: LITERATURE REVIEW AND INTRODUCTION

1.1	Abstract	**1-2**
1.2	Introduction	**1-3**
1.2.1	Subsistence and small-scale farming in Africa	**1-3**
1.2.2	Land usage and space for fodder production in Africa	**1-4**
1.2.3	Water availability and usage for agricultural fodder crops	**1-6**
1.2.4	Hydroponic systems for fodder crop production	**1-7**
1.2.5	Hydroponic application in small-scale cattle farming	**1-8**
1.3	Description and morphology of Barley	**1-9**
1.4	Treatments	**1-10**
1.4.1	Pre-soaking seed as a pre-germination treatment	**1-10**
1.4.2	The importance of sterilisation during germination	**1-11**
1.4.3	Watering requirements during germination	**1-12**
1.4.4	Temperature control during germination	**1-12**
1.4.5	The effect of light quantity and photoperiod during germination	**1-13**
1.4.6	Cultivation and harvesting cycle	**1-14**
1.5	Conclusion	**1-14**
1.6	References	**1-16**

CHAPTER TWO: PROBLEM STATEMENTS, AIM, HYPOTHESIS AND OBJECTIVES

2.1	Problem statement	**2-2**
2.2	Aims	**2-2**
2.3	Hypothesis	**2-2**
2.4	Objectives	**2-2**

CHAPTER THREE: THE INFLUENCES OF SEED SOAKING DURATION AND IRRIGATION FREQUENCY ON THE GERMINATON OF HORDEUM VULGARE SV13 SEED

3.1	Abstract	**3-2**
3.2	Introduction	**3-3**
3.2.1	Seed germination	**3-3**
3.2.2	Germination phases	**3-4**
3.2.3	Seed dormancy and soaking treatments	**3-5**
3.2.4	Seed sterilisation	**3-5**

3.2.5	Coleoptile emergence	**3-5**
3.2.6	Irrigation type and irrigation interval	**3-6**
3.3	Materials and methods	**3-6**
3.3.1	Experimental design	**3-6**
3.3.2	Hydroponic experiment and setup	**3-6**
3.3.3	Factors controlled in the experiment	**3-8**
3.3.4	Treatment preparation	**3-8**
3.3.5	Data collection	**3-10**
3.3.6	Statistical analysis	**3-11**
3.4	Results and discussion	**3-11**
3.5	Conclusion and recommendation	**3-17**
3.6	References	**3-19**

CHAPTER FOUR: THE INFLUENCE OF SEED SOAKING TIMES AND IRRIGATION FREQUENCY ON THE GROWTH OF HORDEUM VULGARE SV13 IN A HYDROPONIC SYSTEM

4.1	Abstract	**4-2**
4.2	Introduction	**4-3**
4.2.1	Seed soaking treatments	**4-4**
4.2.2	Seed sterilisation	**4-4**
4.2.3	Irrigation type and irrigation interval	**4-5**
4.2.4	Cultivation and harvesting cycle	**4-5**
4.3	Materials and methods	**4-6**
4.3.1	Experimental design	**4-6**
4.3.2	Hydroponic experiment and setup	**4-6**
4.3.3	Factors controlled in the experiment	**4-7**
4.3.4	Treatment preparation	**4-7**
4.3.5	Data collection	**4-9**
4.3.6	Statistical analysis	**4-10**
4.4	Results and discussion	**4-10**
4.5	Conclusion and recommendation	**4-16**
4.6	References	**4-18**

CHAPTER FIVE: THE INFLUENCE OF SEED SOAKING TIMES AND IRRIGATION FREQUENCY ON THE NUTRITIONAL VALUE OF HORDEUM VULAGRE SV13

5.1	Abstract	**5-2**
5.2	Introduction	**5-3**
5.3	Materials and methods	**5-4**
5.3.1	Experimental design	**5-4**
5.3.2	Hydroponic experiment and setup	**5-4**

5.3.3	Factors controlled in the experiment	**5-6**
5.3.4	Treatment preparation	**5-6**
5.3.5	Data collection	**5-7**
5.3.6	Statistical analysis	**5-8**
5.4	Results and discussion	**5-9**
5.5	Conclusion and recommendation	**5-16**
5.6	References	**5-18**

CHAPTER SIX: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

6	General conclusions and recommendations	**6-2**
6.1	Introduction	**6-2**
6.2	Review	**6-2**
6.3	Chapter 3 - Germination	**6-3**
6.4	Chapter 4 - Growth	**6-3**
6.5	Chapter 5 - Nitrogen, protein and wet weight	**6-4**
6.6	Major findings	**6-5**
6.7	Recommendations	**6-6**

CHAPTER SEVEN: LIST OF REFERENCES

7	References	**7-2**

LIST OF FIGURES

Figure 1:	Flowchart illustrating a hydroponic fodder system	**1-8**
Figure 2:	Photograph showing the hydroponic growing system design and layout	**3-7**
Figure 3:	Photograph showing radicle emergence in the seed of *Hordeum vulagre* Sv13	**3-10**
Figure 3.1:	Effects of irrigation interval on radicle emergence percentages (Day 1) on seed of *H. vulgare* with a 16-hour soaking time	**3-13**
Figure 3.2:	Effects of irrigation interval on radicle emergence percentages (Day 2) on seed of *H. vulgare* with a 16-hour soaking time	**3-13**
Figure 3.3:	Effects of irrigation interval on radicle emergence percentages on seed of *H. vulgare* with a 1-hour soaking time	**3-14**
Figure 3.4:	Effects of irrigation interval on number of leaves at harvest on seed of *H. vulgare* with a 1-hour soaking time	**3-15**
Figure 3.5:	Effects of irrigation interval on number of leaves at harvest on seed of *H. vulgare* with an 8-hour soaking time	**3-16**
Figure 3.6:	Effects of irrigation interval on number of leaves at harvest on seed of *H. vulgare* with a 16-hour soaking time	**3-16**

Figure 4:	Photograph showing the hydroponic setup and irrigation supplied to each tray	**4-7**
Figure 4.1:	Photograph of Barley seedlings at harvest showing root mat expansion	**4-9**
Figure 4.2:	Effects of irrigation interval on average leaf height, day 8, on seed of *H. vulgare* with a 3-hour soaking time	**4-12**
Figure 4.3:	Effects of irrigation interval on average leaf height, day 8, on seed of *H. vulgare* with a 1-hour soaking time	**4-12**
Figure 4.4:	Effects of irrigation interval on tallest leaf height, day 8, on seed of *H. vulgare* with a 16-hour soaking time	**4-13**
Figure 4.5:	Effects of irrigation interval on tallest leaf height, day 8, on seed of *H. vulgare* with a 1-hour soaking time	**4-14**
Figure 4.6:	Effects of irrigation interval on tallest leaf height, day 8, on seed of *H. vulgare* with a 3-hour soaking time	**4-14**
Figure 4.7:	Effects of irrigation interval on root mat expansion, day 8, on seed of *H. vulgare* with an 8-hour soaking time	**4-15**
Figure 4.8:	Effects of irrigation interval on root mat expansion, day 8, on seed of *H. vulgare* with a 1-hour soaking time	**4-16**
Figure 5:	Photograph showing the hydroponic setup and irrigation supplied to each tray	**5-5**
Figure 5.1:	Photograph of barley seedlings at harvest	**5-8**
Figure 5.2:	Effects of irrigation interval on nitrogen percentage, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time	**5-11**
Figure 5.3:	Effects of irrigation interval on protein percentage, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time	**5-12**
Figure 5.4:	Effects of irrigation interval on dry weight, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time	**5-13**
Figure 5.5:	Effects of irrigation interval on dry weight, post-harvest, on seed of *H. vulgare* with a 3-hour soaking time	**5-13**
Figure 5.6:	Effects of irrigation interval on dry weight, post-harvest, on seed of *H. vulgare* with an 8-hour soaking time	**5-14**
Figure 5.7:	Effects of irrigation interval on wet weight, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time	**5-15**
Figure 5.8:	Effects of irrigation interval on wet weight, post-harvest, on seed of *H. vulgare* with an 8-hour soaking time	**5-15**

LIST OF TABLES

Table 3.1:	Treatments indicating soaking times in conjunction with irrigation frequencies	**3-9**
Table 3.2:	Mean yield results of radicle emergence percentages on days 1 and 2 for *H.vulgare*, as well as number of leaves at harvest, compared to soaking times and irrigation frequencies	**3-12**
Table 4.1:	Treatments indicating soaking times in conjunction with irrigation frequencies	**4-8**

Table 4.2:	Mean yield results of average leaf height, tallest leaf and root mat expansion, compared to soaking times and irrigation frequencies	**4-11**
Table 5.1:	Treatments indicating soaking times in conjunction with irrigation frequencies	**5-6**
Table 5.2:	Mean yield results of nitrogen and protein percentages, wet and dry weights compared to soaking times and irrigation frequencies	**5-10**

CHAPTER ONE

LITERATURE REVIEW AND INTRODUCTION

Review

Food security for small scale farming in South Africa: Hydroponic barley cultivation as an alternative green fodder crop for Sub-Saharan Africa.

R.A. Smith[1], C.P. Laubscher*

[1]Faculty of Applied Sciences, Cape Peninsula University of Technology, P.O. Box 1906, Bellville, 7535, South Africa.

***Email: LaubscherC@cput.ac.za**

1.1 ABSTRACT

Animal fodder requirements of the small-scale farmer in Africa are under strain due the high cost of fodder and feedlot supplementation. Subsistence farming is also decreasing with studies showing a higher dependence on market purchases and market dependency. Land resources for agriculture and livestock are under strain due to population explosion and the requirement for housing. Cultivated land has become non-viable due to overgrazing and overstocking of available grazing land in rural areas. Aridification from climatic changes has a further negative effect on available land and water resources. Fresh water resources, especially in arid and semi-arid regions throughout Africa are also diminishing due to population growth and increased economic activity. Hydroponic cultivation of fodder crops in a controlled environment could alleviate these issues providing a self-sustaining, self-sufficient solution to the small-scale farmer. The space required to produce a fodder crop is reduced to the size of a growing chamber instead of large tracts of open land for field crops. The fodder can be grown year-round, without being affected or impacted upon by climatic and weather conditions. The amount of water required to produce a hydroponically grown crop as opposed to open ground cultivation is greatly reduced.

Keywords: agricultural productivity; aridification; green revolution; growth chamber; *Hordeum vulgare* (barley); land scarcity; organic growth; poverty reduction; self-sustaining cultivation; subsistence farming; water reduction.

1.2 INTRODUCTION

Arid and semi-arid regions of Sub-Saharan African continue to face drought stricken conditions with fresh water resources ever diminishing. Cultivated land has become non-viable due to overgrazing Sigwela (2009), while remaining available land space requirements for grazing and fodder production are also diminishing due to population explosion and the need for housing. There is also increasing pressure, in Africa, on land resources due to human-wildlife conflict and the shift in land use from agricultural to wildlife farming (Chaminuka *et al.*, 2013). This places animal fodder requirements for the small-scale farmer in Africa under strain due the high cost of fodder and feedlot supplementation. Climatic changes which are adversely affecting weather patterns and causing drought, are further reducing the viability of available land resources due to aridification (Driver *et al.*, 2012). Mooney (2005) has shown that due to the nature and fast growth habit of *Hordeum vulgare* (barley), it has been readily used as a fodder crop in hydroponic cultivation. The seed of *H. vulgare* can produce a seedling mat of between 15 cm to 20 cm, ready to harvest, in under 10 days from germination (Chung *et al.*, 1989). This forage mat includes both the germinated and ungerminated seeds, interwoven roots and leaf shoots. The area of land required to produce a viable crop is greatly reduced from vast tracts of open ground to the use of a growing room. Water usage required to grow fodder crops is also reduced from 73 litres per metre of crop, in open cultivation, to 2 litres of water per square meter in a hydroponic chamber (Al-Karaki, 2010). The fodder is grown in a sterile environment free from disease and pathogens and is independent of climatic influences (Jensen & Malter, 1995). Hydroponic cultivation of fodder crops in a controlled, self-contained environment could alleviate these issues providing a self-sustaining, self-sufficient solution to the small-scale farmer.

1.2.1 Subsistence and small-scale farming in Africa

Subsistence farming is mainly associated with the preindustrial sector as a farming type in which nearly all crops or livestock raised are used solely to support the farmer without any significant surplus for sale (Mirriam-Webster, 2016; Sampaolo *et al*., 2016). Although most rural households produce their own food, more recent studies have shown an increased dependence on market purchases, with almost 80 percent of total household income going towards food expenditure. Subsistence agriculture can play an important role in reducing the vulnerability of rural food-insecurity, improving livelihoods and helping to alleviate high food price inflation (Baipheti & Jacobs, 2009). There is a definite need to explore the improvement and upliftment of rural agriculture especially in most of sub-

Saharan Africa where food insecurity affects most of the urban poor population. Their dependence on markets increases, unlike their rural counterparts who are able to exploit natural resources to provide food or generate an income (Ruel *et al.*, 1998; Frayne *et al.*, 2010). A viable, cost effective, fodder crop production system could support local/rural farmers to ensure self-sufficiency and the possibility of increasing output for possible sale to local markets. This would improve production output and reduced land usage.

1.2.2 Land usage and space for fodder production in Africa

The availability of land in Africa for agriculture and livestock farming is rapidly diminishing. This is due to a of number factors, predominantly population increase, overgrazing and the need for housing, as well as the shift in land use from agriculture to wildlife ranching (Chaminuka *et al.*, 2013). South Africa for example has a dual agricultural economy with both well-developed commercial farming and more subsistence-based production in the deep rural areas. The country covers 1.22 million square kilometres of land and has seven identifiable climatic regions, from Mediterranean, sub-tropical to semi-desert. While 12 percent of South Africa's available land could be used for crop production, only 22 percent of this has the potential to be used for agricultural purposes. The greatest problem is the availability of fresh water as the country suffers from uneven and unreliable rainfall. Approximately 1.3 million hectares of agricultural land is under irrigation, counting for around 50 percent of the country's fresh water use (South Africa.info, 2016.) In 2003, the number of livestock on South Africa's farms numbered 13.5 million heads of cattle, 29 million sheep and 6.6 million goats according to the National Department of Agriculture. Agricultural land consists of 100.7 million hectares (81%) of South Africa's total land area of 122.3 million hectares. Of the total agricultural land 84 million hectares (66.8%) is under permanent pasture, whilst the rest 16.7 million hectares, is potentially arable (NDA, 2005). Small scale farming accounts for 86 percent of the farming community which is mainly subsistence in nature and relies mainly on traditional methods of production (NDA, 2004).

The United Nations showed that for the first time globally, the proportion of people living in urban areas exceeded 50 percent with the most intense increase in both Africa and Asia (UN_HABITAT, 2006). The increase in population creates the demand for more housing, which has a direct correlation to cost of farming, as land is at a premium and space for agriculture diminishes. Population projections indicate in as much as a decade a further 2-3 billion people will require feeding. This increase in food production will have a marked impact and demand on land requirements and availability, due to the increase in food and energy prices. This in turn also threatens the tenure security of people living and farming in

rural communities. Holden and Shiferaw (2004) have shown that that land degradation in combination with population growth and stagnant technology can lead to an increase in food insecurity.

South Africa's grassland biome is also under threat due to mismanagement and lack of protection. Aridification is also on the increase due to climatic changes, overgrazing and the increase in atmospheric carbon dioxide (Driver *et al.*, 2012). Climatic risks, such as drought, flooding, frost and hailstorms as well as pests and diseases are also important to consider in rural subsistence farming. These conditions have a high impact in semi-arid and arid areas, which further compound the pressure placed on already strained land requirements (Holden & Ghebru, 2016). Historical overstocking of available grazing land in rural areas by domestic livestock is also a significant contributor to overgrazing (Sigwela, *et al.*, 2009).

Juergen Voegele, the director of Agriculture and Rural Development Department at The World Bank, stated in 2006 "that one of the highest development priorities in the world must be to improve smallholder agricultural productivity, especially in Africa. Smallholder productivity is essential for reducing poverty and hunger, and more and better investment in agricultural technology, infrastructure, and market access for poor farmers is urgently needed. When done right, larger-scale farming systems can also have a place as one of many tools to promote sustainable agricultural and rural development, and can directly support smallholder productivity, for example, through outgrower programs." Africa is also currently witnessing competition for fertile land and water availability among rural communities, especially smallholder famers. Demand for fertile land in Africa will almost certainly intensify along with rapidly increasing global demand for food, in part because the potential for crop area and water use expansion in North America, Europe and most of Asia is very limited (Deininger *et al.*, 2011). In Africa, wildlife related land uses are also making rural households more vulnerable to poverty due to increased human-wildlife conflict and competition for land with livestock production (Metcalf & Kepe, 2008). This has an impact on the availability of arable land for crop growing as well as cattle farming. With land space a growing concern, the successful implementation of a hydroponic fodder system potentially addresses such a shortage. The fodder growing system would reduce the need for large open tracts of land for grazing and or the growing of fodder crops and reduces pressure on available water supplies.

1.2.3 Water availability and usage for agricultural fodder crops

Africa faces a major challenge in minimising agricultural water use, whilst maintaining or improving economic productivity of the agricultural sector. The world's freshwater resources are being placed under increasing pressure from population growth and the increase in economic activity, according to the Global Water Partnership Technical Advisory Committee (TAC, 2000). The Integrated Water Resource Management Review found that improved standards of living, together with increased economic growth has led to increased competition over limited freshwater resources. This, together with a lack of pollution control measures has had a further negative impact on freshwater resources.

The most significant factor limiting South Africa's agricultural sector is the availability of fresh water. The country's average annual rainfall is 450 mm/year, well below the world's average of 860 mm, while evaporation is comparatively high. Rainfall is also distributed unevenly across the country, with humid, subtropical conditions in the east having as high as 1000 mm rainfall and dry, desert conditions in the west with less than 100 mm. Potential evaporation is estimated at 1500 mm/year, resulting in only 8.5% runoff with a combined runoff of 42 mm/year compared with the average for Africa (139 mm/year) and the world (330/year). Not only is the runoff in the country very low, but it is also variable from year to year and from region to region (DWAF, 2002, 2004). Moreover, only 10% of the country receives an annual precipitation of more than 750 mm and more than 50% of South Africa's water resource is used for agricultural purposes (NDA, 2001). Climate change resulting in higher temperatures and worsening rainfall patterns, together with the already scarce water resources in the country are expected to have a significant effect on all sectors of the economy. For example, anecdotal evidence suggests that climate change could lead to a fall of about 1.5% in the country's gross domestic product (GDP) by 2050, a fall roughly equivalent to the total annual foreign direct investment in South Africa at present (DEAT, 2006).

Irrigated agriculture is the major consumer of fresh water supplies in many parts of the world, with particular impact in arid and semiarid regions. The demand on scarce water resources in Africa is increasing with time for both agricultural and non-agricultural purposes. Irrigated agriculture on average counts for more than 70% of all freshwater use, which is more than 90% of all consumption of freshwater. Hydroponic techniques can be used for green fodder production of many forage crops in a hygienic environment free of chemicals like insecticides, herbicides, fungicides and artificial growth promoters. Hydroponic growth is also a well-known technique used to produce higher fodder yield and year-round production,

irrespective of climatic conditions and seasons, whilst still maintaining the lowest amount of water use to produce a high-yield crop as compared to conventional farming methods (Al-Karaki & Al-Hashimi, 2012; Cuddeford, 1989; Sneath & Mcintosh, 2003). It has been reported that approximately 1,5 – 2 litres of water is needed to produce 1 kg of green fodder hydroponically in comparison to 73 litres to produce 1 kg of barley under field conditions (Al-Karaki, 2011). Owing to the fact that no additives are used in the hydroponic process, the water can be recycled and reused to water livestock, once it has passed through the hydroponic system. Methods and technologies that can contribute to improved water use efficiency and productivity, such as hydroponics, merit closer consideration.

1.2.4 Hydroponic systems for fodder crop production

Hydroponics or hydro culture is the scientific technique whereby plants are grown without the need for soil. Plants can be grown in nutrient solutions, with or without the use of artificial substrate. In hydroponics, water, nutrients and air are optimised in the root zone of the plant. This allows the plant to better utilise its energy in foliar, stem growth, flowering and fruit production (Venter, 2010). There are many added advantages to hydroponic crop production. There is no need for soil cultivation and crop rotation, which greatly reduces labour requirements. The growing environment is sterile which eliminates weeds and other pathogens. Hydroponic growth is a methodical approach to production, which increases cleanliness, uniform output and can greatly increase harvest yield (Harris, 1982). In areas where fresh water is limited, desalinated water can be used to great effect. This therefore ensures the potential for hydroponic systems to provide food in non-arable and water scarce areas such as deserts and semi-arid regions (Resh, 1997). There are three main systems used in hydroponics, namely: open or drain to waste, closed or recirculating and open field hydroponics known as fertigation (Venter, 2010). These well researched methods on hydroponic culture constitute as valuable reference for future research into the development of a hydroponic system for fodder crop production for small-scale farmers.

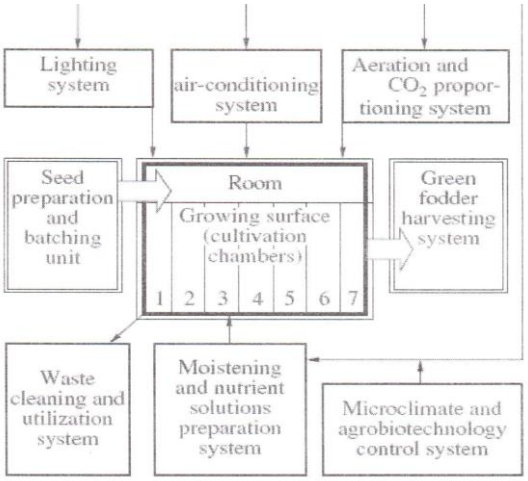

Fig 1. Flowchart illustrating a hydroponic fodder system (El-Deeba *et al.,* 2009).

1.2.5 Hydroponic application in small-scale cattle farming

The use of a hydroponic growing system can greatly benefit the small-scale farmer. The system would allow the growth of a fodder crop in a controlled environment, which is not affected by climatic conditions or seasons. Sneath and McIntosh (2003) reported that the use of a hydroponic chamber for the production of fodder in small scale farming was found to have a profitable application with high value outputs. This was especially true where land space and values, together with alternative feed costs were high. Fodder can also be produced in an environment free from chemicals, fertilisers and artificial growth promoters (Jensen & Malter, 1995). Al-Karaki (2010) reported that water consumption is greatly reduced in a hydroponic system where 1.5 – 2 litres of water are needed to produce 1 kilogram of green fodder, as opposed to 73 litres required to produce 1 kilogram of barley in open field conditions. Mooney (2005) has shown that hydroponic sprouted barley also grows extremely quickly, with a harvest time of between 7-10 days. The harvested fodder, including green shoots, un-germinated seed and roots is also high in protein, fibre, vitamins and minerals (Chung *et al.*, 1989; Lorenz, 1980). Sprouted barley has been found to be a significant source of forage for livestock in arid and semi-arid regions (Al-Karaki & Al-Momani, 2011) and has been found to have a higher nutritive content than other grains. Al-Karaki and Al-Hashimi (2010) also found that barley had higher fodder yields and water efficiency than other grains. Further investigations into the application of such a hydroponic growing system, for use in rural African subsistence farming are required. The need for a cost-effective production system to alleviate the fodder requirements of small-scale farmers is evident. This would, in turn, reduce their dependency on having to buy costly feed and to

improve self-sufficiency. Many variations for hydroponic productions systems are available internationally, however their application needs to be adapted to small-scale farming needs in an African setting. In order to gain further insight and identify existing knowledge of these systems, an overview of barley cultivation is highlighted below.

1.3 Description and morphology of barley

Hordeum vulgare L. is a flowering plant belonging to the family Poaceae, in the order Cyperales, class Liliopsida. The genus *Hordeum* includes approximately 36 different species that are indigenous to 4 different continents. *Hordeum* is cultivated in two and six-rowed varieties, the small barley flowers or florets occurring in groups of three on alternate sides of the plant's spike. Each seed is enclosed in a strong outer covering, called a hull. The naked barley seed within this hull is similar in shape to a kernel of wheat. The life cycle of the plant begins with seed germination. The seed consists of the embryo, a series of outer layers of cells called the pericarp, and the endosperm. The endosperm contains different nutrients that the embryo draws upon as it grows into a plant. The principal compound found in the endosperm is starch, which represents about two-thirds of the mass of the seed. This starch serves as an energy source for the seedling. Another significant carbohydrate, the glucans, are components of the endosperm cell walls. The second largest component of the endosperm is protein. The amount of protein present is generally inversely proportional to the amount of starch. This protein provides a source of amino acids that can be used for protein synthesis by the seedling. Additionally, the grain contains a large variety of other compounds present in minor amounts, including mineral nutrients and different organic compounds, including various vitamins. Radicle emergence is the first sign of growth, followed by coleoptile emergence. The first leaf of the plant grows upwards, within the cylindrical sheath of the coleoptile (Garvin *et al*., 2003).

Hordeum vulgare more commonly known as barley is recognized as one of the very first crops to be domesticated for human consumption and it remains one of the major cereal crops grown in the world. Barley is well adapted to diverse environmental conditions and thus it is produced across a broader geographic distribution than most other cereals. Relative to other cereal crops, barley ranks fourth in total grain production and is used as an animal feed, which makes it essential to the human diet indirectly through meat production (Garvin *et al*., 2003). Sprouted grains used as supplementation in human diets has been used for many years, going back to the 1600s. The benefit to humans and animals alike has been proven to aid in nutrient supplementation. The system of using hydroponically sprouted barley seed as a dietary supplement for animals has been used with great effect

internationally in countries such as the United Kingdom, United States of America and Australia. Germination and sprouting activates enzymes that change the starch, protein, and lipid composition of the grain into simpler forms, for example, starch, a complex polysaccharide is converted to simpler sugars (Abel-Caines & Tierney, 2012). The seed, once germinated, can produce a forage mat of 15 to 20 cm in height, with a production rate of about 7 to 9 kg of fresh forage, which is equivalent to 0.9 to 1.1 kg of dry matter (Fazaeli, 2011). The seeds are allowed to germinate and grow for about a week. After this growing period, a forage mat composed of germinated and un-germinated seeds, their interwoven white roots, and green shoots is obtained (Cuddeford, 1989). This forage mat, roots and leaf blades are then harvested and fed to the animal as forage. The mineral and vitamin levels in hydroponically-sprouted barley are significantly increased over those in grain; in addition, they are absorbed more efficiently due to the lack of enzyme inhibitors in sprouted grain. Sprouted barley provides a good supply of vitamins A, E, C and B complex. The vitamin content of some seeds can increase by up to 20 times their original value within several days of sprouting (MOSES-Midwest Organic & Sustainable Education Service, 2013).

1.4 TREATMENTS

1.4.1 Pre-soaking seed as pre-germination treatment

Germination and sprouting of barley seed activates enzymes that change the starch, protein and lipids of the grain, into simpler forms, such as starch to sugars. Studies have shown it important to pre-soak the seed of barley before sowing, as this encourages the breaking of seed dormancy and increase the rate at which radicle emergence occurs. A number of authors have reported a wide range of seed soaking times, ranging from 3 hours up to 28 hours. Singh *et al.* (1979); Pettersson (1995) and Sang *et al.* (2006) soaked their seed for 3 hours as opposed to Walmsley and Adamson (1990) who used a 6-hour soak time. Arora *et al.* (2010); Al-Karaki and Al-Hashimi (2012); Dymek *et al.* (2012); Ali *et al.* (2013) all used 12 hours of soaking, compared with Al Ajmi *et al.* (2009), who reported using 14 hours of soaking in distilled water. Fazaeli *et al.* (2011) soaked their seed for 20 hours compared to Kleinwächter *et al.* (2014) and El-Deeba *et al.* (2009) who stated soaking of up to 24 hours and lastly Van Campenhout *et al.* (1999) as long as 28 hours. The most predominant soak time taken from research was 16 hrs (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009). Due to such varied reporting, further clarity is necessary to deduce the most beneficial soaking times required to germinate barley seed and how this will affect the germination rate, radicle emergence as well as the growth of the seed into the seedling forage mat.

1.4.2 The importance of sterilization during germination

Aside from soaking the seed to break seed dormancy research also indicated that in most cases, a sterilisation treatment was used to prevent fungal growth. Pettersson (1995) surface soaked the seed for 15 minutes in a mixed solution of H_gCl_2 and formaldehyde both at 0,01%. Al-Karaki and Al-Momani (2011) cleaned the seed of all debris and then sterilised the seed by soaking in 20% sodium hypochlorite solution for 30 minutes, as did (Al Ajmi *et al.,* 2009; Saidi and Omar 2015), compared to Seckin *et al.* (2010) who only used a 5 % sodium hypochlorite solution for 15 minutes, thereafter washing thoroughly in distilled water. Frossard and Oertli (1982) suggest surface sterilisation for 2 minutes in a 0.2% formaldehyde solution and rinsed thoroughly before soaking, whereas Hafsi *et al.* (2009) showed seeds being disinfected with a 2% solution of N_aClO (chlorine). Tamai *et al.* (2000) also used N_aClO but only a 1% solution for 30 minutes followed by a thorough rinsing in deionised water. El-Morsy *et al.* (2013) soaked the seed in warm water containing a 0.1% solution of hypochlorite at a temperature of 24 °C for 1 hour, followed by a rinsing under tap water for 10 minutes. Yousfi *et al.* (2007) surface sterilised the seed with a 1% solution of sodium hypochlorite for 20 minutes, compared with Dung *et al.* (2010) who soaked the seed for 4 hours in a 0.1% (v/v) hypochlorite solution before being transferred onto watering trays to germinate. Ali *et al.* (2013) sterilised their seed using a 3 % solution of H_2O_2 (hydrogen peroxide) for 30 minutes, followed by a thorough rinsing in distilled water. A further sterilisation regime was observed by Rostami *et al.* (2013), who after de-husking their seed washed them in tap water followed by a surface sterilisation in 70 % ethanol for 1 minute, followed by a 7-minute soaking in 0.1% (w/v) mercuric chloride solution thereafter rinsing with sterile distilled water. Nuutila *et al.* (2000) surface sterilised with 70 % ethanol for 5 minutes followed by a further 10 minutes using a 4 % sodium hypochlorite solution and thereafter rinsed thoroughly with sterile water. There is a definite need to examine the various methods and chemical compounds used in sterilisation techniques and how this would affect the germination responses and further growth of barley seed into a seedling forage mat.

1.4.3 Watering requirements during germination

There is little published dictating the amount and frequency of water/irrigation in a hydroponic system. It is important to establish these parameters to ascertain how much water the seedlings will require in order to germinate and produce a seedling mat. Research indicated a wide range of watering types, including both mist and flood irrigation. Fazaeli *et al.* (2011) merely mention a hydroponic unit fitted with sprayer irrigation. Further methods include rinsing once a day (Sung *et al.,* 2005) to being irrigated manually with tap water twice a day at a fixed rate of 600 ml per tray (Al-Karaki & Al-Hashimi, 2012). Dung *et al.* (2010) also showed the grain being watered for 3 minutes every 2 hours, to grain being sprayed with water for 15 minutes every 4 hours (Peer & Leeson, 1985). Al-Karaki and Al-Momani (2011) irrigated the seed twice a day (early in the morning and late in the afternoon) with tap water to provide enough water to keep the seeds/seedlings moist. Sung *et al.* (2005) rinsed the seed once a day with sterile water. Chung *et al.* (1989) laid the seed on a floor and sprayed the seed thoroughly 3 times a day with tap water. There is a definite need to investigate the most efficient type of irrigation method, either mist or flood, as well as irrigation frequency and water requirements best suited to germinating hydroponically grown barley into a seedling mat.

1.4.4 Temperature control during germination

Temperature plays a very important role in the germinating of any seed and would need investigation for use in the hydroponic growing chamber. Plants transpire at higher temperatures as water evaporates more rapidly. A leaf transpires three times as fast at 30 °C than it does at 20 °C (Venter, 2010). Fazaeli *et al.* (2011) suggest a working temperature range from 18 °C to 21 °C, with a relative humidity around 70 percent using air circulation, where Al-Karaki and Al-Momani (2011) maintained the growth chamber at 24 °C ± 2 °C, with the relative humidity between 45 and 70 percent. This is compared with Al Ajmi *et al.* (2009) who also had a similar temperature range of between 20 °C and 23 °C and relative humidity of approximately 70 percent. Sung *et al.* (2005) used a temperature range of 15 °C, 20 °C and 25 °C to germinate the seed in the dark. Anker-Nilssan *et al.* (2008) showed plants being grown in a glasshouse with an ambient day temperature of 15 °C and night temperature of 12 °C, compared with Walmsley *et al.* (1990), who merely relied on natural climatic conditions with temperatures ranging from 15 °C to 30 °C. Yousfi *et al.* (2009) used a daytime temperature of 25 °C and night temperatures of 22 °C, compared to Ali, *et al.* (2013) who used a daytime temperature of 22 °C and night temperature of 18 °C. Arora *et al.* (2010) placed the seed in petri dishes with wet filter paper at 37 °C and sprayed

frequently with water, compared with El-Morsy *et al.* (2013) who germinated the seed at a temperature of 24 °C. With such a variety of temperatures ranging from 15 °C up to 37 °C, there is a definite need to examine temperature range to ascertain which is most beneficial to growing and germinating barley seed in a hydroponic growing system.

1.4.5 The effect of light quantity and photoperiod during germination

Day night control, lighting types and light intensity are essential to establish a set of germination and growing parameters in a hydroponic system. These are required to simulate the natural growing environment. Plants also transpire more rapidly under light than in dark as light stimulates the opening of the plants stomata (Venter, 2010). Most plants require a minimum of 10 000 lux of light to support growth according to Harris (1982) and that there are 3 main properties of light which govern their effect on plants, namely: the blend of light wavelengths, the intensity which is measured in lux and duration also known as photoperiod. El-Deeba *et al.* (2009) stated that 12-16 hours of light per day, using two fluorescent (40W) tubes proving approximately 2000 lux of light was sufficient to germinate barley seeds in their growing chamber. Fazaeli *et al.* (2011) also used florescent lighting of 1000 to 1500 microwatts during 12 to 14 hours of light, compared with Al-Karaki and Al-Mamani (2011) who merely placed their seedlings in the corner of a growing room below a window to utilise natural illumination and day night cycles. Anker-Nilssen (2008) used controlled environmental chambers with daylight as well as additional illumination using eight 400 watt daylight (HQI) Metal halide lamps, compared with Dung *et al.* (2010) who used continuous fluorescent light of 615 lux at the surface of the seedling trays. A day night regime of 16 hours light and 8 hours of darkness was observed by Yousfi *et al.* (2009); and Ali (2013) whereas Fedina *et al.* (2005) used a 12-hour photoperiod. Walmsley *et al.* (1990), merely planted in a greenhouse using natural daylight and darkness. All previous authors showed no use of darkness to germinate the seeds of barley, however, Seckin, *et al.* (2010) placed their seeds on filter paper at 4 °C for 3 hours in the dark with no pre-soaking, followed by a light/dark photoperiod of 16/8 hours at 23 °C, compared to Molnarova and Fargasova (2012) who placed their seed in a dark, temperature controlled chamber of 25 °C for 72 hours. Tamai *et al.* (2000) also used a dark treatment for the germination of seed by placing the seeds on moist paper and allowed to germinate for 24 hours in the dark at 25 °C, compared to Dean-Drummond (1982), who merely stated that seeds were placed on moist sand in the dark for a period of 2 days to allow for germination. Other investigations showed Nuutila *et al.* (2000) using a photoperiod of 19 hours of light and 5 hours of darkness, with a day temperature of 22 °C and night temperature of 13 °C. With so many varied

photoperiods and lighting types, it is evident that further research will have to be conducted to ascertain which to be the most beneficial in germinating and growing barley seed into a seedling mat in a hydroponic system.

1.4.6 Cultivation and harvesting cycle

The growing period and subsequently time to harvest is a further aspect which will require investigation due to the large and varied results found in research. It was discovered that a 10-day growth cycle to be the most popular growing period (Yousfi *et al*., 2009; Al-Karaki & Al-Momani, 2011 & El-Morsy *et al.*, 2013). Days until harvest then varied from 10 days to as little as 6 days (Faezili, *et al.*, 2011). Faezili *et al.* (2011) however, tested harvesting periods from 6 days up to and including 8 days. Sung *et al.* (2005) also harvested over a range of days, from 6 up to and including 10 days. Peer and Leeson (1985) used a 7-day harvest, as opposed to a 9-day harvest (Al Ajami *et al.*, 2009). Poulet *et al.* (2014) however, harvested their seedlings only from 8 days, but up to an including 10 days as well. Further research will have to be conducted to deduce the most effective growing/harvest period on the seedling mat of barley, including whether or not the harvest period has any impact on the nutrient and protein value of the plant.

1.5. Conclusion

The use of sprouted grains and barley has been shown to have a significant impact in its use as a fodder crop. Although there has been some research with regards to barley being used as a fodder crop in other countries, there is a distinct lack of research into the effects of hydroponically grown barley for use on a small scale, with specific application on the African continent. Research has also been done using different strains and cultivars of barley suited to other climatic regions, not using the specific *H. vulgare* Sv13 strain suitable to warmer, African climatic conditions. The potential to produce a sustainable fodder crop, irrespective of climatic conditions on a year-round basis has many positive implications for the small-scale farmer in South Africa and the rest of the African continent. Hydroponically grown barley will allow the small-scale farmer to reduce or even remove the costs of costly feedlots and additional supplementation of food requirements. Improving the productivity of the small-scale farmer in Sub-Saharan Africa, by adding to the few resources already available, will aid in reducing poverty and increasing food security among the rural poor. There is a further need to investigate this method of sprouting grain in a growing chamber, as it will reduce the need for large tracts of land to grow fodder compared to traditional open ground methods. Fresh water is also a scarce commodity, especially in arid and developing countries.

Growing barley as a fodder crop hydroponically has the potential to reduce consumption by using up to 2 litres per square meter of water in a hydroponic system, as opposed to 73 litres per square meter in conventional planting. The cost effectiveness of hydroponically sprouted grain as opposed to open ground planting, with specific reference to land costs, water cost and availability as well as labour and machinery costs, is another aspect that requires investigation. Apart from the initial outlay to equip a hydroponic growing chamber, the costs to produce crops are reduced to labour and the purchase of seed. A unit has the capacity to produce up to 7 times the amount of the initial input i.e. 7 tons of fodder, from 1 ton of seed. Technologies that can improve on small-farm productivity and assist farmers in creating higher yields also aid in reducing yield gaps, which could have a significant impact on local and global food supplies. Taking all these aspects into consideration further research is required into the hydroponic growth of barley as a fodder crop in South Africa as well as the rest of the African continent.

REFERENCES

Abel-Caines, S. & Tierney, C. 2012. Sprouted barley fodder. Coulee Region Organic Produce Pool (CROPP) *Cooperative Organic Farming Technical Bulletin*, (10):1-5.

Al Ajmi, A., Ali Salih, A., Kadim, I. & Othman, Y. 2009. Yield and water use efficiency of barley fodder produced under hydroponic system in GCC countries using tertiary treated sewage effluents. *Journal of Phytology*, 1(5): 342-348.

Ali, S., Farooq, M.A., Yasmeen. T., Hussain, S., Arif, M.S., Abbas, F., Bharwana, S.A. & Zhang, G. 2013. The influence of silicon on barley growth, photosynthesis and ultra-structure under chromium stress. *Ecotoxicology and Environmental Safety*, 89: 66-72.

Al-Karaki, G.N. 2010. Hydroponic green fodder: alternative method for saving water in dry areas. In *Proceedings of the" Second Agricultural Meeting on Sustainable Improvement of Agricultural and Animal Production and Saving Water Use*. September 2010. Sultanate of Oman.

Al-Karaki, G.N. 2011. Utilization of treated sewage waste water for green forage production in a hydroponic system. *Emirates Journal of Food and Agriculture*, 23(1):80-94.

Al-Karak, G.N. & Al-Momani, N. 2011. Evaluation of some barley cultivars for green fodder production and water use efficiency under hydroponic conditions. *Jordan Journal of Agricultural Sciences*, 7(3):448-457.

Al-Karaki, G.N. & Al-Hashimi, M. 2012. Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholarly Research Network (ISRN) Agronomy*, 1:114-126.

Anker-Nilssen, K., Sahlstrøm, S., Knutsen, S. H. & Holtekjølen, A. K. 2008. Influence of growth temperature on content, viscosity and relative molecular weight of water-soluble b-glucans in barley (Hordeum vulgare L.). *Journal of Cereal Science*, 48:670-677.

Arora, S., Jood, S. & Khetarpaul, N. 2010. Effect of germination and probiotic fermentation on nutrient composition of barley based food mixtures. *Food Chemistry*, 119:799-784.

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

Chaminuka, P., Udo, H.M.J., Eilers, K.C.H.A.M. & van der Zipp, A. 2014. Livelihood roles of cattle and prospects for alternative land uses at the wildlife/livestock interface in South Africa. *Land Use Policy*, 38:80-90.

Chung, H.J., Jang, S.H., Cho, H.Y. & Lim, S.T. 2009. Effects of steeping and anaerobic treatment on GABA (γ-aminobutyric acid) content in germinated waxy hull-less barley. *Food Science and Technology*, 42:1712-1716.

Chung, T.Y., Nwokolo, E.N. & Sim, J.S. 1989. Compositional and digestibility changes in sprouted barley and canola seeds. *Plant Foods for Human Nutrition,* 39(3): 267-278.

Cuddeford, D. 1989. Hydroponic grass. *In Practice*, 11(5):211-214.

Dean-Drummond, C.E. 1982. Mechanisms for nitrate uptake into barley (*Hordeum vulgare* L. cv. Fergus) seedlings grown at controlled nitrate concentrations in the nutrient medium. *Plant Science Letters*, 24: 79-89.

DEAT (Department of Environmental Affairs and Tourism), 2006. *World Congress of International Council of Local Environmental Initiatives*. South Africa. https://www.environment.gov.za/sites/default/files/strategic_plans/2003_2006.pdf [22 March 2016].

Deininger, K.W. & Byerlee, D. 2011. *Rising global interest in farmland: can it yield sustainable and equitable benefits*? Washington, D.C. : World Bank. http://siteresources.worldbank.org/DEC/Resources/Rising-Global-Interest-in-Farmland.pdf [15 December 2014].

Driver, A., Sink, K.J., Nel, J.N., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. & Maze, K. 2012. *National Biodiversity assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report*. Pretoria: South African National Biodiversity Institute and Department of Environmental Affairs.

Dung, D.D., Godwin, R. & Nolan, J.V. 2010. Nutrient content and *In sacco* degradation of hydroponic barley sprouts grown using nutrient solution or tap water. *Journal of Animal and Veterinary Advances*, 9(19):2432-2436.

DWAF (Department of Water Affairs and Forestry), 2002. *Proposed First Edition National Water Resource Strategy*, Pretoria.
https://www.dwa.gov.za/Documents/Policies/NWRS/Default.htm [22 March 2016].

DWAF (Department of Water Affairs and Forestry), 2004. *National Water Resource Strategy, Pretoria.*
https://www.dwa.gov.za/iwqs/wrmais/National_Water_Resource_Quality_strategy_ed01_dr05_final.pdf [22 March 2016].

El-Deeba, M.M., El-Awady, M.N., Hegazi, M.M., Abdel-Azeem, F.A. & El-Bourdiny, M.M. 2009. Engineering factors affecting hydroponics grass-fodder production. In The 16th Annual Conference of the Misr Society of Ag. Eng., Agricultural engineering and variables of the present epoch. *Biological Engineering*, 25:1647-1666.

El-Morsy, A.T., Abul-Soud, M. & Emam, M.S.A. 2013. Localised hydroponic green forage technology as a climate change adaptation under Egyptian conditions. *Journal of Agricultural and Biological Sciences*. 9(6):341-350.

Fazaeli, H., Golmohammadi, H.A., Shoayee, A.A., Montajebi, N. & Mosharraf, S.H. 2011. Performance of feedlot calves fed hydroponics fodder barley. *Journal of Agricultural Science and Technology*, 13:367-375.

Fedina, I., Velitchkova, M., Georgieva, K. & Grogorova, I. 2005. UV-B-induced compounds as affected by proline and NaCl in *Hordeum vulgare* L. cv. Alfa. *Environmental and experimental Botany*, 54:182-191.

Frayne, B., Pendleton, W., Crush, J., Acquah, B., Battersby-Lennard, J., Bras, E., Chiweza, A., Dlamini, T., Fincham, R., Kroll, F., Leduka, C., Mosha, A., Mulenga, C., Mvula, P., Pomuti, A., Raimundo, I., Rudolph, M., Ruysenna, S., Simelane, N., Tevera, D., Tsoka, M., Tawodzera, G. & Zanamwe, L. 2010. The State of urban food insecurity in Southern Africa. http://www.afsun.org/wp-content/uploads/2013/09/AFSUN_2.pdf [24 March 2016].

Garvin, D., Raman, H. & Smith, K. 2003. Barley. *Encyclopedia of Food and Culture*. http://www.encyclopedia.com/topic/barley.aspx#1-1G2:3403400063-full [1 June 2017]

Global Water Partnership (GWP) Technical Advisory Committee. 2000. *Integrated Water Resources Management. Technical Advisory Committee background papers No. 4*. Stockholm. http://www.gwp.org/Global/ToolBox/Publications/Background%20papers/04%20Integrated%20Water%20Resources%20Management%20(2000)%20English.pdf [January 2016]

Harris, D. 1982. *Hydroponics: Gardening without soil*. Johannesburg: Centaur Publishers.

Holden, S.T, & Shiferaw, B. 2004. Land degradation, drought and food security in a less-favoured area in the Ethiopian highlands: a bio-economic model with market imperfections. *Agricultural Economics*, 30(1), 31-49.

Holden, S.T. & Ghebru, H. 2016. Land tenure reforms, tenure security and food security in poor agrarian economies: Casual linkages and research gaps. *Global Food Security*, 10:21-28.

Jensen, H. & Malter, A. 1995. Protected agriculture a global review. *World Bank Technical Paper,* 253:156. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/1995/04/01/000009265_3970311122818/Rendered/PDF/multi_page.pdf [25 March 2016]

Kleinwächter, M., Müller, C., Methner, F.J. & Selmar, D. 2014. Biochemical heterogeneity of malt is caused by both biological variation and differences in processing: I. individual grain analyses of biochemical parameters in differently steeped *Hordeum vulgare* L.) malts. *Food Chemistry,* 147:25-33.

Lorenz, K. 1980. Cereal sprouts: composition, nutritive value, food applications. *Critical reviews in Food Science and Nutrition,* 13(4):353-385.

Metcalfe, S. & Kepe, T. 2008. Your elephant on our land: the struggle to manage wildlife mobility on Zambian communal land in the Kavango-Zambezi trans-frontier conservation area. *Environment and Development*, 17:99-117.

Merriam-Webster, 2016. *Subsistence farming*. http://www.merriam-webster.com/dictionary/subsistence%20farming [22 March 2016].

Mooney, J. 2005. Growing cattle feed hydroponically. *Meat and Livestock Australia*. http://www.foddersolutionsafrica.com/wp-content/uploads/2013/02/Growing-Cattle-Feed-Hydroponically.pdf [20 April 2016].

MOSES-Midwest Organic and Sustainable Education Service. 2012. http://mosesorganic.org/farming/farming-topics/livestock/sprouted-%20barley-fodder-a-revolution-in-animal-feed [22 April 2014].

National Department of Agriculture (NDA). 2004. *Trends in the agricultural sector 2003: directorate, agricultural information*. Pretoria. http://www.nda.agric.za/docs/statsinfo/Trends_2003.pdf [23 March 2016].

National Department of Agriculture (NDA). 2005. *Abstract of agricultural statistics 2005: directorate agricultural information*. Pretoria. http://www.daff.gov.za/docs/statsinfo/P110112005.pdf [23 March 2016].

Nuutila, A.M., Hämäläinen, J. & Mannonen, L. 2000. Optimisation of media nitrogen and copper concentrates for regeneration of green plants from polyembryogenic culture of barley (*Hordeum vulgare* L.). *Plant Science*, 151: 85-92.

Peer, D.J. & Leeson, S. 1985. Nutrient content of hydroponically sprouted barley. *Animal feed Science and Technology*, 13:191-202.

Resh, H.M. 1997. *Hydroponic Food Production*. Santa Barbara. Woodbridge Press.

Rostami, H., Giri, A., Nejad, A.S.M. & Moslem, A. 2013. Optimisation of multiple shoot induction and plant regeneration in Indian barley (*Hordeum vulgare*) cultivars using mature embryos. *Saudi Journal of Biological Sciences*, 20:251-255.

Ruel, M.T., Garrett, J.L., Morris, S.S., Maxwell, D., Oshaug, A., Engle, P., Menon, P., Slack, A. & Haddad, L. 1998. Urban challenges to food and nutrition security: a review of food security, health and caregiving in the cities. *Food Consumption and Nutrition Division Discussion Paper No. 51*. https://core.ac.uk/download/files/153/6289467.pdf [23 March 2016].

Saidi, A.R.M.A. & Omar, J.A. 2015. The biological and economical feasibility of feeding barley green fodder to lactating Awassi ewes. *Open Journal of Animal Sciences*, 5: 99-105.

Sampaolo, M., Sinha, S., Curley, R. & Setia, S. 2016. Subsistence farming. *Encyclopedia Britannica*. http://global.britannica.com/topic/subsistence-farming [22 March 2016].

Sang, N., Li, G. & Xin, X. 2006. Municipal landfill leachate induces cytogenic damage in root tips of *Hordeum vulgare*. *Ecotoxicology and Environmental Safety*, 63: 469-473.

Seckin, B., Turkan, I., Sekmen, A.H. & Ozfidan, C. 2010. The role of antioxidant defense systems at differential salt tolerance of *Hordeum marinum* Huds. (sea barleygrass) and *Hordeum vulgare* L. (cultivated barley). *Environmental and experimental Botany*. 69: 76-85.

Sigwela, A.M., Kerley, G.I.H., Mills, A.J. & Cowling, R.M. 2009. The impact of browsing-induced degradation on the reproduction of subtropical thicket canopy shrubs and trees. *South African Journal of Botany*. 75:262-267.

Sneath, R. & Mcintosh, F. 2003. *Review of hydroponic fodder production for beef cattle: report 332*. Australia. Department of Primary Industries . http://blogs.cornell.edu/organicdairyinitiative/files/2014/05/Hydroponicfodder-article-11wpnm0.pdf [23 march 2016].

SouthAfrica.info, 2016. *South African a*griculture. http://www.southafrica.info/business/economy/sectors/agricultural-sector.htm#.VvU6_eJ961s [23 March 2016].

Sung, H.G., Shin, H.T., Ha, J.K., Lai, H.L., Cheng, K.J. & Lee, J.H. 2005. Effect of germination temperature on characteristics of phytase production from barley. *Bioresource Technology*, 96:1297–1303.

Tamai, T., Shimada, Y., Sugimoto, T., Shiraishi, N. & Oji, Y. 2000. Potassium stimulates the efflux of putrescine in roots of barley seedlings. *Journal of Plant Physiology*, 157: 619-626.

UN-HABITAT, 2006. State of the World's cities report 2006-2007. *Earthscan*. http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2101&AspxAutoDetectCookieSupport=1 [23 March 2016].

Venter, G. 2010. *Successful Hydroponics*. United States of America: Xlibris Corporation.

Walmsley, J. & Adamson, H. 1990. Gabaculine inhibition of chlorophyll synthesis in light and darkness in intact barley (Hordeum vulgare) seedlings. *Plant Science*, 68:65-70.

Yousfi, S., Wissal, M., Mahmouddi, H., Abdelly, C. & Gharsalli, M. 2007. Effect of salt on physiological responses of barley to iron deficiency. *Plant Physiology and Biochemistry*, 45:309-314.

Yousfi, S., Rabhi, M., Abdelly, C. & Gharsalli, M. 2009. Iron deficiency tolerance traits in wild (Hordeum maritimum) and cultivated barley (Hordeum vulgare). *Comptes Rendus – Biologies*, 332(6): 523-533.

CHAPTER TWO

PROBLEM STATEMENT, AIMS, HYPOTHESIS AND OBJECTIVES

2.1 PROBLEM STATEMENT

2.2 AIMS

This study aims to test seed germination and hydroponic growth of barley in a seedling mat form without a growth medium, in order to ascertain the most efficient combination of soaking and irrigation treatments.

2.3 HYPOTHESIS

The growth of *Hordeum vulgare* Sv13 will be favourably influenced by the treatments applied in this study. It is hypothesized that the manipulation of seed soaking times will influence the rate of the emergence of the seed radicle. It is also hypothesized that the effects of irrigation frequency in conjunction with soaking times will influence the speed of the growth and development of the seed to form a seedling/forage mat.

2.4 OBJECTIVES OF THE RESEARCH

2.4.1 MAIN OBJECTIVE

The main objective of the proposed study will be to determine the most effective manipulation of germination and hydroponic growth conditions of *Hordeum vulgare* Sv13, to best suit to the small-scale farmer in African and arid climates. The experiment will include the manipulation of hydroponic growing conditions in a controlled environment, in a growing chamber, to germinate the seed of *H. vulgare* Sv13 with the goal of producing a forage mat crop, consisting of germinated seeds, their interwoven white roots and leaf growth.

2.4.2. SPECIFIC OBJECTIVES:

a) To identify the minimum amount of seed-soak time required by *Hordeum vulgare* Sv13 in order to break the seed coat and promote radicle emergence.
b) To ascertain the least amount of water and watering frequency to achieve germination and growth.
c) To compare the post-harvest wet and dry weights of the seedling/forage mat, to that of the pre-germinated seed.
d) To compare the crude nitrogen and protein content of the germinated seedlings at the end of the growing period of 8 days, against the crude nitrogen and protein content of the initial dry seed.

CHAPTER THREE

THE INFLUENCES OF SEED SOAKING DURATION AND IRRIGATION FREQUENCY ON THE GERMINATION OF *HORDEUM VULGARE* SV13 SEED

3.1 ABSTRACT

Hydroponically grown fodder is of great importance to Sub-Saharan Africa and specifically South Africa, considering the current water crisis. Hydroponically grown barley can increase the fodder output of subsistence farmers and decrease the required amount of water required to produce the same fodder via traditional open ground methods. It also reduces the amount of land space required and can function independently and without effect from climate and climatic change. This study investigated the effects of seed soaking times and irrigation frequency on the germination of *Hordeum vulgare* Sv13 seed, in a hydroponic growing room. Each experiment lasted for 8 days, which included a pre-soaking of the seed before being placed into a hydroponic system. The seed was weighed into 100 g increments and placed into sterile containers containing distilled water at room temperature to soak. Once soaked, the seeds were transferred to a hydroponic system and irrigated using flood irrigation. The aim of this study was to ascertain the most effective combination of seed soaking times in conjunction with irrigation frequency in order to break seed dormancy, induce radicle emergence and for germination to occur. It was found that a combination of a 1-hour soaking treatment, in conjunction with a 2 hourly irrigation interval to have the most significance ($P \leq 0.05$) on number of leaves produced at harvest, which differed significantly from the control of a 16-hour soaking time yet was in accordance with the 2 hourly irrigation interval control. The most significant treatment combination on that of radicle mergence occurred using a 1-hour soaking treatment, in conjunction with an 8 hourly irrigation interval. Both of these treatments differed significantly from the control of 16-hour soak time with a 2 hourly irrigation interval.

Key words: land-use reduction; organic fodder; subsistence farming; water reduction.

3.2 INTRODUCTION

Hordeum vulgare more commonly known as barley is recognized as one of the very first crops to be domesticated for human consumption and it remains one of the major cereal crops grown in the world (Garvin *et al.*, 2003). Barley is the fourth-largest cereal worldwide in terms of grain production, with almost 60% used as animal feed, around 30% for malt production, 7% for seed production, and only 3% for human food (Baik & Ullrich, 2008). Due to the relative ease of germination and growth it has been widely used in hydroponic cultivation. The system of using hydroponically sprouted barley seed as a dietary supplement for animals has been used with great effect internationally in countries such as the United Kingdom, United States of America and Australia (Abel-Caines & Tierney, 2012). Barley seed requires minimal treatment to germinate, without any medium or chemicals, to grow into a forage mat (Al-Karaki & Al-Hashimi, 2012). A forage mat is described as consisting of leaf shoots, ungerminated seed and roots are harvested within a period of 8 to 10 days (Cuddeford, 1989). This study investigated the use of barley as fodder crop specifically for use in South Africa and other arid countries, where land space and water availability are dwindling resources, using a local strain of barley; Sv13. The results were used to determine the most efficient combination of soaking and irrigation treatments for use in a hydroponic growing chamber, to germinate and grow the seed into a forage mat, using the least amount of water, without impacting on overall growth. The aim of this study was to determine if a pre-germination soaking of seeds is beneficial, in conjunction with irrigation. It also determined the most efficient irrigation interval required to break seed dormancy and initiate radicle emergence in the barley seed.

3.2.1 Seed Germination

A seed is described as a ripened ovule, consisting of an embryo and a stored food supply, both of which are encased in a protective covering. Hartmann *et al.* (1997) describes germination as the activation of metabolic machinery of the embryo leading to the emergence of a new seedling plant. Germination is described a complex process during which the seed must physically recover from maturation drying and resume a sustained intensity of metabolism, whilst completing cellular events to allow for the embryo to emerge and prepared for subsequent seedling growth (Nonogaki *et al.*, 2010). Hartmann *et al.* (1997) also stated that there are three conditions that must be fulfilled in order for germination to occur. The first is that the seed must be viable and the embryo alive and

capable of germination. The second is that there must be suitable environmental conditions namely; available water, correct temperature regimes, a proper supply of oxygen and in some cases adequate light. The third condition is the overcoming of primary dormancy which must be overcome in order for the seed to germinate.

3.2.2 Germination Phases

Phase 1 – Water uptake by Imbibition

Early seed germination begins with the imbibition of water by the seed until all of the matrices and cell contents are fully hydrated (Nonogaki *et al.*, 2010). Initially water uptake is rapid, during the first 10 to 30 minutes (Hartmann *et al.*, 1997). This imbibition of water is what breaks the seeds' dormancy. Bradbeer (1992) describes barley seeds as having conditional dormancy, that when freshly harvested are shown to germinate at 10 °C but not at 15 °C, but that after a period of dry storage there is a widening range of conditions under which the seeds will germinate. Bradbeer, (1992) also stated that seeds of *H. vulgare* are best sown at a temperature of 20 °C should they have been subjected to a period of dry storage according to the International Seed Testing Association in 1985.

Phase 2 – Lag Phase of Germination

After the initial phase of imbibition the seed enters a slower wetting phase with limited water uptake, which can be from an hour for small seeds up to several hours for larger seeds. Although this phase is recognised as a period of reduced or no water uptake following imbibition it is a highly active phase physiologically. Cellular activities critical to normal germination during the lag phase include: mitochondrial maturation; protein synthesis; metabolism of storage reserves and enzyme production (Hartmann *et al.*, 1997).

Phase 3 – Radicle emergence

This phase is characteristic of the emergence of the radicle from the seed coat and associated with the completion of germination. This is initially the result of cell enlargement associated with the growth of the radicle and subsequently the rest of the seedling (Nonogaki *et al.*, 2010). Soon after radicle elongation begins, cell division can be detected in the radicle tip. (Hartmann *et al.,* 1997).

3.2.3 Seed dormancy and soaking treatments

Studies have suggested that a period of soaking the seed, before sowing, to be beneficial to increase rate of germination, soften the seed coat and break the seed dormancy. The number of hours recommended for soaking barley seed varied greatly from 3 hours (Pettersson, 1995; Sang *et al.*, 2006; Singh *et al.*, 1979) up to and including 28 hours (Van Campenhout *et al.*, 1999). The most predominant soak time documented was 16 hrs (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009). This was used as the control. Other sources reported success using seed soak times of 6; 12; 20 and 24 hours. Walmsley & Adamson (1990) found that 6 hours were sufficient in order to break dormancy, whilst others (Ali *et al.*, 2013; Al-Karaki & Al-Hashimi, 2012; Dymek *et al.*, 2012;) found 12 hours sufficient. Fazaeli *et al*. (2011) ascertained that 20 hours of soaking lead to radicle emergence whereas Kleinwächter *et al.* (2014) found that 24 hours of soaking was required to break seed dormancy.

3.2.4 Seed Sterilisation

The importance of sterilisation of the seed during the soaking procedure was evident in many sources. Al-Karaki and Al-Momani (2011) noted that it was important to soak the seed in a 20 % sodium hypochlorite (bleach) solution for 30 mins to prevent the formation of any fungal contamination. The same solution was confirmed by, Al-Karaki and Al-Hashimi (2012) when soaking their seed. The seed trays used in the hydroponic system were also cleaned in the same solution before sowing. Sneath and Macintosh (2003)**,** also noted the importance of having clean seed and alluded to fungal growth, in their report, but did not provide any solutions to combat the problem. Ramakrishna *et al.*(1991) tested both the effects of sodium hypochlorite (NaOCl) and Mercuric chloride (HgCl2) on a range of pathogens, proving that surface sterilisation of the seed is important to remove unwanted fungal growth. Frossard and Oertli (1982) also used a surface sterilisation of 0.2 % formaldehyde solution with positive results.

3.2.5 Coleoptile Emergence

A further factor that was considered in the germination process was coleoptile emergence. The coleoptile of a grass seedling is described as an ephemeral organ that protects the primary leaf during the first phase of plant development. Fröhlich and Kutschera (1995), described that after an initial period of darkness the first enclosed leaf emerges through a pore at the apex of the seed, piercing the coleoptile, leading to rapid cell elongation. As

coleoptile emergence is used as gauge to determine when the germination process begins it was decided to measure and record emergence to ascertain the speed at which the seeds were germinating.

3.2.6 Irrigation type and irrigation interval

There is little published research that indicated the amount and frequency of water/irrigation in a hydroponic system, used to germinate barley seed. It was important to establish these parameters to ascertain how much water the seedlings would require in order to germinate and produce a seedling mat. Studies have shown a wide range of watering types, including both mist and flood irrigation. These included rinsing seeds once a day (Sung *et al.*, 2005) to being irrigated manually with tap water twice a day at a fixed rate of 600 ml per tray (Al-Karaki & Al-Hashimi, 2012). Research also showed the grain being watered for 3 minutes every 2 hours (Dung *et al.*, 2010) to grain being sprayed with water for 15 minutes every 4 hours (Peer & Leeson, 1985). It was decided to use an irrigation interval of 2 hours (Dung *et al.*, 2010) as a control. This was compared against various intervals of 4, 8, 10 and 12 hours respectively.

3.3 MATERIALS AND METHODS

3.3.1 Experimental Design

The experiment was conducted in February in the plant tissue culture laboratory at the Bellville Campus of the Cape Peninsula University of Technology (CPUT). A growing room measuring 230 cm x 450 cm was used in order to control light and temperature, in order to determine the best growing conditions.

3.3.2 Hydroponic experiment and setup

The growing room was equipped with shelving units measuring 200 cm in height, 127 cm in length and 40 cm deep. The shelving unit consisted of 6 shelves, spaced 37 cm apart, measuring 120 cm x 40 cm. Each shelf was fitted with two fluorescent light bulbs. A corrugated fibreglass sheet, cut to the size of the shelf below and positioned at an angle of 55 degrees for drainage purposes. A D-shaped gutter was fixed to the front, bottom end of each shelf. This was used to catch the run off from the fibreglass sheets. The run off was then fed, via the gutter, back to a sump creating an ebb and flow closed watering system. The seeds, once cleaned and soaked, were placed into perforated aluminium containers measuring 10 cm x 20 cm. The perforations were evenly spaced across the bottom surface

of the tray with an approximate 2 cm spacing between each perforation. There was no medium used, as once the seeds germinated they formed a root mat, which held the seedlings in place. The aluminium trays containing the seeds were then placed onto the fibreglass sheeting and each tray fitted with an irrigation tube. The irrigation water was delivered to the seeds in their respective trays, with a pump (HJ 1542 submersible), delivering 622.5 ml per minute to each tray over a period of 2 minutes, delivering 1245 ml in total. The pump was attached to a timer (MajorTech model MTD7), which regulated the amount of water to each tray.

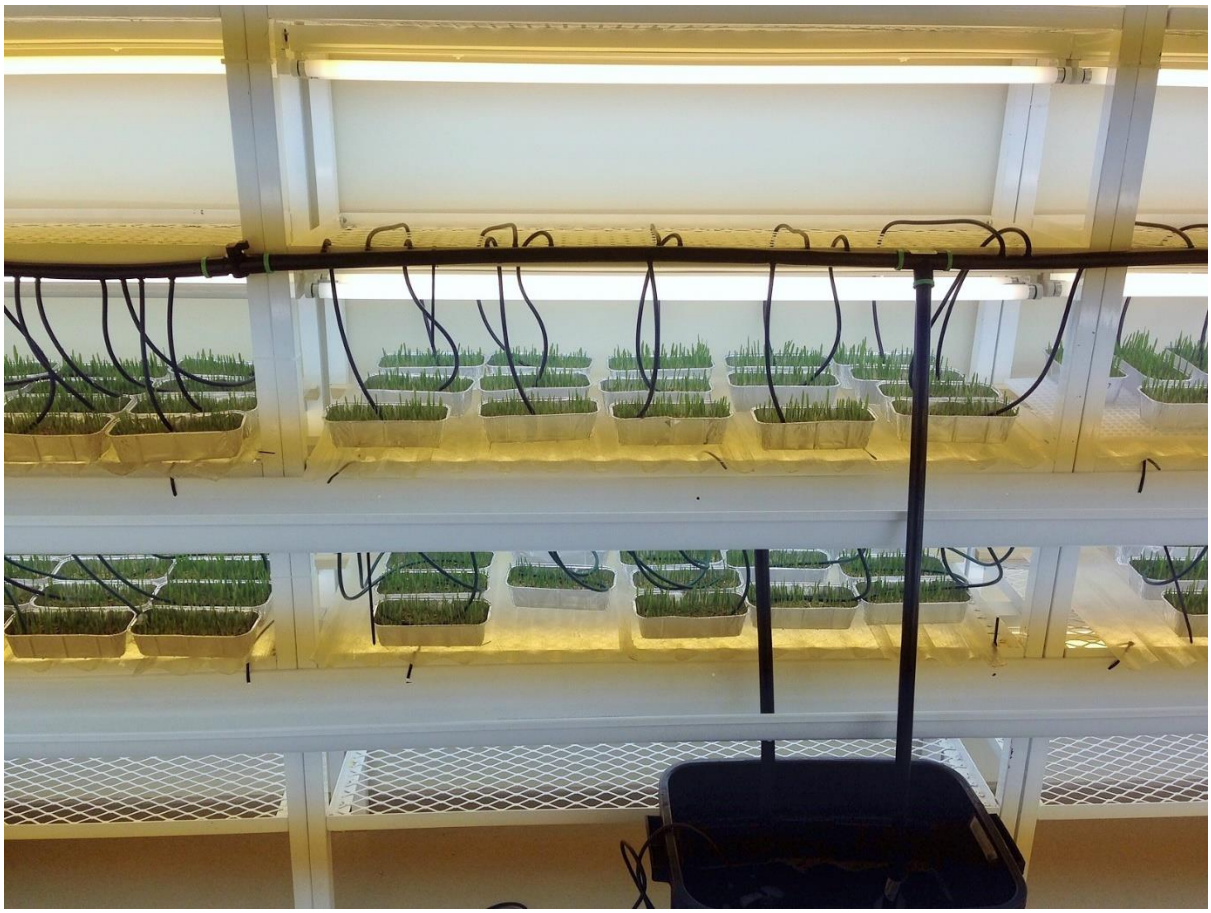

Fig. 2: Photograph showing the hydroponic growing system design and layout (Smith, 2014).

The temperature of the room was kept at a constant temperature of 23 ºC, as it was found that a temperature range of 20 ºC to 30 ºC did not have significant impact on growth (Pardo *et al.*, 2006). The temperature was controlled using two Samsung Smart Inverter™ air conditioners. Fresh air was brought into the growing chamber through heap filters from outside the building.

Lighting was provided by using fluorescent tubes (Frossard & Oertli, 1982; Hafsi *et al.*, 2009). The fluorescent lights used were Osram (L36/640) cool white fluorescent tubes, which provided 5,96 kilo lux of light. This light intensity was measured using an ExTech – Heavy Duty Digital Light Meter, model number HD 400. The lighting system was set to provide a photoperiod of 16 hour day/8 hour night environment via a Panasonic TB178K timer control unit (Ali *et al.*, 2013).

3.3.3 Factors controlled in the experiment

Before the treated seed was placed into the growing system, the entire setup was thoroughly cleaned and disinfected, including the sump, the Perspex shelves and seed containers. The sump was filled with deionised water, containing a 20 % solution of sodium hypochlorite (bleach), and the system flushed in order to disinfect all surfaces.

3.3.4 Treatment preparation

The seed of *H. vulgare* Sv13 was obtained from Kaap Agri Bedryf Ltd. located in Malmsbury, Western Cape. The seeds used originated from the Swartland District of the Western Cape. The seed of *H. vulgare* Sv13, was first weighed out into 100 g increments. There were 25 treatments with 10 repetitions for each treatment. Each treatment consisted of a pre-soaking time in conjunction with a post soaking irrigation frequency (Table 3.1).

3.1 Treatments indicating soaking times in conjunction with irrigation frequencies.

Treatment	Description	Treatment	Description
1	1 hr soak - 2 hr irrigation	14	8 hr soak - 10 hr irrigation
2	1 hr soak - 4 hr irrigation	15	8 hr soak - 12 hr irrigation
3	1 hr soak - 8 hr irrigation	16 (c)	16 hr soak - 2 hr irrigation
4	1 hr soak - 10 hr irrigation	17	16 hr soak - 4 hr irrigation
5	1 hr soak - 12 hr irrigation	18	16 hr soak - 8 hr irrigation
6	3 hr soak - 2 hr irrigation	19	16 hr soak - 10 hr irrigation
7	3 hr soak - 4 hr irrigation	20	16 hr soak - 12 hr irrigation
8	3 hr soak - 8 hr irrigation	21	24 hr soak - 2 hr irrigation
9	3 hr soak - 10 hr irrigation	22	24 hr soak - 4 hr irrigation
10	3 hr soak - 12 hr irrigation	23	24 hr soak - 8 hr irrigation
11	8 hr soak - 2 hr irrigation	24	24 hr soak - 10 hr irrigation
12	8 hr soak - 4 hr irrigation	25	24 hr soak - 12 hr irrigation
13	8 hr soak - 8 hr irrigation		

Each repetition consisted of a starting weight of 100 g of seed, which was placed into a sterilised plastic container, containing 500 ml of distilled water with a 20 % solution of sodium hypochlorite (bleach) at room temperature (Bradbeer, 1992). It was decided to test a range of seed soaking times, namely: 1, 3, 8, 16 and 24 hours, which were all compared against the control of 16 hours. Once the allotted soaking time was completed the seeds were washed under running, deionised water and placed into their respective growing containers/trays. The containers were then placed into the hydroponic system to germinate. The seeds were allowed to germinate and grow for a period of 8 days into a forage mat, using a photoperiod of 16-hour day/ 8-hour darkness at 23 °C. The seed was not given an initial photoperiod of darkness after soaking.

Irrigation was provided via drip irrigation tubes, flooding each seed tray with 1245 ml of water, with the excess running off through drainage holes in the seed container. The runoff was collected and channelled back in the hydroponic system's sump for re-use. The sump was refilled, when necessary, using distilled water with a 20 % bleach solution. The same afore mentioned 5 treatments, consisting of 10 repetitions for each treatment, were subjected to 5 different irrigation intervals. These consisted of flood irrigation filling each seed tray with water every 2; 4; 8; 10 and 12 hours, with the control being a 2 hourly water interval (Dung *et al.*, 2010).

This experiment focused on these two variables to determine the best soaking time and irrigation frequency required to break the dormancy of the seed and cause germination and radicle emergence to occur.

3.3.5 Data collection

The seeds in their respective containers were inspected at the same time each morning during the initial 48-hour period of germination, for the presence of any radicle emergence. The number of seeds displaying radicle emergence, visible on the surface of the seed bed, in each container, was counted. A grid of blocks measuring 2 cm x 2 cm, was placed over the surface of the seeds of each container, dividing the space into 50 blocks. The number of seeds showing radicle emergence within each 2 cm x 2 cm block was counted and then extrapolated out for whole container, which was used to determine the percentage of radicle emergence per tray after 24 hours and again after 48 hours.

Fig.3: Photograph showing radicle emergence in the seed of *Hordeum vulgare* Sv13. (Smith, 2014).

At the end of the growing period, before the seedling mat was harvested, the number of germinated leaves was counted, again using the grid of 2 cm x 2 cm placed over the sprouted leaf shoots and extrapolated out for the whole container. This then determined the percentage of germination that had occurred over the 8-day growing period.

3.3.6 Statistical analysis

Data collected was analysed using One-Way analysis of variance (ANOVA). The analysis was performed using STASTICA Software Programme 2010 (StatSoft Inc., Tulsa OK, USA). Where F-value was found to be significant, Fisher's least significant difference (LSD) was used to compare the means at P≤0.05 level of significance (Steel & Torrie, 1980).

3.4 RESULTS AND DISCUSSION

It was found that when comparing all soak treatments in conjunction with all irrigation treatments on radicle emergence after a 24-hour period (Day 1), that there was only one combination that had significance, namely treatment 18, which consisted of 16 hours soaking with 8 hourly irrigation intervals as indicated in Table 3.2 with $P \leq 0.01$ and a one-way ANOVA F-Statistic of 16,04. This confirmed the control for a soaking time of 16 hours as stated by (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009), yet differed significantly from the 2 hourly irrigation control as set out by Dung *et al.* (2010). When comparing all treatments on Day 2 (Table 3.2) it showed significance with treatments 3 (1-hour soak with an 8-hour irrigation) and 18 (16-hour soak with an 8-hour irrigation) with $P \leq 0.01$ and a one-way ANOVA F-Statistic of 13,76, with treatment 3 having the highest mean value. Treatment 3 differed from both controls having a 1-hour soak and an 8 hourly irrigation interval. Treatment 18 confirmed the 16-hour control, but also differed from irrigation control of 2 hours, having an 8 hourly irrigation interval. The number of leaves at harvest, after a growing period of 8 days, was used to measure the germination rate of *H. vulgare* seed in the experiment. When comparing all treatments (Table 3.2) it was found that treatment 1 was the most significant, which consisted of a 1-hour soaking time in conjunction with 2 hourly irrigation with a mean number of total leaves equal to 1022 where $P \leq 0.05$ and a one-way ANOVA F-Statistic of 23,12. This differed greatly from the soaking control of 16 hours but was in agreement with Dung *et al.* (2010) findings of a 2 hourly irrigation frequency.

Table 3.2 Mean yield results of radicle emergence percentages on days 1 and 2 for *H.vulgare*, as well as number of leaves at harvest, compared to soaking times and irrigation frequencies.

Treatment	Description	Radicle Emergence % Day 1	Radicle Emergence % Day 2	No. of Leaves
1	1 hr soak - 2 hr irrigation	1,1±0,99efg	1,8±1,03efghij	1022±220,2a
2	1 hr soak - 4 hr irrigation	0,3±0,67fg	2,5±defg	946±139,6ab
3	1 hr soak - 8 hr irrigation	3±1,76c	9,5±5,8a	669,2±159,2fg
4	1 hr soak - 10 hr irrigation	0,1±0,32g	0,7±0,82ghij	431,2±83,7ij
5	1 hr soak - 12 hr irrigation	0±0g	0,1±0,32ij	414,4±79ij
6	3 hr soak - 2 hr irrigation	101±0,99efg	2,2±0,79defgh	929,6±180,9abc
7	3 hr soak - 4 hr irrigation	0,7±1,06fg	3,5±2,72cde	719,6±155,1efg
8	3 hr soak - 8 hr irrigation	2,1±1,52cde	5,2±2,04bcdefg	815,1±182,8cde
9	3 hr soak - 10 hr irrigation	0±0g	0±0j	411,6±82,5j
10	3 hr soak - 12 hr irrigation	0,1±0,32g	0,5±0,53hij	439,6±110,5ij
11	8 hr soak - 2 hr irrigation	1,2±0,92efg	2±0,82defghi	968,8±256,7ab
12	8 hr soak - 4 hr irrigation	0,7±1,34fg	2,9±2,56def	742±105,8efg
13	8 hr soak - 8 hr irrigation	2,9±1,6cd	5,2±2,57bcdefg	770±98,1def
14	8 hr soak - 10 hr irrigation	0,5±0,85fg	1,3±4,49fghij	537,6±125,3hi
15	8 hr soak - 12 hr irrigation	0,1±0,32g	0,4±0,52hij	442,4±123ij
16 (c)	16 hr soak - 2 hr irrigation	3±2c	3,5±2cde	968,8±231ab
17	16 hr soak - 4 hr irrigation	2,2±2cde	3,9±4cde	700±144efg
18	16 hr soak - 8 hr irrigation	8,1±3a	8,3±3a	742±98,1efg
19	16 hr soak - 10 hr irrigation	0±0g	0,1±0ij	487,2±ij
20	16 hr soak - 12 hr irrigation	0±0g	0,1±0ij	406±56,6j
21	24 hr soak - 2 hr irrigation	1,6±1,43def	2,5±1,35defg	868±214,5bcd
22	24 hr soak - 4 hr irrigation	3,1±2,81c	3,2±3,77def	641,2±122,7gh
23	24 hr soak - 8 hr irrigation	5,5±3,50b	6,1±3b	638±80,1gh
24	24 hr soak - 10 hr irrigation	0,67±0,97gh	0,66±1,03ghij	369,8±76,7j
25	24 hr soak - 12 hr irrigation	0±0g	0,36±0,67hij	369,6±87,4j
	One-way ANOVA (F-Statistic)	16,04 **	13,76 **	23,12 **

Effects of all soaking treatments in conjunction with all irrigation treatments on the seed of *H. vulgare*. Mean values annotated by different letters differ significantly at $P \leq 0.01$ ± standard deviation as calculated by Fisher's least significant difference.

3.4.1 Radicle Emergence Day 1

Results showed that the most significant radicle emergence on Day 1, occurred with treatment 18, which had a soaking time of 16 hours and an 8 hourly irrigation interval. Fig 3.1 shows the individual statistical results for the group of treatments with a 16-hour soaking treatment.

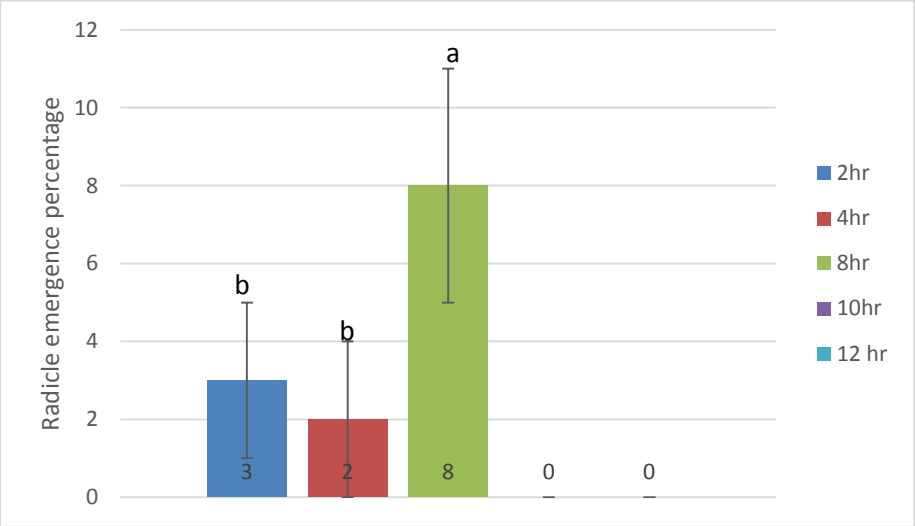

Fig. 3.1 Effects of irrigation interval on radicle emergence percentages (Day 1) on seed of *H. vulgare* with a 16-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.01$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 26,027.

3.4.2 Radicle Emergence Day 2

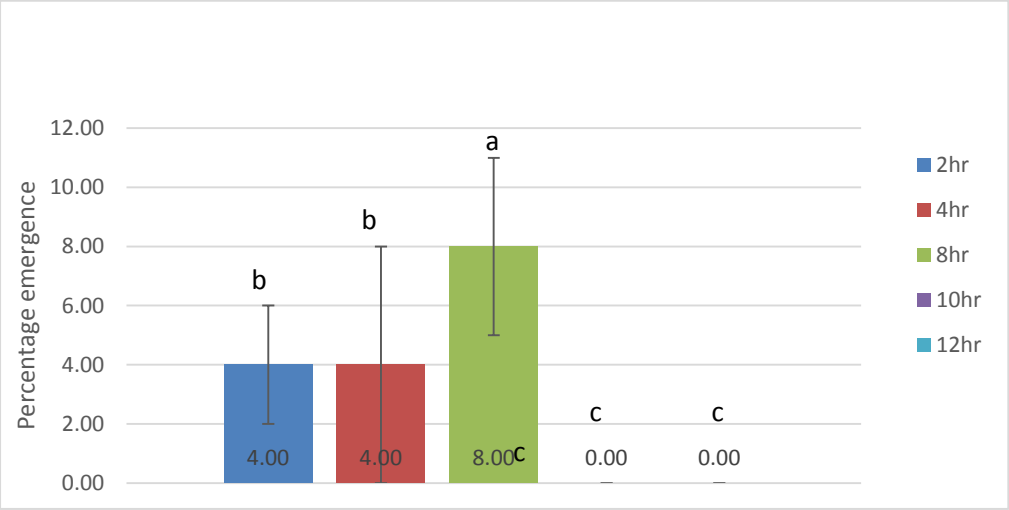

Fig. 3.2 Effects of irrigation interval on radicle emergence percentages (Day 2) on seed of *H. vulgare* with a 16-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.01$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 21,72.

Fig 3.2 confirmed the individual treatment of 16 hours (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009) soaking time in conjunction with the 5 different irrigation frequencies, with 8 hourly irrigation intervals, (treatment 18: 16-hour soak with an 8-hour irrigation) having the highest significance. This differed significantly from the seed being irrigated every 2 hours as reported by Dung *et al*. (2010). However, on Day 2, results also showed significant difference with treatment 3 (Table 3.2) of 1-hour soaking time in conjunction with an 8-hourly irrigation interval, with a mean of 9.5 % (Fig 3.3). The 1-hour soak time differed greatly from the control of 16 hours (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009), however was more in line with a 3-hour soak time as reported by Singh *et al.* (1979); Petterson, (1995) and Sang *et al.* (2006). The 8 hourly irrigation differed greatly from the control of 2 hours (Dung *et al.*, 2010) and was more in line with 4 hourly irrigation (Peer & Leeson, 1985).

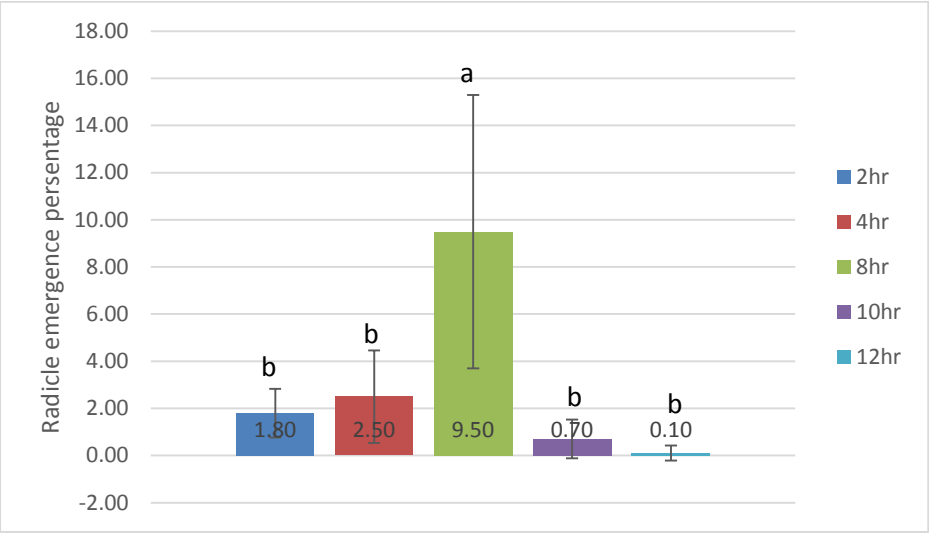

Fig. 3.3 Effects of irrigation interval on radicle emergence percentages on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.05$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 18,33.

3.4.3 Number of Leaves at Harvest

Treatment 1 (1-hour soak with 2-hour irrigation - Table 3.2) was shown to have the highest statistical value. This differed greatly from the soaking control of 16 hours (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009) yet confirmed the irrigation control of 2 hourly intervals as reported by Dung *et al.* (2010). Three other treatments were also found to have significance, however, less so than that of treatment 1, namely treatments, 2, 11 and 16 (Table 3.2). Figure 3.4 shows the correlation

between the highest mean of 1022 leaves, in conjunction with the other 4 irrigation times when using a 1-hour soaking time.

Treatments 2 and 11 consisted of 1 hour soaking in conjunction with 4 hourly irrigation, 8-hour soaking in conjunction with 2 hourly irrigation and mean leaves number 968,8 (Fig 3.5) Treatment 16 had a 16-hour soaking in conjunction with 2 hourly irrigation respectively (Fig 3.6).

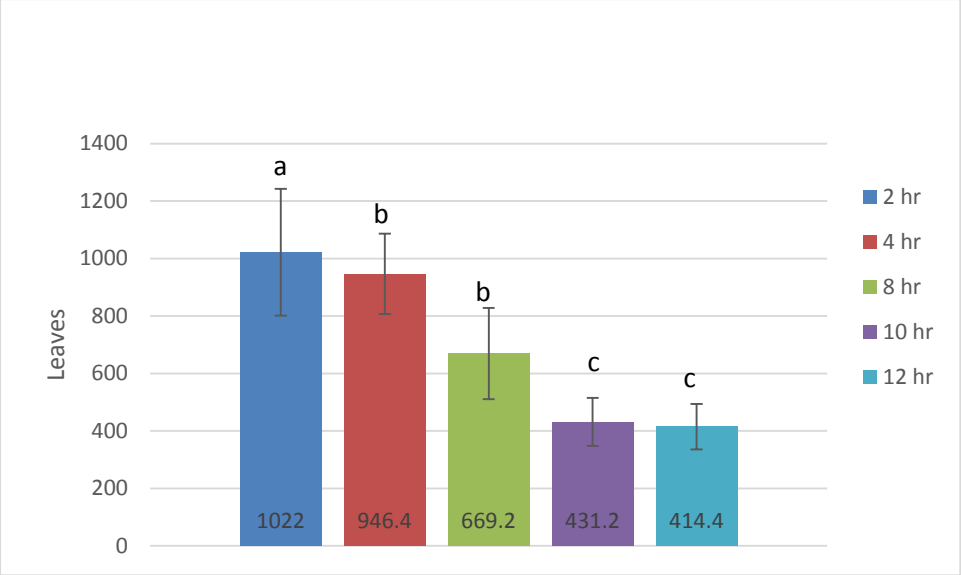

Fig. 3.4 Effects of irrigation interval on number of leaves at harvest on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 37,44.

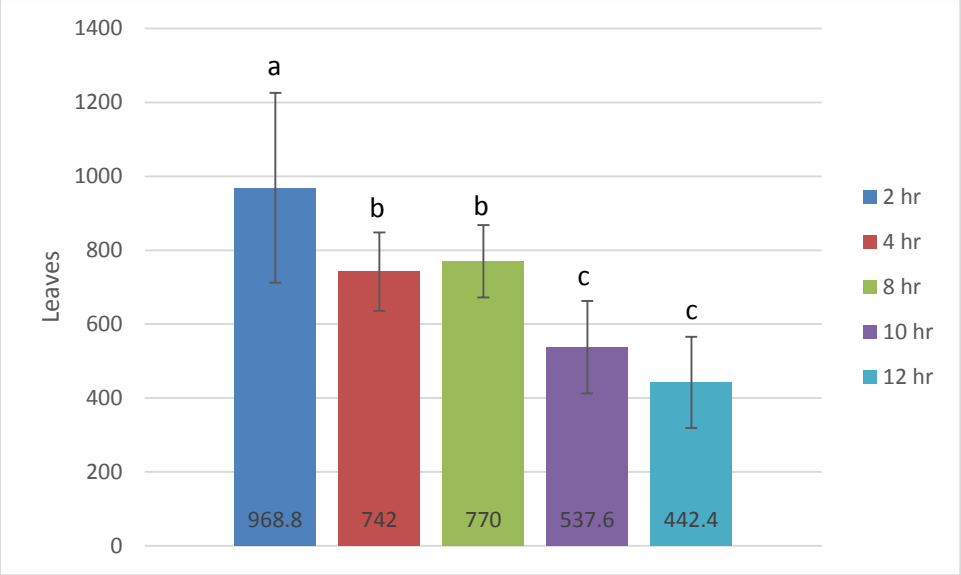

Fig. 3.5 Effects of irrigation interval on number of leaves at harvest on seed of *H. vulgare* with an 8-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 18,23.

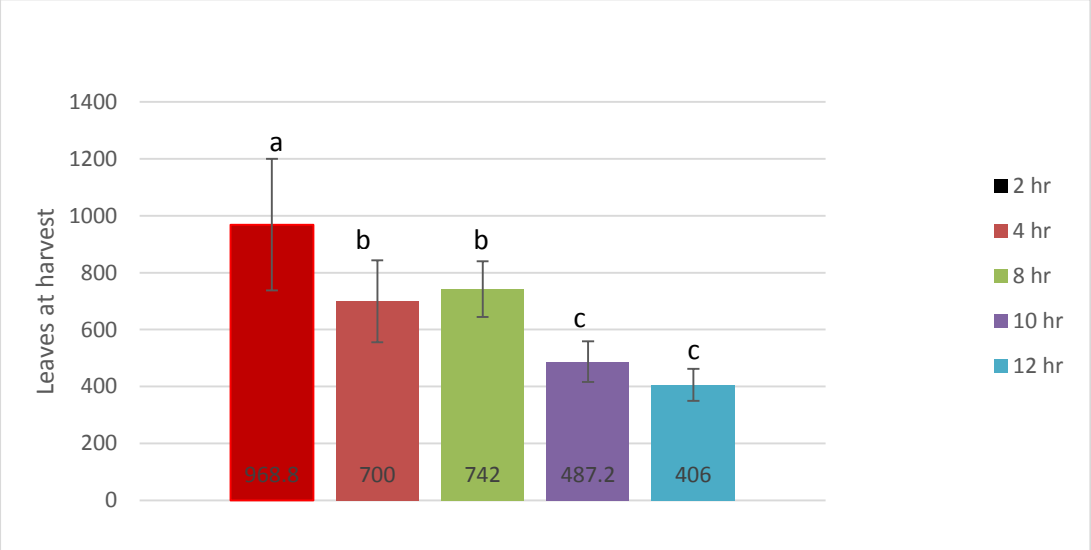

Fig. 3.6 Effects of irrigation interval on number of leaves at harvest on seed of *H. vulgare* with a 16-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 26,92.

3.5 CONCLUSION AND RECOMMENDATION

3.5.1 Radicle Emergence

The highest radicle emergence percentage mean value on Day 1 was achieved using a 16-hour soaking time, which confirmed the control, in conjunction with an 8-hourly irrigation interval, which produced a mean of 8.1 %. The irrigation interval of 8 hours differed greatly from that of 2-hour control. The same soaking and irrigation times produced a mean of 8.3 % on Day 2. There was a significantly higher mean of 9.5 % on Day 2 with the 1-hour soaking treatment and 8 hourly irrigation interval. Although the soaking treatment control of 16 hours was confirmed by the results in Day 1 and Day 2 radicle emergence percentages, it is important to note that a 1-hour soaking treatment in conjunction with a 2 hourly irrigation interval produced the highest results. It can be concluded that in order to increase germination and subsequent radicle emergence in the seed of *H. vulgare*, that soaking time can be decreased to only 1 hour. More importantly when looking at water saving techniques it can be concluded that the seed responded more positively to less water than was indicated by the control of 2 hourly irrigation intervals. It must be noted that the seed was not exposed to a dark treatment once soaking was completed. Additional testing would be required to ascertain if the seed would respond in the same manner soak and irrigation treatments and produce the same results, if exposed to an initial dark period of 48 hours (Fröhlich & Kutschera, 1995).

3.5.2 Germination rate

The highest mean total for number of leaves was produced with treatment 1 (1-hour soak with 2 hourly irrigation – Table 3.2). Of lesser importance, although still significant where treatments 2; 11 and 16. Treatments 11 and 16 both produced a mean leaves total of 968. They both produced using a 2 hourly irrigation interval yet differed with an 8-hour soak and 16-hour soak respectively. It can therefore be concluded that only a 1-hour soaking treatment is the most beneficial soaking treatment to produce the highest number of leaves, which differed greatly from the 16-hour control, yet the control of 2 hourly irrigation interval is confirmed by treatment 1 with the highest leaf mean of 1022 leaves produced. Both means of 968 in treatments 11 and 16 were produced using 2 hourly irrigation interval.

It is interesting to note that the highest mean in both radicle emergence and number of leaves were both produced with only a 1-hour soaking treatment. This would significantly reduce the time required in soaking from the control of 16 hours down to 1 hour. With regards to breaking seed dormancy and causing radicle emergence to occur, the seed

responded more positively to a drier climate, in that the highest means produced came from an 8 hourly irrigation interval. With regards to germination and growth the seeds responded more favourably to an increased irrigation frequency of 2 hours. All treatments were irrigated using flood irrigation. Further testing would be required to ascertain if spray irrigation would be more beneficial to the germination of *H. vulgare* seed.

REFERENCES

Abel-Caines, S. & Tierney, C. 2012. Sprouted barley fodder. Coulee Region Organic Produce Pool (CROPP) *Cooperative Organic Farming Technical Bulletin*, (10):1-5.

Ali, S., Farooq, M.A., Yasmeen, T., Hussain, S., Arif, M.S., Abbas, F., Bharwana, S.A. & Zhang, G. 2013. The influence of silicon on barley growth, photosynthesis and ultra-structure under chromium stress. *Journal of Ecotoxicology and Environmental Safety*, 89:66-72.

Al-Karaki, G.N. & Al-Momani, N. 2011. Evaluation of some barley cultivars for green fodder production and water use efficiency under hydroponic conditions. *Jordan Journal of Agricultural Sciences*, 7(3):448-457.

Al-Karaki, G.N. & Al-Hashimi, M. 2012. Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholarly Research Network (ISRN) Agronomy*, 1:114-126.

Baik, B.K. & Ullrich, S.E., 2008. Barley for food: characteristics, improvement, and renewed interest. *Journal of Cereal Science*, 48:233-242.

Bradbeer, J.W. 1992. *Seed Dormancy and Germination*. *Second Edition*. Glasgow: Blackie Academic & Professional.

Chung, H.J., Jang, S.H., Cho, H.Y. & Lim, S.T. 2009. Effects of steeping and anaerobic treatment on GABA (g-aminobutyric acid) content in germinated waxy hull-less barley. *Food Science and Technology*, 42:1712–1716.

Cuddeford, D. 1989. Hydroponic grass. *In Practice*, 11(5):211-214.

Dung, D.D., Godwin, R. & Nolan, J.V. 2010. Nutrient content and *in sacco* degradation of hydroponic barley sprouts grown using nutrient solution or tap water. *Journal of Animal and Veterinary Advances*, 9(19):2432-2436.

Dymek, K., Dejmek, P., Panarese, V., Vicente, A.A., Wadsö, L., Finnie, C. & Galindo, F.G. 2012. Effect of pulsed electric field on the germination of barley seeds. *Food Science and Technology*, 47:161-166.

Fazaeli, H., Golmohammadi, H.A., Shoayee, A.A., Montajebi, N. & Mosharraf, S.H. 2011. Performance of feedlot calves fed hydroponics fodder barley. *Journal of Agricultural Science and Technology*, 13:367-375.

Fröhlich, M. & Kutschera, 1995. Changes in soluble sugars and proteins during development of rye coleoptiles. *Journal of Plant Physiology*, 146:122-125.

Frossard, R. & Oertli, J.J. 1982. Growth and germination of fungal spores in guttation fluids of barley grown with different nitrogen sources. *Transactions of the British Mycological Society*, 78(2): 239-245.

Garvin, D., Raman, H. & Smith, K. 2003. Barley. *Encyclopedia of Food and Culture*. http://www.encyclopedia.com/topic/barley.aspx#1-1G2:3403400063-full [1 June 2017]

Guiga, W., Boivin, P., Oumier, N., Fournier, F. & Fick, M. 2008. Quantification of the inhibitory effect of steep effluents on barley germination. *Process Biochemistry*, 43:311-319.

Hafsi, C., Russo, M.A., Sgherri, C., Izzo, R., Navari-Izzo, F. & Abdelly, C. 2009. Implication of phospholipase D in response of Hordeum vulgare root to short-term potassium deprivation. *Plant Physiology*, 166:499-506.

Hartmann, H.T., Kester, D.E., Davies, Jr., F.T. & Geneve, R.L. 1997. *Plant Propagation: Principles and Practices. Sixth Edition*. New Jearsey: Prentice-Hall, Inc.

Kleinwächter, M., Müller, C., Methner, F.J. & Selmar, D. 2014. Biochemical heterogeneity of malt is caused by both biological variation and differences in processing: I. individual grain analyses of biochemical parameters in differently steeped *Hordeum vulgare* L.) malts. *Food Chemistry,* 147:25-33.

Nonogaki, H., Basel, G.W. & Bewley, J.D. 2010. Germination – Still a mystery. *Plant Science*, 179: 574-581.

Pardo, E., Malet, M., Marı´n, S., Sanchis, V. & Ramos, A.J. 2005. Effects of water activity and temperature on germination and growth profiles of ochratoxigenic *Penicillium verrucosum* isolates on barley meal extract agar. *Food Microbiology,* 106:25–31.

Peer, D.J. & Leeson, S. 1985. Nutrient content of hydroponically sprouted barley. *Animal feed Science and Technology*, 13:191-202.

Petterson, S. 1995. Low root zone temperature effects on net mineral nutrient uptake and distribution in barley (Hordeum vulgare). *Plant Physiology*, 145:459-464.

Ramakrishna, N., Lacey, J. & Smith, J.E. 1991. Effect of surface sterilisation, fumigation and gamma irradiation on the microflora and germination of barley seeds. *International Journal of Food Microbiology*, 13:47-54.

Sang, N., Lee, G. & Xin, X. 2006. Municipal landfill leachate induces cytogenic damage in root tips of Hordeum vulgare. *Ecotoxicology and Environmental Safety*, 63:469-473.

Singh, B.D., Singh, R.B., Singh, R.M., Singh, Y. & Singh, J. 1979. Effects of insecticides on germination, early growth and cytogenetic behaviour of barley (Hordeum vulgare). *Environmental and Experimental Botany*, 19:127-132.

Sneath, R. & Mcintosh, F. 2003. *Review of hydroponic fodder production for beef cattle: report 332*. Australia. Department of Primary Industries.

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

Sung, H.G., Shin, H.T., Ha, J.K., Lai, H.L., Cheng, K.J. & Lee, J.H. 2005. Effect of germination temperature on characteristics of phytase production from barley. *Bioresource Technology*, 96:1297–1303.

Van Campenhout, L., Shen, H.Y., Iserentant, D. & Verachtert, H. 1999. The gas environment of germinating barley in various microbial states during malting. *Process Biochemistry*, 34:929-937.

Walmsley, J. & Adamson, H. 1990. Gabaculine inhibition of chlorophyll synthesis in light and darkness in intact barley (Hordeum vulgare) seedlings. *Plant Science,* 68(1):65-70.

CHAPTER FOUR

THE INFLUENCE OF SEED SOAKING TIMES AND IRRIGATION FREQUENCY ON THE GROWTH OF HORDEUM VULGARE SV13 IN A HYDROPONIC SYSTEM

4.1 Abstract

Hydroponically grown fodder is of great importance to Sub-Saharan Africa and specifically South Africa, considering the current water crisis. Hydroponically grown barley can increase the fodder output of subsistence farmers and decrease the required amount of water required to produce the same fodder via traditional open ground methods. It also reduces the amount of land space required and can function independently and without effect from climate and climatic change. This study investigated the effects of seed soaking times and irrigation frequency on the growth of *Hordeum vulgare* Sv13 seed, in a hydroponic growing room. Each experiment lasted for 8 days, which included a pre-soaking of the seed before being placed into a hydroponic system. The seed was weighed into 100 g increments and placed into sterile containers containing distilled water at room temperature to soak. Once soaked, the seeds were transferred to a hydroponic system and irrigated using flood irrigation. The aim of this study was to ascertain the most effective combination of seed soaking times in conjunction with irrigation frequency and their impact on the height and root mat expansion of the barley seedlings in a forage mat. It was discovered that a 3-hour soaking time in conjunction with a 2 hourly irrigation interval to have the most significant impact on the average height of the seedlings. This differed significantly from the soaking control of 16 hours yet was concurrent with the irrigation control of 2 hourly intervals. The treatment having the most significance on the tallest recorded leaf after the 8-day growing period was a 16-hour soaking time in conjunction with a 12 hourly irrigation interval. This confirmed the soak control of 16 hours yet differed significantly from the irrigation control of 2 hours. An 8-hour soaking time in conjunction with a 4 hourly irrigation frequency was found to be most effective on root mat expansion. This differed significantly from both the soaking control of 16 hours and irrigation frequency of 2 hours.

Key words: land-use reduction; organic fodder; subsistence farming; water reduction.

4.2 INTRODUCTION

The potential benefits of feeding hydroponically grown, sprouted grains as a fodder are well known according to Naik *et al.* (2016). Barley (*Hordeum vulgare)* is recognised as being one of the first crops to have been domesticated for human consumption and remains one of the major cereal crops grown worldwide (Garvin *et al*., 2003). Barley is the fourth-largest cereal worldwide in terms of grain production, with almost 60% used as animal feed, around 30% for malt production, 7% for seed production, and only 3% for human food (Baik & Ullrich, 2008). The demand for feeds and forage has increased worldwide due to the increase in livestock population (Pattanaik *et al.*, 2015:74). Due to the relative ease of germination and growth it has been widely used in hydroponic cultivation.

Hydroponics is the definition given to the technique of growing plants without soil or substrate in a nutrient solution. The term “hydroponics” derives from two Greek words “Hydros” and “Ponos” referring water and labour (work) respectively (Venter: 2010:33). Internationally, both in the United Kingdom, United States of America and Australia, the system of using hydroponically sprouted barley has been used to great success as a dietary supplement for animals (Abel-Caines & Tierney, 2012).

This study investigated the germination of barley seed as fodder crop, for use in South Africa and other arid countries using a local strain of barley; *H. vulgare* Sv13, to be grown in a hydroponic growth chamber. With dwindling water resources in Africa and around the world, water reduction is of great importance and together with seedling growth was the main aim of this paper. Barley seed require minimal treatment to germinate, without any medium, chemicals, fungicides and artificial growth promoters (Al-Karaki & Al-Momani, 2011), to grow into a forage mat. Cuddeford (1989) described a forage mat of consisting of both leaf shoots and roots, together with any ungerminated seed.

Hydroponic cultivation allows for crop production in a controlled, sterile environment. Farmers in India found that feeding their dairy cattle hydroponically grown barley increased their milk yield from 0.5 to 2.5 litres per day. Besides the yield output increase, they also found an improvement in animal health as well as an increase in the fat content of their cow’s milk (Naik *et al.,* 2013). It also ensures year-round production and reduced water consumption (Cuddeford, 1989), as opposed to run-to-waste systems in field production (Al-Karaki & Al-hashmi, 2012). Al-Karaki & Al-Momani (2011), found that hydroponic production

used only 2 - 3 % of the water required for field production of the same crop. Agriculture and natural water resources around the world are being affected by climate change, which in turn impacts the sustainability of food and water resources (Rockström *et al.*, 2007). Water and agriculture are highly interdependent and critical to the economy and security of most societies (Al-Karaki & Al-Momani, 2011). The aim of this study was to ascertain the lowest amount of water required in order to germinate and grow barley seed into a seedling mat for use as a forage crop in a hydroponic growing chamber.

4.2.1 Seed soaking treatments

Studies suggested that a period of soaking, before sowing, to be beneficial to increase rate of germination, soften the seed coat and break the seed dormancy. The number of hours recommended for soaking barley seed varied greatly from 3 hours (Petterson, 1995; Sang *et al.*, 2006; Singh *et al.*, 1979) up to and including 28 hours (Van Campenhout *et al.*, 1999). The most predominant soak time documented was 16 hrs (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009). This was used as the control. Other sources reported success using seed soak times of 6; 12; 20 and 24 hours. Walmsley & Adamson (1990) found that 6 hours were sufficient in order to break dormancy, whilst others (Al-Karaki & Al-Hashimi, 2012; Dymek *et al.*, 2012; Ali *et al.*, 2013) found 12 hours sufficient. Fazaeli *et al.* (2011) ascertained that 20 hours of soaking lead to radicle emergence whereas Kleinwächter *et al.* (2014) found that 24 hours of soaking was required to break seed dormancy.

4.2.2 Seed Sterilisation

The importance of seed sterilisation during the soaking procedure was evident in many sources. Al-Karaki and Al-Momani (2011) noted that it was important to soak the seed in a 20 % sodium hypochlorite (bleach) solution for 30 mins to prevent the formation of any fungal contamination. The same solution was used by Al-Karaki and Al-Hashimi (2012), when soaking their seed. The seed trays used in the hydroponic system were also cleaned in the same solution before the sowing of the seed. Sneath and Macintosh (2003), also noted the importance of having clean seed and alluded to fungal growth, in their report, but did not provide any solutions to combat the problem. Ramakrishna *et al.* (1991), tested both the effects of sodium hypochlorite (NaOCl) and Mercuric chloride (HgCl2) on a range of pathogens, proving that surface sterilisation of the seed is important to remove unwanted fungal growth. Frossard and Oertli (1982), also used a surface sterilisation of 0.2 % formaldehyde solution, with positive results.

4.2.3 Irrigation type and irrigation interval

There was little published research found that indicated the amount and frequency of water/irrigation in a hydroponic system, used to germinate barley seed. It was important to establish these parameters to ascertain how much water the seedlings would require in order to germinate and produce a seedling mat. Studies showed a wide range of watering types, including both mist and flood irrigation. These included rinsing seeds once a day (Sung *et al.*, 2005) to being irrigated manually with tap water twice a day at a fixed rate of 600 ml per tray (Al-Karaki & Al-Hashimi, 2012). Research also showed the grain being watered for 3 minutes every 2 hours (Dung *et al.*, 2010) to grain being sprayed with water for 15 minutes every 4 hours (Peer & Leeson, 1985). It was decided to make the control an irrigation interval of 2 hours (Dung *et al.*, 2010). This was compared against various intervals of 4, 8, 10 and 12 hours respectively.

4.2.4 Cultivation and Harvesting Cycle

Fodder produced hydroponically has a short growth period, from 7 to 10 days (Mooney, 2005; Cuddeford, 1989). Various authors reported different harvesting and growth cycles for the cultivation of a barley fodder mat ranging from a 6-day harvest to a 10-day harvest cycle. Fazaeli *et al.* (2011) harvested their material after 6 days and found that the seedling height ranged from 15 cm to 20 cm in height, with an average height of 17.5 cm. It was also discovered that 0.9 kg to 1.1 kg of seed produced 7 kg to 9 kg of fresh fodder material. Those that reported using a 7-day harvest cycle were Naik *et al.* (2011) and Snow *et al.* (2008). Naik *et al.* (2011) confirmed the fresh weight at harvest ratio of 1:7-9 (seed to fresh weight at harvest) as was found by Fazaeli *et al.* (2011). Naik *et al.* (2013) only found a ratio of 1:5-6 where 1 kg of seed produced 5-6 kg of fresh fodder. The crop was however cultivated without the use of a growing chamber and a regulated climate. Naik *et al.* (2011) reported a seedling height of 20-25 cm in height, with an average of 22.5cm. Snow *et al.* (2008) found that the average leaf height at harvest was 25.5 cm. Emam (2016) and Naik *et al.* (2013) used a harvest cycle of 8 days. Although having conducted their experimentation on maize seed Naik *et al.* (2014) also used an 8-day harvest cycle. Emam (2016) found that the seedling height was between 6 cm and 10 cm, with an average height of 8 cm. Fayed (2011) and Al-Karaki and Al-Momani (2011), found a 10-day harvest cycle to be beneficial and reported a seedling height ranging from 10 cm to 15 cm, with an average height of 12.5 cm.

It was decided to use an 8-day harvest cycle using a photoperiod of 16-hour day/ 8-hour darkness. This, in conjunction with post germination irrigation frequency, was used to determine the most effective method to break seed dormancy, cause germination and growth into a seedling mat.

4.3 MATERIALS AND METHODS

4.3.1 Experimental Design

The experiment was conducted in March in the plant tissue culture laboratory at the Bellville Campus of the Cape Peninsula University of Technology (CPUT). A growing room measuring 230 cm x 450 cm was used in order to control light and temperature, in order to determine the best growing conditions.

4.3.2 Hydroponic experiment and setup

The growing room was equipped with shelving units measuring 200 cm in height, 127 cm in length and 40 cm deep. The shelving unit consisted of 6 shelves, spaced 37 cm apart, measuring 120 cm x 40 cm. Each shelf was fitted with two fluorescent light bulbs. A corrugated fibreglass sheet, cut to the size of the shelf below and positioned at an angle of 55 degrees for drainage purposes. A D-shaped gutter was fixed to the front, bottom end of each shelf. This was used to catch the run off from the fibreglass sheets. The run off was then fed, via the gutter, back to a sump creating an ebb and flow closed watering system. The seeds, once cleaned and soaked, were placed into perforated aluminium containers measuring 10 cm x 20 cm. The perforations were evenly spaced across the bottom surface of the tray with an approximate 2 cm spacing between each perforation. There was no medium used, as once the seeds germinated they formed a root mat, which held the seedlings in place. The aluminium trays containing the seeds were then placed onto the fibreglass sheeting and each tray fitted with an irrigation tube. The irrigation water was delivered to the seeds in their respective trays, with a pump (HJ 1542 submersible), delivering 622.5 ml per minute to each tray over a period of 2 minutes, delivering 1245 ml in total. The pump was attached to a timer (MajorTech model MTD7), which regulated the amount of water to each tray.

The temperature of the room was kept at a constant temperature of 23 ºC, as it was found that a temperature range of 20 ºC to 30 ºC did not have significant impact on growth (Pardo *et al.*, 2006). The temperature was controlled using two Samsung Smart Inverter™ air

conditioners. Fresh air was brought into the growing chamber through heap filters from outside the building.

Lighting was provided by using fluorescent tubes (Frossard & Oertli, 1982; Hafsi *et al.*, 2009). The fluorescent lights used were Osram (L36/640) cool white fluorescent tubes, which provided 5,96 kilo lux of light. This light intensity was measured using an ExTech – Heavy Duty Digital Light Meter, model number HD 400. The lighting system was set to provide a photoperiod of 16 hour day/8 hour night environment via a Panasonic TB178K timer control unit (Ali *et al.*, 2013).

Fig. 4: Photograph showing the hydroponic setup and irrigation supplied to each tray (Smith, 2014).

4.3.3 Factors controlled in the experiment

Before the treated seed was placed into the growing system, the entire setup was thoroughly cleaned and disinfected, including the sump, the Perspex shelves and seed containers. The sump was filled with deionised water, containing a 20 % solution of sodium hypochlorite (bleach), and the system flushed in order to disinfect all surfaces.

4.3.4 Treatment preparation

The seed of *H. vulgare* Sv13 was obtained from Kaap Agri Bedryf Ltd. located in Malmsbury, Western Cape. The seeds used originated from the Swartland District of the Western Cape. The seed of *H. vulgare* Sv13, was first weighed out into 100 g increments. There were 25

treatments with 10 repetitions for each treatment. Each treatment consisted of a pre-soaking time in conjunction with a post soaking irrigation frequency (Table 4.1).

Table 4.1 Treatments indicating soaking times in conjunction with irrigation frequencies.

Treatment	Description	Treatment	Description
1	1 hr soak - 2 hr irrigation	14	8 hr soak - 10 hr irrigation
2	1 hr soak - 4 hr irrigation	15	8 hr soak - 12 hr irrigation
3	1 hr soak - 8 hr irrigation	16 (c)	16 hr soak - 2 hr irrigation
4	1 hr soak - 10 hr irrigation	17	16 hr soak - 4 hr irrigation
5	1 hr soak - 12 hr irrigation	18	16 hr soak - 8 hr irrigation
6	3 hr soak - 2 hr irrigation	19	16 hr soak - 10 hr irrigation
7	3 hr soak - 4 hr irrigation	20	16 hr soak - 12 hr irrigation
8	3 hr soak - 8 hr irrigation	21	24 hr soak - 2 hr irrigation
9	3 hr soak - 10 hr irrigation	22	24 hr soak - 4 hr irrigation
10	3 hr soak - 12 hr irrigation	23	24 hr soak - 8 hr irrigation
11	8 hr soak - 2 hr irrigation	24	24 hr soak - 10 hr irrigation
12	8 hr soak - 4 hr irrigation	25	24 hr soak - 12 hr irrigation
13	8 hr soak - 8 hr irrigation		

Each repetition consisted of a starting weight of 100 g of seed, which was placed into a sterilised plastic container, containing 500 ml of distilled water with a 20 % solution of sodium hypochlorite (bleach) at room temperature (Bradbeer, 1992). It was decided to test a range of seed soaking times, namely: 1, 3, 8, 16 and 24 hours, which was compared against the control of 16 hours. Once the allotted soaking time was completed, the seeds were washed under running, deionised water and placed into their respective growing containers/trays. Each container measured 10 cm x 20 cm. This ensured that the washed seed measured 1 cm in depth. The containers were then placed into the hydroponic system to germinate. The seeds were allowed to germinate and grow for a period of 8 days into a forage mat, using a photoperiod of 16-hour day/ 8-hour darkness at 23 °C. The seed was not given an initial photoperiod of darkness after soaking.

Irrigation was provided via drip irrigation tubes, flooding each seed tray with 1245 ml of water, with the excess running off through drainage holes in the seed container. The runoff was collected and channelled back in the hydroponic system's sump for re-use. The sump

was refilled, when necessary, using distilled water with a 20 % bleach solution. The same afore mentioned 5 treatments, consisting of 10 repetitions for each treatment, were subjected to 5 different irrigation intervals. These consisted of flood irrigation filling each seed tray with water every 2; 4; 8; 10 and 12 hours, with the control being a 2 hourly water interval (Dung *et al.*, 2010).

This experiment focused on these two variables, namely soaking time and irrigation frequency to determine the most effective soaking time and irrigation frequency on seedling height and growth.

4.3.5 Data collection

At the end of the 8-day growing cycle, before removing the seedlings from their trays, a grid of blocks measuring 2 cm x 2 cm, was placed over the surface of the container, dividing the space into 50 blocks. This was used to measure the height of each leaf in the respective 2 cm x 2 cm block to determine the average leaf height per block. The average for each block was then extrapolated to determine the average leaf height for the whole container. The tallest leaf in each tray was also measured and recorded. Thereafter the seedling mat was removed from its tray and the depth of the root mat was recorded to determine whether the initial 1 cm of soaked seed had expanded over the 8-day growing period.

Fig.4.1: Photograph of barley seedlings at harvest showing root mat expansion (Smith, 2014).

4.3.6 Statistical analysis

Data collected was analysed using One-Way analysis of variance (ANOVA). The analysis was performed using STASTICA Software Programme 2010 (StatSoft Inc., Tulsa OK, USA). Where F-value was found to be significant, Fisher's least significant difference (LSD) was used to compare the means at P≤0.05 level of significance (Steel & Torrie, 1980).

4.4 RESULTS AND DISCUSSION

Results showed that when comparing all soak treatments in conjunction with all irrigation treatments (Table 4.2) on average leaf height, that the treatment with the most significance was treatment 6, with a 3 hour soaking time with a 2 hourly irrigation interval with $P \leq 0.01$ and a one-way ANOVA F-Statistic of 16,10. This differed greatly from the soaking control (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009) of 16 hours and was agreement with Dung *et al.* (2010) with an irrigation control of 2 hours. The tallest mean leaf height and highest significance were recorded at 14,33 cm in treatment 20 (16-hour soak with 12-hour irrigation - Table 4.2), with $P \leq 0.01$ and a One-way ANOVA F-Statistic of 27,92. This was in accordance with the soak control of 16 hours yet differed greatly from the irrigation control of 2 hours. Each tray of seed which weighed 100 grams equated to a 2 cm sowing depth. The highest mean root expansion, after the 8-day growing cycle, was found in treatment 12 (8-hour soak with 4 hourly irrigation - Table 4.2), with a root mat expansion of 3,07 cm. with $P \leq 0.01$ and a one-way ANOVA F-Statistic of 17,57.

Table 4.2 Mean yield results of average leaf height, tallest leaf and root mat expansion, compared to soaking times and irrigation frequencies.

Treatment	Description	Average Leaf Height	Tallest Leaf	Root Mat Expansion
1	1 hr soak - 2 hr irrigation	9,36±0,49ab	14,27±1,2ab	2,84±0,25abc
2	1 hr soak - 4 hr irrigation	8,90±0,85bcde	13,24±0,5defg	3,03±0,24ab
3	1 hr soak - 8 hr irrigation	9,35±0,53ab	13,55±0,8abcde	2,78±0,34bcd
4	1 hr soak - 10 hr irrigation	7,01±1,13kl	12,77±1,3efghij	2,40±0,49fghi
5	1 hr soak - 12 hr irrigation	7,55±0,58ijk	12,99±0,8defghi	2,11±0,29j
6	3 hr soak - 2 hr irrigation	9,49±0,61a	14,22±0,6ab	2,84±0,21abc
7	3 hr soak - 4 hr irrigation	8,35±0,41ef	12,74±0,8fghij	2,80±0,35bcd
8	3 hr soak - 8 hr irrigation	8,98±0,58abcd	13,85±0,8abcde	2,50±0,24efg
9	3 hr soak - 10 hr irrigation	6,23±0,40m	6,23±0,4k	2,18±0,45hij
10	3 hr soak - 12 hr irrigation	7,26±0,95jkl	12,9±0,8defghij	2,09±0,36j
11	8 hr soak - 2 hr irrigation	8,42±0,69def	13,27±1cdefg	2,82±0,21abc
12	8 hr soak - 4 hr irrigation	8,43±0,41def	12,43±0,9hij	3,07±0,32a
13	8 hr soak - 8 hr irrigation	8,23±0,36fg	13,14±0,9cedfgh	2,51±0,35efg
14	8 hr soak - 10 hr irrigation	8,46±0,59def	12,85±0,8defghij	2,26±0,31ghij
15	8 hr soak - 12 hr irrigation	8,18±0,58fg	12,93±0,7defghij	2,05±0,26j
16 (c)	16 hr soak - 2 hr irrigation	9,16±0,57abcd	12,59±0,5ghij	2,74±0,36cde
17	16 hr soak - 4 hr irrigation	8,12±0,29fghi	12,40±1,1hij	2,84±0,35abc
18	16 hr soak - 8 hr irrigation	7,77±0,27ghij	12,32±1ij	2,42±0,29fgh
19	16 hr soak - 10 hr irrigation	7,59±131fghi	12,15±1j	2,15±0,21ij
20	16 hr soak - 12 hr irrigation	7,99±0,59fgh	14,33±0,9a	2,02±0,23jk
21	24 hr soak - 2 hr irrigation	8,13±0,57fgh	13,49±0,8bcdef	2,70±0,22cde
22	24 hr soak - 4 hr irrigation	8,12±0,53fghi	12,18±1,2j	2,70±0,32cde
23	24 hr soak - 8 hr irrigation	7,33±0,66jkl	12,68±1ghij	2,55±0,20def
24	24 hr soak - 10 hr irrigation	8,57±cdef	13,60±0,8abcd	1,76±0,19kl
25	24 hr soak - 12 hr irrigation	6,83±1l	12,59±1,1ghij	1,56±0,25j
	One-way ANOVA (F-Statistic)	16,10 **	27,92 **	17,57 **

Effects of all soaking treatments in conjunction with all irrigation treatments on the seed of *H. vulgare*. Mean values annotated by different letters differ significantly at $P \leq 0.01$ ± standard deviation as calculated by Fisher's least significant difference.

4.4.1 Average leaf height

Of slightly less significance were treatments 1 and 3 (Table 4.2), which both had a 1-hour soaking treatment followed by a 2 hourly and 8 hourly irrigation interval respectively. The mean leaf height for treatment 6 (3-hour soak with 2 hourly irrigation) was 9.49 cm, whilst treatment 1 had a mean leaf count of 9.36 cm and treatment 3 a mean leaf count of 9.35 cm. All three treatments differed significantly from the control of 16 hours soaking time (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*,

2009), with treatment 6 having a 3-hour soaking time (Fig 4.2) as reported by (Singh *et al.*, 1979.; Petterson, 1995; Sang *et al.*, 2006) and treatments 1 and 3 having only a 1-hour soaking time (Fig 4.3). Treatments 1 and 6 (Table 4.2) confirmed the irrigation control of 2 hours (Dung *et al.*, 2010), with treatment 3 showing an irrigation interval of 8 hours.

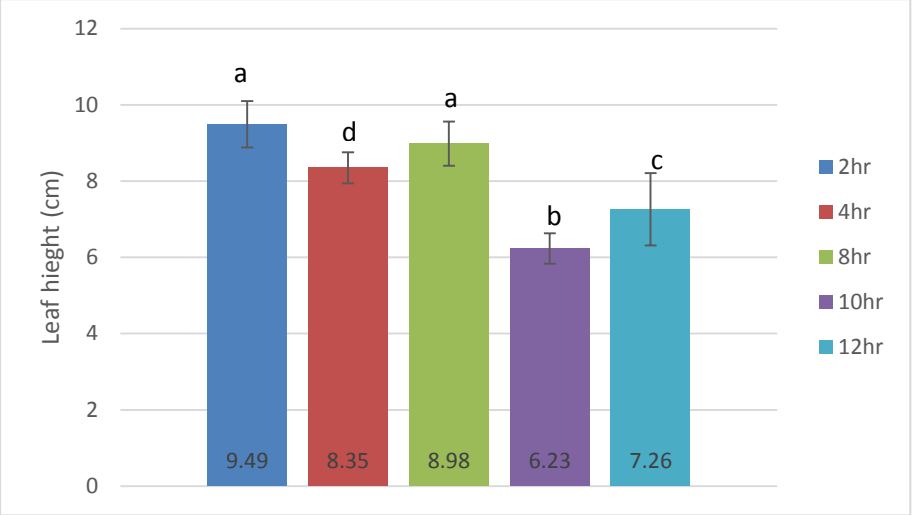

Fig. 4.2 Effects of irrigation interval on average leaf height, day 8, on seed of *H. vulgare* with a 3-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at *P* ≤ 0.001 as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 44,73.

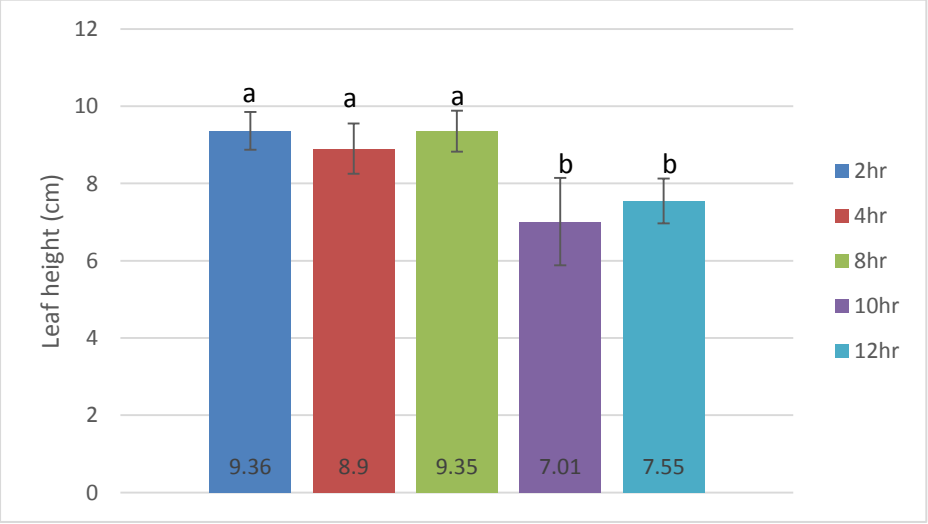

Fig. 4.3 Effects of irrigation interval on average leaf height, day 8, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at *P* ≤ 0.001 as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 23.16.

4.4.2 Tallest leaf height

Figure 4.4 shows the results of the 16-hour soak treatment in conjunction with the 5 irrigation intervals.

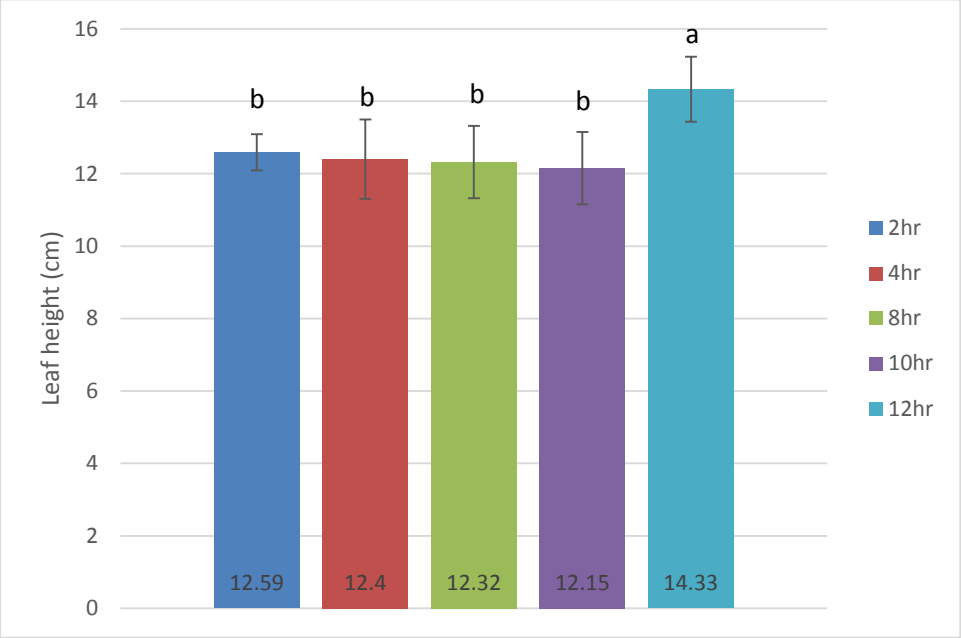

Fig. 4.4 Effects of irrigation interval on tallest leaf height, day 8, on seed of *H. vulgare* with a 16-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 9,69.

Of lesser significance were treatments 1 (1-hour soak and 2 hourly irrigation) and 6 (3-hour soak with 2 hourly irrigation), which both had an irrigation interval of 2 hours, in line with the irrigation control. Treatment 1 (1-hour soak with 2 hourly irrigation - Table 4.2) had only a 1-hour soaking (Fig 4.5) and treatment 6 (Fig 4.6) had a 3-hour soak. These both differed greatly from the control of 16 hours. Although of lesser significance to treatment 20 (16-hour soak with 12 hourly irrigation) statistically, treatments 1 and 6 had similar mean values of 14,27 cm and 14,22 cm respectively.

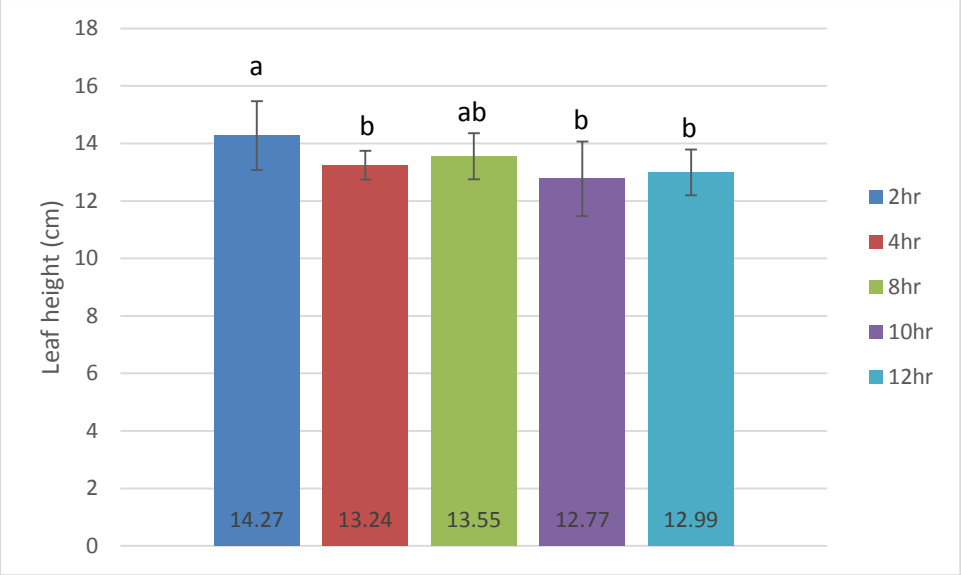

Fig. 4.5 Effects of irrigation interval on tallest leaf height, day 8, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.01$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 3,62.

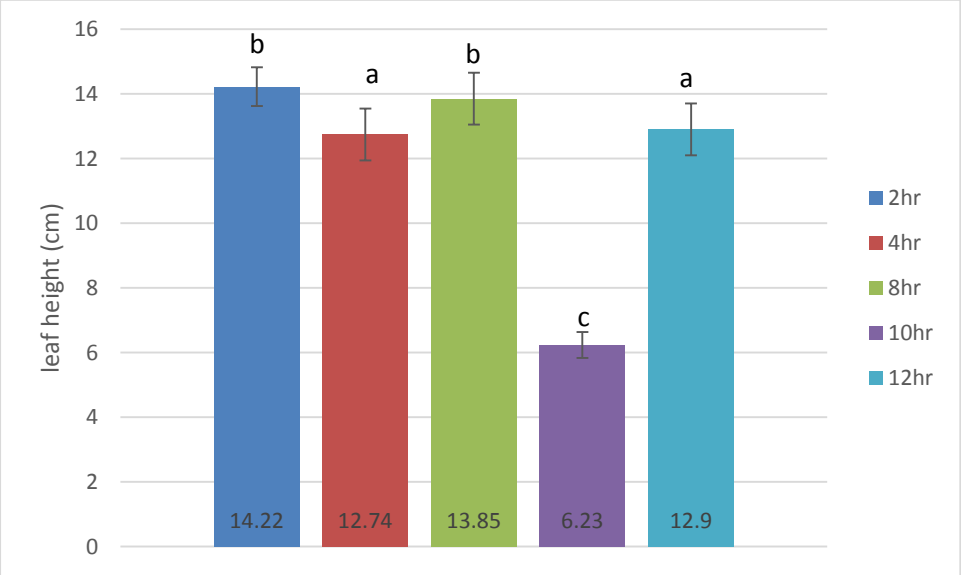

Fig. 4.6 Effects of irrigation interval on tallest leaf height, day 8, on seed of *H. vulgare* with a 3-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.01$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 216,87.

Although harvesting after 8 days, the results of leaf height were similar to those reported by Fazaeli *et al.* (2011), who only used a 6-day growing cycle and seedling height which ranged from 15 cm to 20 cm, compared with 14,33 cm in this experiment. Fayed (2011) and Al-Karaki and Al-Momani (2011) used a growing cycle of 10 days and similarly had a leaf height of between 10 cm and 15 cm.

4.4.3 Root mat expansion

Of lesser significance than treatment 12 (8-hour soak with 4 hourly irrigation - Table 4.2), with a mean of 3,03 cm was treatment 2 (Table 4.2) with a soak time of 1 hour and irrigation interval of 4 hours (Fig 4.8). Both of these treatments differed significantly from the control of 16 hours soaking time (Singh *et al.*, 1979.; Petterson, 1995; Sang *et al.*, 2006) and 2 hourly irrigation (Dung *et al.*, 2010).

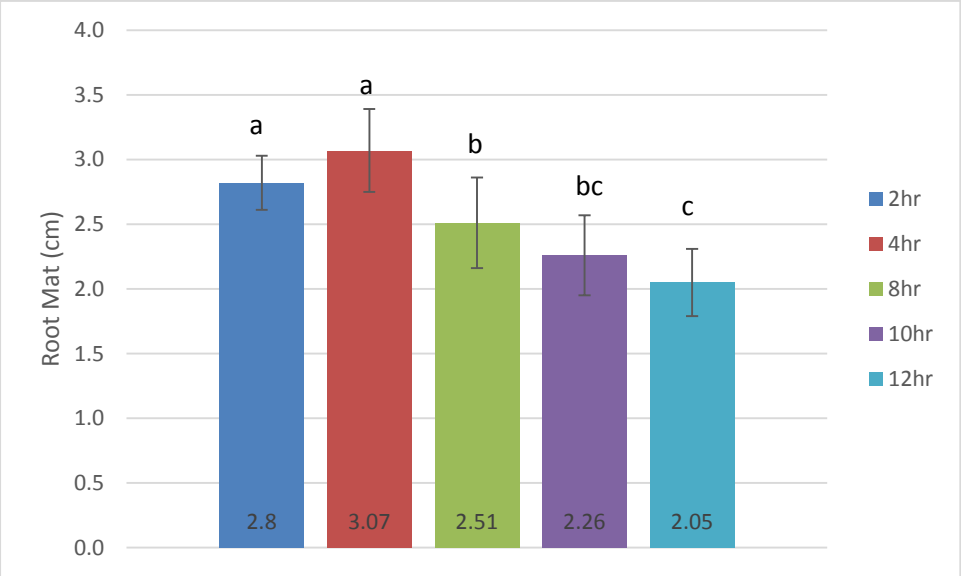

Fig. 4.7 Effects of irrigation interval on root mat expansion, day 8, on seed of *H. vulgare* with an 8-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 19,5.

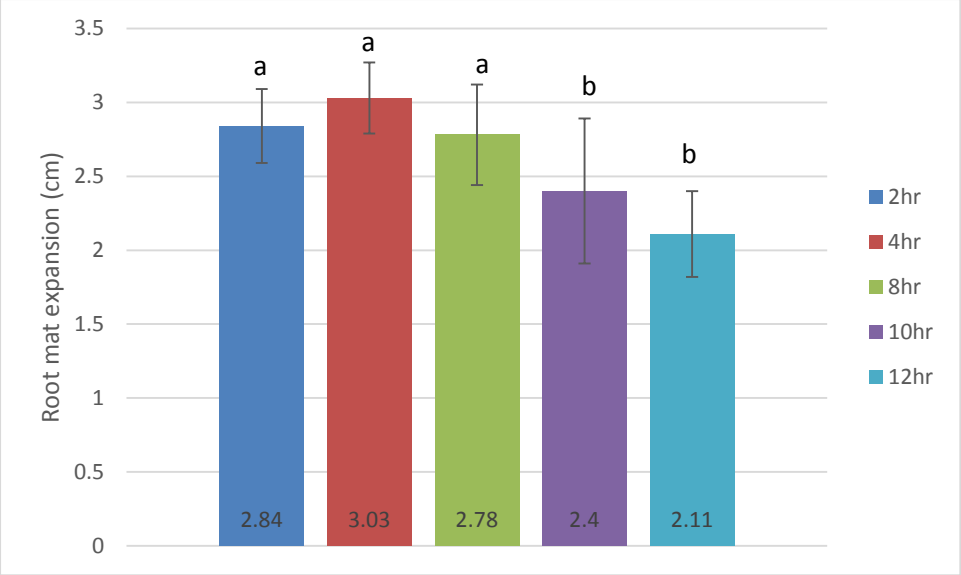

Fig. 4.8 Effects of irrigation interval on root mat expansion, day 8, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 12,35.

4.5 CONCLUSION AND RECOMMENDATION

4.5.1 Average leaf height

Examining the results it was concluded that the seeds of *H. vulgare* responded more favourably to a shorter soaking time and an increased irrigation time. The highest mean totals correlated with the soaking times of 1 and 3 hours respectively and irrigation times of 2 hourly and 8 hourly intervals. Looking at Table 4.3 it could be seen that average leaf height was increased the more frequent the irrigation interval, with mean average heights ranging from 8,12 cm (Treatment 22: 24-hour soak with 4 hourly irrigation - Table 4.2) up to 9,49 cm (Treatment 6: 3-hour soak with 2 hourly irrigation - Table 4.2). All of these higher values corresponded to either a 2 hourly or 4 hourly irrigation interval. It was concluded that a shorter soaking time was required to produce an increased average height in the seed reducing the time required in the soaking process. Treatment 3 (1-hour soak with 8 hourly irrigation - Table 4.2) showed a mean average height of 9,35 cm with an irrigation time of 8 hours, as opposed to treatment 1 (1-hour soak with 2 hourly irrigation - Table 4.2) which had a mean average height 9,36 cm. With such a small difference of 0.01 cm, it could be concluded that the irrigation interval could be increased to every 8 hours, which reduced the amount of water required to produce the highest average leaf height. Further investigations would be required to ascertain if the introduction of nutrients would have any effect in

increasing the average leaf height of the barley seedlings during the growing process. The experiment was conducted using drip irrigation. It would beneficial to ascertain if using spray irrigation would have any effect on the average height of the seedling during the growing process.

4.5.2 Tallest leaf

It is of interest that the most significant mean for the tallest recorded leaf height (14,33 cm) came from treatment 20 (Table 4.2), which consisted of a 16-hour soak time and 12 hourly irrigation frequency. Although less significant statistically, treatments 1 (1-hour soak and 2-hour irrigation) and treatment 6 (3-hour soak and 2 hourly irrigation), were also of importance with mean values of 14,27 cm and 14,22 cm respectively. It can therefore be concluded that a shorter soaking time of either 1 or 3 hours would produce the same height in the seedling as a 16-hour soaking time, which would allow the grower to reduce the time spent in soaking of the seed. Although treatment 20 showed the highest mean value of 14,33 cm, it seemed that the seedlings and their correlating heights responded more to the increased irrigation frequency of 2 hours, which confirmed irrigation the control. Further testing would be required to ascertain if a decrease in irrigation frequency would adversely affect the height of the seedling if a liquid fertiliser were to be introduced to the irrigation regimen and the irrigation type being changed to spray irrigation.

4.5.3 Root mat expansion

The highest mean value of 3,07 was recorded with treatment 12 (Table 4.2) with an 8-hour soaking time and 4 hourly irrigation frequency. Of less significance was treatment 2 (1-hour soak with a 4 hourly irrigation interval - Table 4.2) with a similar mean of 3,03 cm and only 0,04 cm difference. Treatment 2 (Table 4.2) would therefore allow the grower to again reduce soaking time in order to get similar results, with both treatments having had the most effect with an irrigation frequency of 4 hours. It would beneficial to ascertain if a change in irrigation type, from drip to spray, would improve the root expansion of the seedling and if the addition of liquid fertiliser would do the same.

REFERENCES

Abel-Caines, S. & Tierney, C. 2012. Sprouted barley fodder. Coulee Region Organic Produce Pool (CROPP) *Cooperative Organic Farming Technical Bulletin*, (10):1-5.

Ali, S., Farooq, M.A., Yasmeen, T., Hussain, S., Arif, M.S., Abbas, F., Bharwana, S.A. & Zhang, G. 2013. The influence of silicon on barley growth, photosynthesis and ultra-structure under chromium stress. *Journal of Ecotoxicology and Environmental Safety*, 89:66-72.

Al-Karaki, G.N. & Al-Momani, N. 2011. Evaluation of some barley cultivars for green fodder production and water use efficiency under hydroponic conditions. *Jordan Journal of Agricultural Sciences*, 7(3):448-457.

Al-Karaki, G.N. & Al-Hashmi, M. 2012. Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholarly Research Network (ISRN) Agronomy*, 1:114-126.

Baik, B.K. & Ullrich, S.E., 2008. Barley for food: characteristics, improvement, and renewed interest. *Journal of Cereal Science*, 48:233-242.

Bradbeer, J.W. 1992. *Seed Dormancy and Germination*. *Second Edition*. Glasgow: Blackie Academic & Professional.

Chung, H.J., Jang, S.H.,Cho, H.Y. & Lim, S.T., 2009. Effects of steeping and anaerobic treatment on GABA (g-aminobutyric acid) content in germinated waxy hull-less barley. *Food Science and Technology*, 42:1712–1716.

Cuddeford, D. 1989. Hydroponic grass. *In Practice*, 11(5):211-214.

Dung, D.D., Gowdin, I.R. & Nolan, J.V. 2010. Nutrient Content and in sacco degradation of hydropinic barley sprouts growth using nutrient solution or tap water. *Journal of Animal and Veterinary Advances*, 9(18):2432-2436.

Dymek, K., Dejmek, P., Panarese, V., Vicente, A.A., Wadsö, L., Finnie, C. & Galindo, F.G. 2012. Effect of pulsed electric field on the germination of barley seeds. *Food Science and Technology*, 47:161-166.

Emam, M.S.A., 2016. The sprout production and water use efficiency of some barley cultivars under intensive hydroponic system. *Middle East Journal of Agriculture Research*, 5:161-170.

Fayed, A.F., 2011. Comparative study and feed evaluation of sprouted barley grains on rice straw versus *Tamarix Mannifera* on performance of growing Barki Lambs in Sinai. *Journal of American Science*, 7(1):954-961.

Fazaeli, H., Golmohammadi, H.A., Shoayee, A.A., Montajebi, N. & Mosharraf, S.H. 2011. Performance of feedlot calves fed hydroponics fodder barley. *Journal of Agricultural Science and Technology*, 13:367-375.

Frossard, R. & Oertli, J.J. 1982. Growth and germination of fungal spores in guttation fluids of barley grown with different nitrogen sources. *Transactions of the British Mycological Society*, 78(2): 239-245.

Garvin, D., Raman, H. & Smith, K. 2003. Barley. *Encyclopedia of Food and Culture*. http://www.encyclopedia.com/topic/barley.aspx#1-1G2:3403400063-full [1 June 2017]

Guiga, W., Boivin, P., Oumier, N., Fournier, F. & Fick, M., 2008. Quatification of the inhibitory effect of steep effluents on barley germination. *Process Biochemistry*, 43:311-319.

Hafsi, C., Russo, M.A., Sgherri, C., Izzo, R., Navari-Izzo, F. & Abdelly, C. 2009. Implication of phospholipase D in response of Hordeum vulgare root to short-term potassium deprivation. *Plant Physiology*, 166:499-506.

Kleinwächter, M., Müller, C., Methner, F.J. & Selmar, D. 2014. Biochemical heterogeneity of malt is caused by both biological variation and differences in processing: I. individual grain analyses of biochemical parameters in differently steeped *Hordeum vulgare* L.) malts. *Food Chemistry,* 147:25-33.

Mooney, J. 2005. Growing cattle feed hydroponically. *Meat and Livestock Australia*. http://www.foddersolutionsafrica.com/wp-content/uploads/2013/02/Growing-Cattle-Feed-Hydroponically.pdf [20 April 2016].

Naik, P.K., Gaikwad, S.P., Gupta, M.J., Dhuri, R.B., Dhumal, G.M. & Singh, N.P., 2013. *Low cost devices for hydroponics fodder production*. [Online] Indian Dairymen-The Spirit of the Dairy Industry. [Accessed 19 November 2017]. Available from: https://www.researchgate.net/publication/258241382_Low_cost_devices_for_Hydroponics_fodder_production

Naik, P.K., Dhuri, R.B. & Singh, N.P. 2011. *Technology for production and feeding of hydroponics green fodder*. [Online]. India. Extension folder No.45/ 2011, ICAR Research Goa. [Accessed 19 November 2017]. Available from : http://www.academia.edu/5116703/Technology_for_production_and_feeding_of_hydroponics_green_fodder

Naik, P.K., Dhuri, R.B., Karunakaran, M., Swain, B.K. & Singh, N.P., 2014. Effect of feeding hydroponics maize fodder on digestibility of nutrients and milk production in lactating cows. *Indian Journal of Animal Sciences*, 8:880-883.

Naik, P.K., Karunakaran, M., Chakurkar, E.M., Swain, B.K. & Singh, N.P., 2016. Diagestibility of nutrients in crossbred heifers supplemented with hydroponically sprouted maize grains. *Indian Journal of Animal Sciences*, 86(10):1210-1212.

Pardo, E., Malet, M., Marı´n, S., Sanchis, V. & Ramos, A.J. 2005. Effects of water activity and temperature on germination and growth profiles of ochratoxigenic *Penicillium verrucosum* isolates on barley meal extract agar. *Food Microbiology,* 106:25–31.

Pattanaik, A.K., Verma, A.K., Jadhav, S.E., Dutta, N, & Saikia, B.N. (eds). 2015. *Eco-responsive feeding and nutrition: Linking Livestock and Livelihood*. India: Bytes & Bytes.

Peer, D.J. & Leeson, S. 1985. Nutrient content of hydroponically sprouted barley. *Animal feed Science and Tecnology*, 13:191-202.

Petterson, S. 1995. Low root zone temperature effects on net mineral nutrient uptake and distribution in barley (Hordeum vulgare). *Plant Physiology*, 145:459-464.

Ramakrishna, N., Lacey, J. & Smith, J.E. 1991. Effect of surface sterilisation, fumigation and gamma irradiation on the microflora and germination of barley seeds. *International Journal of Food Microbiology*, 13:47-54.

Rockström, J., Lannerstad, M. & Falkenmark, M. 2007. Assessing the eater challenge of a new green revolution in developing countries. *Proceedings of the National Academy of Sciences of the United States of America*, 104(15): 6253-6250.

Sang, N., Lee, G. & Xin, X. 2006. Municipal landfill leachate induces cytogentic damage in root tips of Hordeum vulgare. *Ecotoxicology and Environmental Safety*, 63:469-473.

Singh, B.D., Singh, R.B., Singh, R.M., Singh, Y. & Singh, J. 1979. Effects of insecticides on germination, early growth and cytogentetic behaviour of barley (Hordeum vulgare). *Environmental and Experimental Botany*, 19:127-132.

Sneath, R. & Mcintosh, F. 2003. *Review of hydroponic fodder production for beef cattle: report 332*. [Online]. Australia. Department of Primary Industries . [Accessed 20 June 2014]. Available from: http://blogs.cornell.edu/organicdairyinitiative/files/2014/05/Hydroponicfodder-article-11wpnm0.pdf

Snow, A.M., Ghaly, A.E. & Snow, A. 2008. A Comparative Assessment of Hydroponically Grown Cereal Crops for the Purification of Aquaculture Wastewater and the Production of Fish Feed. *American Journal of Agricultural and Biological Sciences*, 3(1): 364-378.

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

Sung, H.G., Shin, H.T., Ha, J.K., Lai, H.L., Cheng, K.J. & Lee, J.H. 2005. Effect of germination temperature on characteristics of phytase production from barley. *Bioresource Technology*, 96:1297–1303.

Van Campenhout, L., Shen, H.Y., Iserentant, D. & Verachtert, H. 1999. The gas environment of germinating barley in various microbial states during malting. *Process Biochemistry*, 34:929-937.

Venter, G. 2010. *Successful Hydroponics: A comprehensive practical guide to scientifically based hydroponic crop production*. Unites States of America: Xlibris Corporation.

Walmsley, J. & Adamson, H. 1990. Gabaculine inhibition of chlorophyll synthesis in light and darkness in intact barley (Hordeum vulgare) seedlings. *Plant Science,* 68(1):65-70.

CHAPTER FIVE

THE INFLUENCE OF SEED SOAKING TIMES AND IRRIGATION FREQUENCY ON THE NUTRTIONAL VALUE OF HORDEUM VULGARE SV13

5.1 ABSTRACT

Nutrient value of hydroponically sprouted barley is of great importance in fodder production. This study investigated the effects of seed soaking times and irrigation frequency on the nutrient values, specifically crude nitrogen and protein, of *Hordeum vulgare* Sv13 seed, sprouted and grown in a hydroponic growing room. Each experiment lasted for 8 days, which included a pre-soaking of the seed before being placed into a hydroponic system. The seed was weighed into 100 g increments and placed into sterile containers containing distilled water at room temperature to soak. Once soaked, the seeds were transferred to a hydroponic system and irrigated using flood irrigation. The aim of this study was to ascertain the most effective combination of seed soaking times in conjunction with irrigation frequency and their impact on nitrogen and protein levels as well as wet and dry weights of the barley seedlings sprouted into a forage mat. These measurements were taken, post-harvest, from seedlings after an 8-day growing cycle. Once weighed for wet weight the seedlings were oven dried and ground down to determine dry weight. The ground samples were then tested for nitrogen and protein analysis. The most effective treatment achieving the highest mean for wet weight was a 1-hour pre-soaking treatment followed by a 4 hourly irrigation interval. Both treatments differed from the soaking control of 16 hours and the irrigation control of 2 hours. Results showed that the most beneficial treatment on the dry weight of the seedlings came from a 3-hour pre-soak in conjunction with a 10 hourly irrigation interval, which differed significantly from the controls. It was found that the same treatments applied to both crude nitrogen and protein levels, namely a 1-hour pre-soaking of the seed together with a 12 hourly irrigation interval. This also differed significantly from the controls of 16 hours for soaking and a 2 hourly irrigation interval.

Keywords: fodder feed; fodder nutrition; ruminant feed.

5.2 INTRODUCTION

Hydroponically sprouted barley, *H. vulgare*, has been used with great success internationally to supplement animal fodder (Abel-Caines & Tierney, 2012). Barley is listed as one of the top 5 cereals in use worldwide, with almost 60 % being used for animal feed (Baik & Ullrich, 2008). Emam (2016), states that hydroponic fodder produces sprouts of high quality that are disease free, high in nutrients and protein, with a short growth period of between 7 and 10 days to harvest. Baik and Ullrich (2008) confirm barley's importance for use as a fodder crop because of its high nutritional value and palatability, as did (Naik *et al.*, 2015). Farmers in India found that feeding their dairy cattle hydroponically grown barley increased their milk yield from 0.5 to 2.5 litres per day. Besides the yield output increase, they also found an improvement in animal health as well as an increase in the fat content of their cow's milk (Naik *et al*., 2013). The demand for feeds and forage has increased worldwide due to the increase in livestock population (Pattanaik *et al.*, 2015:74). Due to the relative ease of germination and growth it has been widely used in hydroponic cultivation. Barley seed requires minimal treatment to germinate, without any medium or chemicals, to grow into a forage mat (Al-Karaki & Al-Hashimi, 2012). A forage mat is described as consisting of leaf shoots, ungerminated seed and roots are harvested within a period of 8 to 10 days (Cuddeford, 1989). Hydroponically sprouted barley and other grains for fodder are widely published by many authors, with varying results. Fazaeli *et al.* (2012) concluded that nutritional value increased during sprouting, compared with the original grain. Peer and Leeson (1985a), noted that the amount of protein remained relatively unchanged compared with that of unsprouted barley, but increased in sprouted barley due to the decrease in other components when sprouted. Peer & Leeson (1985b) concluded that there was an increase in protein and a decrease in nitrogen of that compared to the original unsprouted seed after a growing period of 7 days. Although Naik *et al.* (2012) conducted their experiment on maize, they also concluded that there was an increase in protein and nitrogen levels which was attributed to the loss in dry weight during the sprouting and growth period, compared with the original ungerminated seed. Fazaeli *et al.* (2011) noted a fresh weight gain of about 4.5 times to that of the original seed, due to the uptake of water in the germination process compared to Peer and Leeson (1985b); and Dung *et al.* (2010) who noted a fresh weight increase of up to 5.7 times to that of the original weight of the ungerminated seed due.

This study investigated the germination of barley seed as fodder crop, for use in South Africa and other arid countries using a local strain of barley; *H. vulgare* Sv13, which was grown in a hydroponic growth chamber, with specific emphasis on water consumption and its possible reduction in the germination process.

The aim of this study was to determine if a pre-germination soaking treatment on the seed of *H. vulgare* is beneficial in conjunction with varying irrigation frequencies. This together with the impact these treatments would have on the nitrogen value, protein content, wet weight and dry weight of the seedling forage mat post-harvest, compared with the original ungerminated seed.

5.3 MATERIALS AND METHODS

5.3.1 Experimental design

The experiment was conducted in May in the plant tissue culture laboratory at the Bellville Campus of the Cape Peninsula University of Technology (CPUT). A growing room measuring 230 cm x 450 cm was used in order to control light and temperature, in order to determine the best growing conditions.

5.3.2 Hydroponic experiment and setup

The growing room was equipped with shelving units measuring 200 cm in height, 127 cm in length and 40 cm deep. The shelving unit consisted of 6 shelves, spaced 37 cm apart, measuring 120 cm x 40 cm. Each shelf was fitted with two fluorescent light bulbs. A corrugated fibreglass sheet, cut to the size of the shelf below and positioned at an angle of 55 degrees for drainage purposes. A D-shaped gutter was fixed to the front, bottom end of each shelf. This was used to catch the run off from the fibreglass sheets. The run off was then fed, via the gutter, back to a sump creating an ebb and flow closed watering system. The seeds, once cleaned and soaked, were placed into perforated aluminium containers measuring 10 cm x 20 cm. The perforations were evenly spaced across the bottom surface of the tray with an approximate 2 cm spacing between each perforation. There was no medium used, as once the seeds germinated they formed a root mat, which held the seedlings in place. The aluminium trays containing the seeds were then placed onto the fibreglass sheeting and each tray fitted with an irrigation tube. The irrigation water was delivered to the seeds in their respective trays, with a pump (HJ 1542 submersible), delivering 622.5 ml per minute to each tray over a period of 2 minutes, delivering 1245 ml in

total. The pump was attached to a timer (MajorTech model MTD7), which regulated the amount of water to each tray.

The temperature of the room was kept at a constant temperature of 23º C, as it was found that a temperature range of 20º C to 30º C did not have significant impact on growth (Pardo *et al.*, 2006). The temperature was controlled using two Samsung Smart Inverter™ air conditioners. Fresh air was brought into the growing chamber through heap filters from outside the building.

Lighting was provided by using fluorescent tubes (Frossard & Oertli, 1982; Hafsi *et al.*, 2009). The fluorescent lights used were Osram (L36/640) cool white fluorescent tubes, which provided 5,96 kilo lux of light. This light intensity was measured using an ExTech – Heavy Duty Digital Light Meter, model number HD 400. The lighting system was set to provide a photoperiod of 16 hour day/8 hour night environment via a Panasonic TB178K timer control unit (Ali *et al.*, 2013).

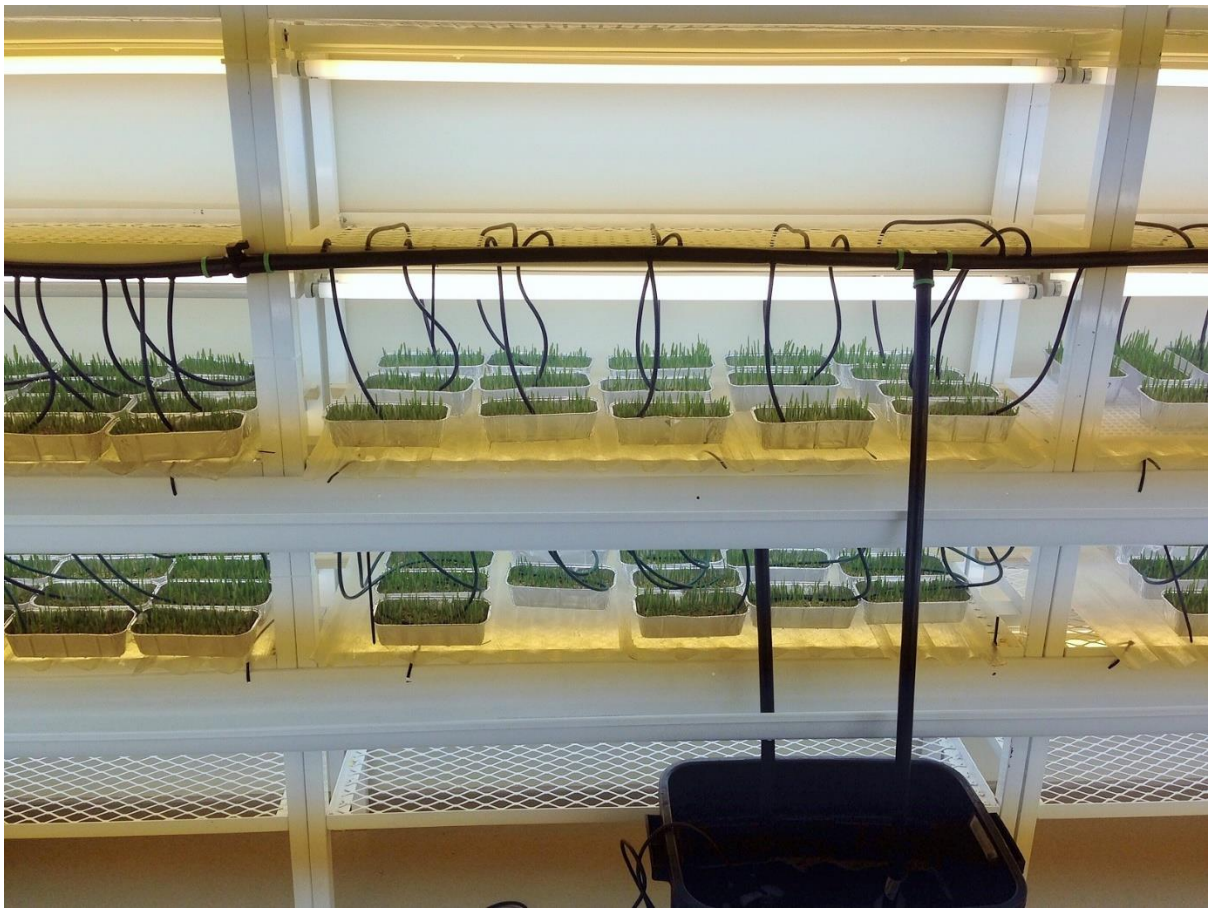

Fig.5: Photograph showing the hydroponic setup and irrigation supplied to each tray (Smith, 2014).

5.3.3 Factors controlled in the experiment

Before the treated seed was placed into the growing system, the entire setup was thoroughly cleaned and disinfected, including the sump, the Perspex shelves and seed containers. The sump was filled with deionised water, containing a 20 % solution of sodium hypochlorite (bleach), and the system flushed in order to disinfect all surfaces.

5.3.4 Treatment preparation

The seed of *H. vulgare* Sv13 was obtained from Kaap Agri Bedryf Ltd. located in Malmsbury, Western Cape. The seeds used originated from the Swartland District of the Western Cape. The seed of *H. vulgare* Sv13, was first weighed out into 100 g increments. There were 25 treatments with 10 repetitions for each treatment. Each treatment consisted of a pre-soaking time in conjunction with a post soaking irrigation frequency (Table 5.1).

Table 5.1 Treatments indicating soaking times in conjunction with irrigation frequencies.

Treatment	Description	Treatment	Description
1	1 hr soak - 2 hr irrigation	14	8 hr soak - 10 hr irrigation
2	1 hr soak - 4 hr irrigation	15	8 hr soak - 12 hr irrigation
3	1 hr soak - 8 hr irrigation	16 (c)	16 hr soak - 2 hr irrigation
4	1 hr soak - 10 hr irrigation	17	16 hr soak - 4 hr irrigation
5	1 hr soak - 12 hr irrigation	18	16 hr soak - 8 hr irrigation
6	3 hr soak - 2 hr irrigation	19	16 hr soak - 10 hr irrigation
7	3 hr soak - 4 hr irrigation	20	16 hr soak - 12 hr irrigation
8	3 hr soak - 8 hr irrigation	21	24 hr soak - 2 hr irrigation
9	3 hr soak - 10 hr irrigation	22	24 hr soak - 4 hr irrigation
10	3 hr soak - 12 hr irrigation	23	24 hr soak - 8 hr irrigation
11	8 hr soak - 2 hr irrigation	24	24 hr soak - 10 hr irrigation
12	8 hr soak - 4 hr irrigation	25	24 hr soak - 12 hr irrigation
13	8 hr soak - 8 hr irrigation		

Each repetition consisted of a starting weight of 100 g of seed, which was placed into a sterilised plastic container, containing 500 ml of distilled water with a 20 % solution of sodium hypochlorite (bleach) at room temperature (Bradbeer, 1992). It was decided to test a range of seed soaking times, namely: 1, 3, 8, 16 and 24 hours, which was compared against

the control of 16 hours. Once the allotted soaking time was completed the seeds were washed under running, deionised water and placed into their respective growing containers/trays. Each container measured 10 cm x 20 cm. This ensured that the washed seed measured 1 cm in depth. The containers were then placed into the hydroponic system to germinate. The seeds were allowed to germinate and grow for a period of 8 days into a forage mat, using a photoperiod of 16-hour day/ 8-hour darkness at 23 °C. The seed was not given an initial photoperiod of darkness after soaking.

Irrigation was provided via drip irrigation tubes, flooding each seed tray with 1245 ml of water, with the excess running off through drainage holes in the seed container. The runoff was collected and channelled back in the hydroponic system's sump for re-use. The sump was refilled, when necessary, using distilled water with a 20 % bleach solution. The same afore mentioned 5 treatments, consisting of 10 repetitions for each treatment, were subjected to 5 different irrigation intervals. These consisted of flood irrigation filling each seed tray with water every 2; 4; 8; 10 and 12 hours, with the control being a 2 hourly water interval (Dung *et al.*, 2010).

5.3.5 Data collection

Once the allotted growth period of 8 days was completed the trays were removed from the experiment and all excess remaining surface water allowed to drain away. The seedlings in their respective trays were then weighed to ascertain their fresh/wet weight, using a Kern KB 360-3N scale which measures up to the 100^{th} of a gram. The weight of the container was subtracted from this measurement to determine the weight of the seedling mat. Once the fresh weight of the plant material was measured, the seedling mat was removed from its tray and placed into brownpaper bags and dried out in an oven (Labtech LDO-150F) at between 60 ºC – 70 ºC for a period of between 36 to 48 hours. Once completely dry the plant material was weighed again to determine the dry weight. Once weighed, the dried plant material was ground down and passed through a sieve, using a Culatti Typ MFC CZ13 mill. Samples of the dried plant material were then sent to the Agrifood Technology Station for protein and nitrogen analysis.

Fig.5.1: Photograph of barley seedlings at harvest (Smith, 2014).

5.3.6 Statistical analysis

Data collected was analysed using One-Way analysis of variance (ANOVA). The analysis was performed using STASTICA Software Programme 2010 (StatSoft Inc., Tulsa OK, USA). Where F-value was found to be significant, Fisher's least significant difference (LSD) was used to compare the means at $P \leq 0.05$ level of significance (Steel & Torrie, 1980).

5.4 RESULTS AND DISCUSSION

When focusing on nitrogen percentages of the seedlings post-harvest, treatment 5 (1-hour soak with 12 hourly irrigation - Table 5.2) was the most significant, with a mean percentage of 2.29 % with $P \leq 0.001$ and a one-way ANOVA F-Statistic of 4,5. This differed greatly from the 16 hour irrigation control (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009), with a soaking time of 1 hour as well as from the irrigation control of 2 hours (Dung *et al.*, 2010) having in irrigation interval of 12 hours. The same pattern was noted with protein percentages of the germinated seedling mat. Treatment 5 (Table 5.2) was the most significant with a mean of 14,33 % with $P \leq 0.001$ and a one-way ANOVA F-Statistic of 4,4. Examining the dry weight of the seedling mat post-harvest, treatments 4 (1-hour soak and 10 hourly irrigation) and 9 (3-hour soak with 10 hourly irrigation intervals - Table 5.2) were the most significant, both having mean values of 86,31 grams with $P \leq 0.01$ and a one-way ANOVA F-Statistic of 9,9. Both treatments differed greatly from the soaking control of 16 hours having had a 1 and 3 hour soaking time and an irrigation time of 10 hours which differed from the irrigation control of 2 hours. The most significant wet weight of the seedling mat post-harvest, was treatment 2 (1-hour soak with 4 hourly irrigation - Table 5.2) which had a mean value of 294,94 grams with $P \leq 0.01$ and a one-way ANOVA F-Statistic of 87,37. This treatment differed considerably from both controls with a soaking time of 1 hour and irrigation interval of 4 hours.

Table 5.2 Mean yield results of nitrogen and protein percentages, wet and dry weights compared to soaking times and irrigation frequencies.

Treatment	Description	Nitrogen	Protein	Dry Weight	Wet Weight
	dry seed	2,05±0,16h	12,95±0,99hi		
1	1 hr soak - 2 hr irrig	2,24±0,08ab	13,97±0,47ab	73,35±7,34k	267,46±9,94cde
2	1 hr soak - 4 hr irrig	2,14±0,05cdefg	13,37±0,34cdefgh	82,96±4,76cdef	294,94±20,70a
3	1 hr soak - 8 hr irrig	2,13±0,04defg	13,29±0,25defgh	81,41±1,10fgh	258,34±20,46fg
4	1 hr soak - 10 hr irrig	2,17±0,05bcde	13,54±0,28bcde	86,31±1,07a	192,02±24,42j
5	1 hr soak - 12 hr irrig	2,29±0,02a	14,33±0,14a	84,60±2,40abcde	180,04±11,34j
6	3 hr soak - 2 hr irrig	2,19±0,08bcd	13,66±0,51bcd	76,66±6,32ij	272,29±13,84cd
7	3 hr soak - 4 hr irrig	2,12±0,04defgh	13,23±0,22defghi	82,05±1,07defg	278,82±18,06bc
8	3 hr soak - 8 hr irrig	2,16±0,05cde	13,52±0,34cde	83,97±1,35abcdef	243,09±17,07h
9	3 hr soak - 10 hr irrig	2,15±0,04cdef	13,45±0,25cdef	86,31±1,19a	188,83±10,45j
10	3 hr soak - 12 hr irrig	2,16±0,05cedf	13,49±0,258cdef	84,73±1,12abcd	182,58±11,52j
11	8 hr soak - 2 hr irrig	2,15±0,04cdefg	13,42±0,26cedfgh	75,74±7,64jk	266,34±14,33de
12	8 hr soak - 4 hr irrig	2,1±0,04efgh	13,13±efghi	82,30±1,08cdefg	287,97±15,22ab
13	8 hr soak - 8 hr irrig	2,10±0,04efgh	13,13±0,28efghi	81,98±0,89defg	230,47±10,05i
14	8 hr soak - 10 hr irrig	2,14±0,04cedfg	13,35±0,23cdefgh	86,07±1,23ab	191,14±j
15	8 hr soak - 12 hr irrig	2,10±0,04efgh	13,12±0,25efghi	84,01±1,14abcdef	190,97±8,16j
16 (c)	16 hr soak - 2 hr irrig	2,08±0,04gh	12,98±0,25ghi	78,66±4,95hij	262,59±17,43def
17	16 hr soak - 4 hr irrig	2,05±0,03h	12,84±0,16i	83,15±3,51bcdef	269,13±13,69cde
18	16 hr soak - 8 hr irrig	2,08±0,06gh	12,98±0,39ghi	81,53±0,94efgh	228,80±3,60i
19	16 hr soak - 10 hr irrig	2,11±0,03defgh	13,22±defghi	85,34±0,94abc	198,42±8,75j
20	16 hr soak - 12 hr irrig	2,17±0,03bcde	13,54±0,19bcde	84,31±0,86abcdef	188,34±12,32j
21	24 hr soak - 2 hr irrig	2,13±0,04defg	13,30±0,23defgh	77,29±5,53ij	246,35±9,94gh
22	24 hr soak - 4 hr irrig	2,11±efgh	13,16±0,30efghi	79,22±7,57ghi	251,28±16,32fgh
23	24 hr soak - 8 hr irrig	2,15±cedf	13,47±0,31cedf	81,87±1,84defg	223,73±9,38i
24	24 hr soak - 10 hr irrig	2,20±0,09bc	13,75±0,56bc	84,74±1,10abcd	161,69±5,49k
25	24 hr soak - 12 hr irrig	2,09±0,03fgh	13,05±0,18fghi	84,06±0,99abcdef	183,77±10,47j
	One-way ANOVA (F-Statistic)	4,5 ***	4,4 ***	9,9 **	87,37 **

Effects of all soaking treatments in conjunction with all irrigation treatments on the seed of *H. vulgare*. Mean values annotated by different letters differ significantly at $P \leq 0.001$ ± standard deviation as calculated by Fisher's least significant difference for nitrogen and protein percentages and $P \leq 0.01$ dry and wet weights in grams.

5.4.1 Nitrogen

Of lesser significance than treatment 5 (1-hour soak with 12 hourly irrigation - Table 5.2) was treatment 1 (1-hour soak with 2 hourly irrigation - Table 5.2) with a mean percentage of 2,24 %. Although less significant statistically there was only a difference of 0,05 %. Both treatments differed greatly from the soaking control of 16 hours (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et al.*, 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009). Treatment 1 (Fig 5.2) was in agreement with Dung *et al.* (2010) and the control of 2 hourly irrigation, however treatment 5 differed greatly from the control with an irrigation time of 12 hours. The ungerminated seed of *H. vulgare* was also sent for nitrogen analysis. Of interest to note, was that the mean value was only 2,05 % (Table 5.2). Although different statistically, this mean was only 0,24 % lower than the highest mean of treatment 5 (Table 5.2), despite there being an increase in the percentage of nitrogen.

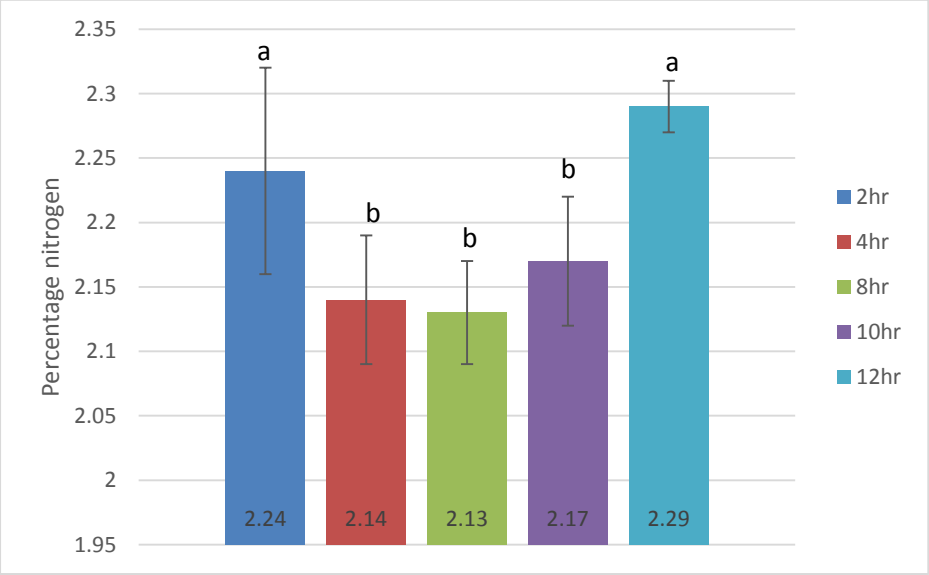

Fig. 5.2 Effects of irrigation interval on nitrogen percentage, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0,000171.

5.4.2 Protein

Similar results to that of the nitrogen percentages could be seen in the protein percentages of the seedlings, post-harvest. Of lesser significance than treatment 5 (1-hour soak with 12 hourly irrigation - Table 5.2) statistically, was treatment 1 (1-hour soak with 2 hourly irrigation - Table 5.2), with a mean protein percentage of 13,97 %. Both treatments differed greatly from the soaking control of 16 hours (Frossard & Oertli, 1982.; Sung *et al.,* 2005.; Guiga *et*

al., 2008.; Hafsi *et al.*, 2009.; Chung *et al.*, 2009), having had only a 1-hour soaking time (Fig. 5.3). Treatment 5 (1-hour soak with a 12 hourly irrigation - Table 5.2) differed greatly from the irrigation control of 2 hours (Dung *et al.*, 2010) yet treatment 1 (Table 5.2) was in accordance with their findings. Treatment 1 (Table 5.2) although less significantly statistically, had a mean value of only 0,36 % less that of treatment 5 (Table 5.2). It is interesting to note that although the amount of protein increased in the germinated seedling the protein value of the ungerminated seed is only 1.38 % less than the highest mean value of treatment 5 (Table 5.2).

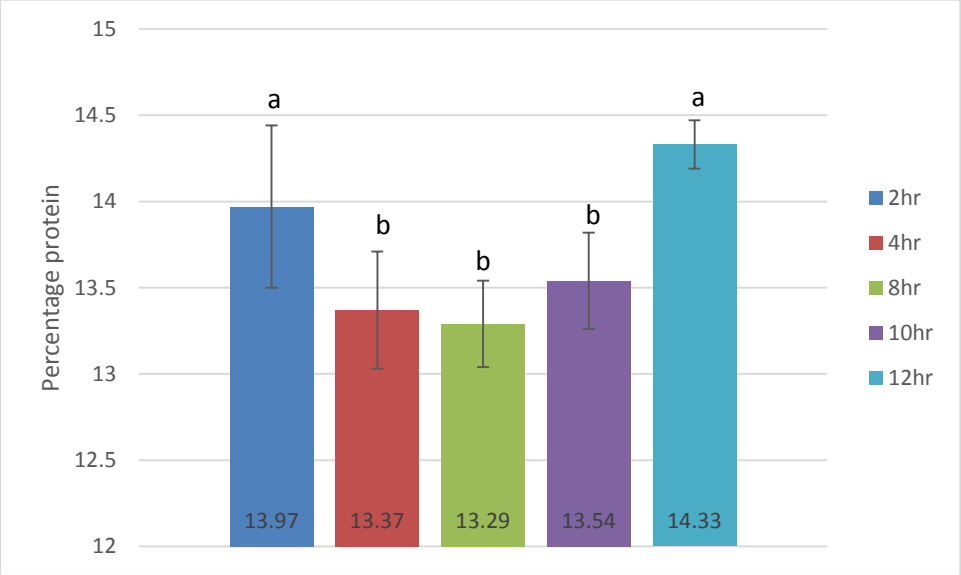

Fig. 5.3 Effects of irrigation interval on protein percentage, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0,000172.

5.4.3 Dry weight

Treatment 14 (8-hour soak with a 10 hourly irrigation interval - Table 5.2) was of less significance statistically than treatments 4 (1-hour soak with 10 hourly irrigation - Fig. 5.4) and 9 (3-hour soak with 10 hourly irrigation - Fig 5.5).

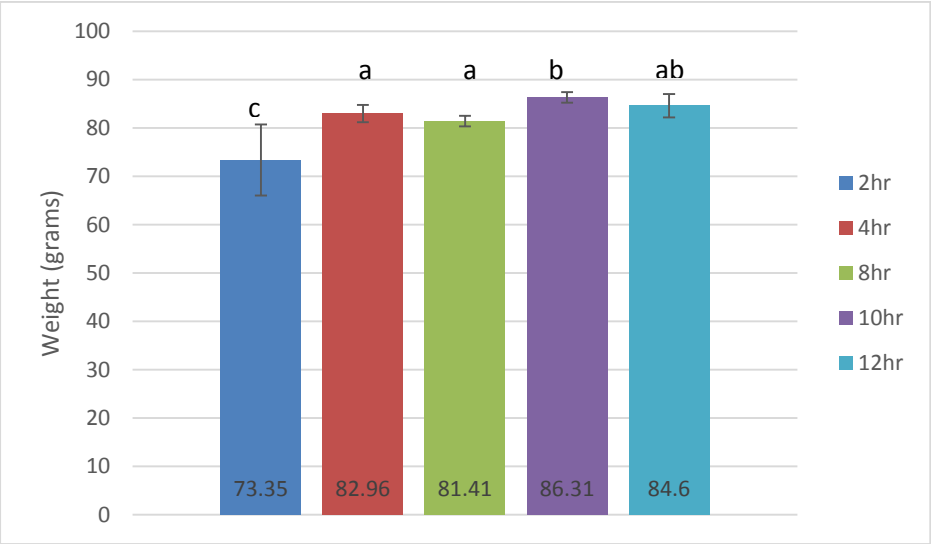

Fig. 5.4 Effects of irrigation interval on dry weight, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0.

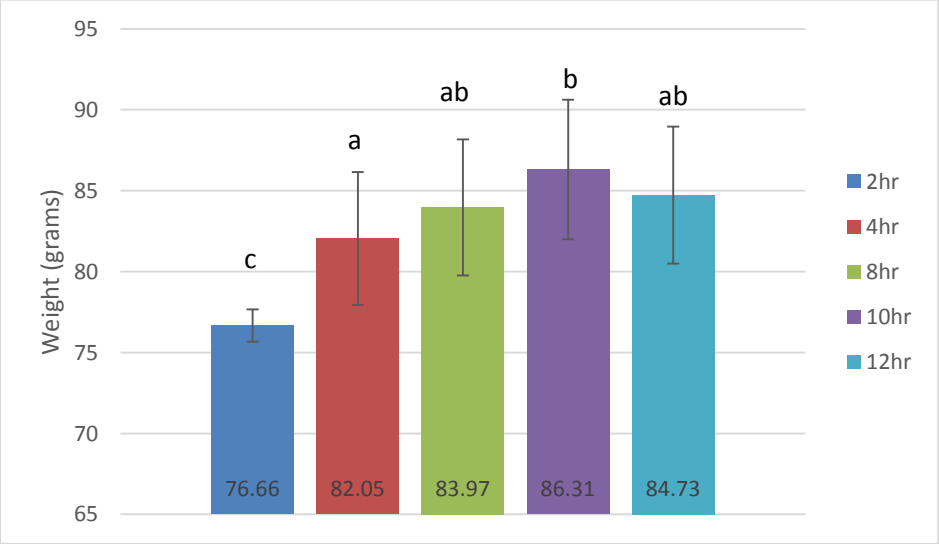

Fig. 5.5 Effects of irrigation interval on dry weight, post-harvest, on seed of *H. vulgare* with a 3-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0.

All of the dry weight means were significantly different from the soaking control of 16 hours. Treatment 4 (Table 5.2) had a 1-hour soaking time, treatment 9 a soaking time of 3 hours and treatment 14 (Fig 5.6), eight hours. All 3 treatments differed greatly from the irrigation control of 2 hours, having an irrigation interval of 10 hours. Although less significant statistically the mean of treatment 14 (8-hour soak with a 10-hourly irrigation - Table 5.2) was only 0,24 grams less than that of treatments 4 and 9.

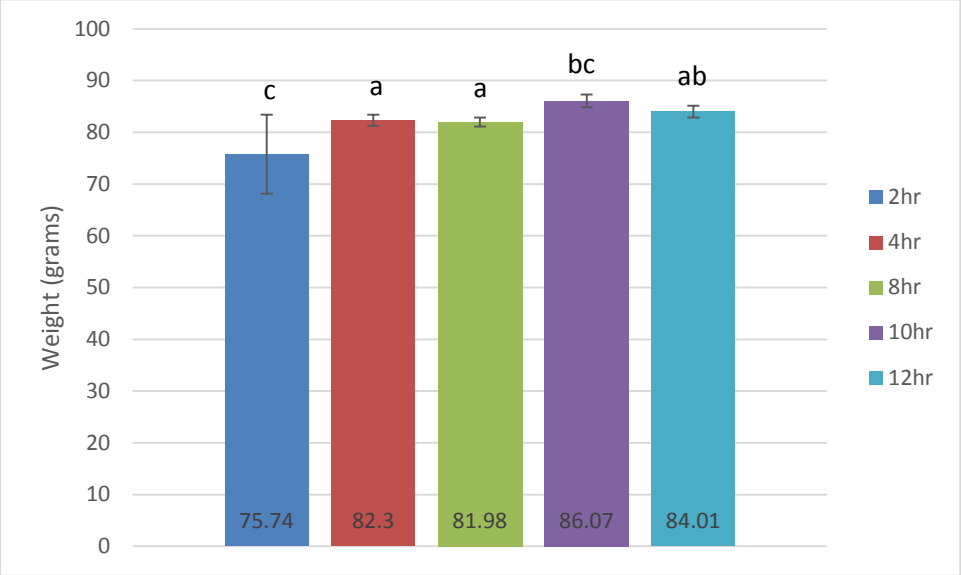

Fig. 5.6 Effects of irrigation interval on dry weight, post-harvest, on seed of *H. vulgare* with an 8-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.001$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0,000001.

5.4.4 Wet weight

Treatment 2 (1-hour soak with 4 hourly irrigation - Table 5.2) had the highest statistical significance with a mean of 294,94 grams. Of lesser significance statistically was treatment 12 (Table 5.2) with a mean of 287,97 grams and a soaking time 8 hours and irrigation interval of 4 hours. Both treatments differed from the soaking control of 16 hours with treatment 2 (Fig 5.7) having a 1-hour soak and treatment 12 an 8-hour soaking time (Fig 5.8). Both treatments 2 and 12 had an irrigation interval of 4 hours. Although treatment 12 was of less significance to treatment 2, its mean was only 6,97 grams less than that of treatment 2.

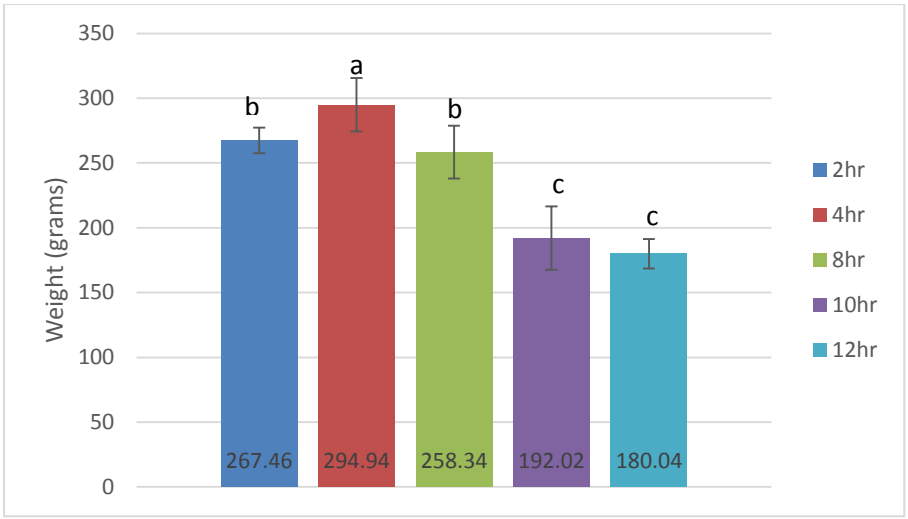

Fig. 5.7 Effects of irrigation interval on wet weight, post-harvest, on seed of *H. vulgare* with a 1-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.01$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0.

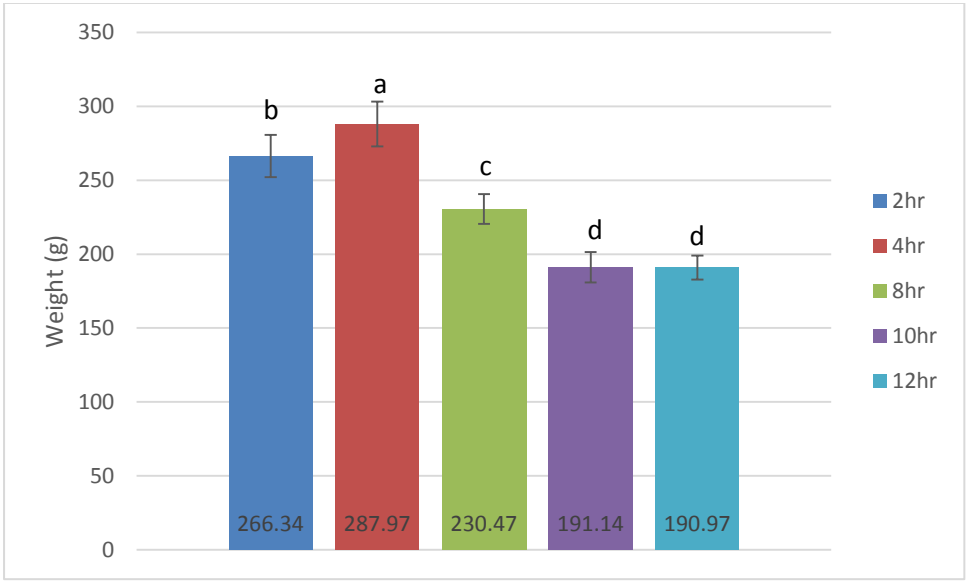

Fig. 5.8 Effects of irrigation interval on wet weight, post-harvest, on seed of *H. vulgare* with an 8-hour soaking time. Bars indicate mean values ± SD. The mean values represented by the bars annotated with different letters differ significantly at $P \leq 0.01$ as calculated by Fisher's least significant difference. The one-way ANOVA F-statistic is 0.

5.5 CONCLUSION AND RECOMMENDATION

5.5.1 Nitrogen and protein

The highest nitrogen and protein mean percentages (Treatment 5: Table 5.2) were achieved with a 1-hour soaking treatment in conjunction with a 12 hourly irrigation interval. Neither of these results agreed with the controls of 16 hours for soaking and 2 hourly irrigation intervals. This indicated that in order to achieve the highest level of nutrients in the seedling at harvest time that the seed requires a shorter soaking treatment (1 hour) as well as a longer (12 hour) irrigation interval. An irrigation interval of 12 hours is not, however, beneficial to the growth of the seedlings as was discovered during the growing experiment. It was of interest to note that the next highest mean statistically belonged to treatment 1 (1-hour soak with a 2 hourly irrigation interval), which was only marginally less than the highest mean achieved in treatment 5 (Table 5.2) which also had a 1-hour soaking time but an irrigation interval of 2 hours. This was in line with the control and produced sturdier, healthier looking seedlings. The shorter soaking time is beneficial to the grower to reduce time spent pre-soaking the seed, but does not aid in water reduction, being irrigated every 2 hours. Only crude nitrogen and protein were tested in this experiment and further investigation into trace element levels, would be required to determine a full nutrient spectrum of the seedlings, post-harvest. Other studies also showed higher nutrient levels when shortening the length of the growing period from 8 to 4 days, which could also be examined.

5.5.2 Dry and wet weights

All of the highest dry weight means were achieved with a 10-hour irrigation interval. The most significant results were achieved using a 1 and 3-hour soaking treatment, as shown in treatments 4 (1-hour soak with 10-hour irrigation) and 9 (3-hour soak with 10-hour irrigation - Table 5.2). Although less significant, treatment 14 (8-hour soak with 10-hour irrigation - Table 5.2) with a soaking time of 8 hours was only 0,24 grams less than treatments 4 and 9. This indicated that the pre-soaking time of the seed before germination can be reduced to 1 hour. All 3 treatments showed that a drier environment produced the highest dry weight, as all 3 treatments had only a 10 hourly irrigation interval. The highest wet weight recorded came from that of treatment 12 (Table 5.2), with a soaking time of 8 hours and irrigation interval of 4 hours. It can be concluded that the seedlings benefitted from a longer pre-soaking treatment. They still required moderate watering as the irrigation interval was every 4 hours. Neither of treatments agreed with the controls for soaking nor irrigation. The

second highest mean value was achieved with treatment 2 (Table 5.2) with a 1-hour soak and 4 hourly irrigation. This proved that the pre-soaking time could be reduced without it having an adverse effect on the total post-harvest weight of the seedling, however the water consumption required to enable growth remained relatively high. Investigation into the use of a nutrient solution to the irrigation water would be required to establish if this would improve overall wet weight, post-harvest, and if the introduction of a nutrient solution would allow the irrigation interval to be decreased thereby saving water.

REFERENCES

Abel-Caines, S. & Tierney, C. 2012. Sprouted barley fodder. Coulee Region Organic Produce Pool (CROPP) *Cooperative Organic Farming Technical Bulletin*, (10):1-5.

Ali, S., Farooq, M.A., Yasmeen, T., Hussain, S., Arif, M.S., Abbas, F., Bharwana, S.A. & Zhang, G. 2013. The influence of silicon on barley growth, photosynthesis and ultra-structure under chromium stress. *Journal of Ecotoxicology and Environmental Safety*, 89:66-72.

Al-Karaki, G.N. & Al-Hashmi, M. 2012. Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholarly Research Network (ISRN) Agronomy*, 1:114-126.

Baik, B.K. & Ullrich, S.E., 2008. Barley for food: characteristics, improvement, and renewed interest. *Journal of Cereal Science*, 48:233-242.

Bradbeer, J.W. 1992. *Seed Dormancy and Germination*. *Second Edition*. Glasgow: Blackie Academic & Professional.

Chung, H.J., Jang, S.H.,Cho, H.Y. & Lim, S.T., 2009. Effects of steeping and anaerobic treatment on GABA (g-aminobutyric acid) content in germinated waxy hull-less barley. *Food Science and Technology*, 42:1712–1716.

Cuddeford, D. 1989. Hydroponic grass. *In Practice*, 11(5):211-214.

Dung, D.D., Gowdin, I.R. & Nolan, J.V. 2010. Nutrient Content and in sacco degradation of hydropinic barley sprouts growth using nutrient solution or tap water. *Journal of Animal and Veterinary Advances*, 9(18):2432-2436.

Emam, M.S.A., 2016. The sprout production and water use efficiency of some barley cultivars under intensive hydroponic system. *Middle East Journal of Agriculture Research*, 5:161-170.

Fazaeli, H., Golmohammadi, H.A., Shoayee, A.A., Montajebi, N. & Mosharraf, S.H., 2011. Performance of feedlot calves fed hydroponics fodder barley. *Journal of Agricultural Science and Technology*, 13:367-375.

Fazaeli, H., Golmohammadi, H.A., Tabatabayee, S.N. & Asghari-Tabrizi, M., 2012. Productivity and nutritive value of barley green fodder yield in hydroponic system. *World Applied Sciences Journal*, 16(4): 531-539.

Frossard, R. & Oertli, J.J. 1982. Growth and germination of fungal spores in guttation fluids of barley grown with different nitrogen sources. *Transactions of the British Mycological Society*, 78(2): 239-245.

Guiga, W., Boivin, P., Oumier, N., Fournier, F. & Fick, M., 2008. Quatification of the inhibitory effect of steep effluents on barley germination. *Process Biochemistry*, 43:311-319.

Hafsi, C., Russo, M.A., Sgherri, C., Izzo, R., Navari-Izzo, F. & Abdelly, C. 2009. Implication of phospholipase D in response of Hordeum vulgare root to short-term potassium deprivation. *Plant Physiology*, 166:499-506.

Naik, P.K., Dhurri, R.B., Swain, B.K. & Singh, N.P. 2012. Nutrient changes with growth of hydroponics fodder maize. *Indian Journal of Animal Nutrition*, 29(2):161-163.

Naik, P.K., Gaikwad, S.P., Gupta, M.J., Dhuri, R.B., Dhumal, G.M. & Singh, N.P., 2013. *Low cost devices for hydroponics fodder production*. [Online] Indian Dairymen-The Spirit of the Dairy Industry. [Accessed 19 November 2017]. Available from: https://www.researchgate.net/publication/258241382_Low_cost_devices_for_Hydroponics_fodder_production

Naik, P.K., Swain, B.K. & Singh, N.P., 2015. Production and utilisation of hydroponics fodder. *Indian Journal of Animal Nutrition*, 32(1): 1-9.

Pardo, E., Malet, M., Marı´n, S., Sanchis, V. & Ramos, A.J. 2005. Effects of water activity and temperature on germination and growth profiles of ochratoxigenic *Penicillium verrucosum* isolates on barley meal extract agar. *Food Microbiology,* 106:25–31.

Pattanaik, A.K., Verma, A.K., Jadhav, S.E., Dutta, N, & Saikia, B.N. (eds). 2015. *Eco-responsive feeding and nutrition: Linking Livestock and Livelihood*. India: Bytes & Bytes.

Peer, D.J. & Leeson, S. 1985a. Feeding value of hydroponically sprouted barley for poultry and pigs. *Animal Feed Scince and Technology*, 13: 183-190.

Peer, D.J. & Leeson, S. 1985b. Nutrient content of hydroponically sprouted barley. *Animal feed Science and Tecnology*, 13:191-202.

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

Sung, H.G., Shin, H.T., Ha, J.K., Lai, H.L., Cheng, K.J. & Lee, J.H. 2005. Effect of germination temperature on characteristics of phytase production from barley. *Bioresource Technology*, 96:1297–1303.

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSION

6. GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

Land space, changing climate and dwindling water resources play a large role in the cultivation, subsequent availability and cost of fodder crops. Hydroponic cultivation of fodder crops alleviates these issues allowing crops to be grown in a smaller space, independent of climatic changes, using a fraction of the water requirements compared to the irrigation of soil-based crops. Yield is also increased and the fodder crop is produced without a medium and essentially organic, without the need for additional nutrients and pesticides.

6.2 REVIEW

The use of sprouted grains and barley has been shown to have a significant impact in its use as a fodder crop. Although there has been some research with regards to barley being used as a fodder crop in other countries, there is a distinct lack of research into the effects of hydroponically grown barley for use on a small scale, with specific application on the African continent. Research has also been conducted using different strains and cultivars of barley suited to other climatic regions, not using the specific *H. vulgare* Sv13 strain suitable to warmer, African climatic conditions. The potential to produce a sustainable fodder crop, irrespective of climatic conditions on a year-round basis has many positive implications for the small-scale farmer in South Africa and the rest of the African continent. Hydroponically grown barley will allow the small-scale farmer to reduce or even remove the costs of costly feedlots and additional supplementation of food requirements. Improving the productivity of the small-scale farmer in Sub-Saharan Africa, by adding to the few resources already available, will aid in reducing poverty and increasing food security among the rural poor. There is a further need to investigate this method of sprouting grain in a growing chamber, as it will remove the need for large tracts of land to grow fodder compared to traditional open ground methods. Fresh water is also a scarce commodity, especially in arid and developing countries. Growing barley as a fodder crop hydroponically has the potential to reduce consumption by using up to 2 litres per square meter of water in a hydroponic system, as opposed to 73 litres per square meter in conventional planting. The cost effectiveness of hydroponically sprouted grain as opposed to open ground planting, with specific reference to land costs, water cost and availability as well as labour and machinery costs, is another aspect that requires investigation. Apart from the initial outlay to equip a hydroponic growing chamber, the costs to produce crops are reduced to labour and the purchase of seed. A unit has the capacity to produce up to 7 times the amount of the initial input i.e. 7 tons of fodder,

from 1 ton of seed. Technologies that can improve on small-farm productivity and assist farmers in creating higher yields also aid in reducing yield gaps, which could have a significant impact on local and global food supplies. Taking all these aspects into consideration further research is required into the hydroponic growth of barley as a fodder crop in South Africa as well as the rest of the African continent.

6.3 CHAPTER 3 - GERMINATION

The highest radicle emergence percentage mean value on Day 1 was achieved using a 16-hour soaking time in conjunction with an 8-hourly irrigation interval, which produced a mean of 8.1 %. The irrigation interval of 8 hours differs greatly from that of 2-hour control. The same soaking and irrigation times produced a mean of 8.3 % on Day 2. There was a significantly higher mean of 9.5 % on Day 2 with the 1-hour soaking treatment and 8 hourly irrigation interval. Although the soaking treatment control of 16 hours is confirmed by the results in Day 1 and Day 2 radicle emergence percentages, it is important to note that a 1-hour soaking treatment in conjunction with a 2 hourly irrigation interval produced the highest results. It can be concluded that in order to induce germination and subsequent radicle emergence in the seed of *H. vulgare*, that soaking time can be decreased to only 1 hour and the irrigation interval set to every 8 hours. The highest mean total for number of leaves, which was a measure of germination percentage, was produced with a 1-hour soak with 2 hourly irrigation intervals. This also concludes a reduction in pre-soaking of the seed. Despite the irrigation interval of 2 hours it is important to note that this only amounts to 15 litres of water per day.

6.4 CHAPTER FOUR – GROWTH

After examining the results, it can be concluded that the seeds of *H*. *vulgare* responded more favourably when dealing with average leaf height, to a shorter soaking time and an increased irrigation time. The highest mean totals correlating with soaking times of 1 and 3 hours respectively. The 1-hour soak producing an average leaf height of 9,36 cm and the 3-hour soaking time an average height of 9,49 cm, with only 0,13 cm difference. It can therefore be concluded that pre-soaking can be reduced to only 1 hour, saving the grower time. When looking at the irrigation interval in relation to average leaf height the highest mean of 9,49 cm came from the 2 hourly irrigation interval, however a mean of 9,35 cm was derived from an 8 hourly irrigation interval. With the difference between the two average heights amounting to only 0,14 cm, therefore it can be deduced that the irrigation interval

could be increased to irrigating every 8 hours when would reduce the amount of water required to grow the seed into a seedling mat.

When considering the tallest leaf measurements, the highest mean was achieved from a 16-hour soak together with a 12-irrigation interval, producing a height of 14,33 cm. Focusing on soaking treatments, a mean of 14,27 cm was produced using a 1-hour pre-soak. With the difference in mean totals of only 0,06 cm it can be concluded that the pre-soaking treatment time can be reduced to only 1 hour without there being any negative impact on height, saving the small-scale farmer time in the growing process. It is of interest to note that when looking at irrigation intervals the highest mean on tallest leaf was derived from a 12 hourly irrigation interval. Although this positively allows a decrease in water consumption, this result seems to be an anomaly as it was observed that generally the seedlings preferred a higher concentration of water. This can be seen in the results where the second highest means both came from 2 hourly irrigation intervals. It can therefore be concluded that the best combination of treatments to produce the tallest leaf is a 1-hour soaking time in combination with a 2 hourly irrigation interval.

Root mat expansion was also used to determine growth in the seedling forage mat. This was determined by measuring the root mat, post-harvest to ascertain the size difference (expansion) from the initial 2cm thickness of the soaked seed once in the growing tray. The highest mean was achieved using an 8-hour soak together with a 4 hourly irrigation interval, with a total expansion of 3,07 cm and an increase in 1,07 cm.

6.5 CHAPTER 5 – NITROGEN, PROTEIN AND WET WEIGHT

It was discovered that both crude nitrogen and protein responded to the combined treatments in the same manner. The highest means produced came from a 1-hour soak in conjunction with a 12 hourly irrigation interval. This shows that both crude nitrogen and protein responded more positively to a drier environment. The nitrogen percentage of the dried seed, before any treatment application was 2,05 %. The increase in nitrogen post-harvest only increased to 2,29 %, with a difference of 0,24 %. Crude protein responded in the same manner, with the percentage protein in the dry seed amounting to 12,95 % and the post-harvest percentage totalling 14,33 %, a difference of 1,38 %. This proves that both nitrogen and protein responded more positively to a drier environment.

The wet weight of the seedling mat, which included roots, shoots and ungerminated leaves was also measured post-harvest as a further indication of growth in the seed. The highest mean produced was derived from the 1-hour soaking treatment together with the 4 hourly

irrigation interval. This indicates that the seedlings benefitted from a wetter environment in the growing chamber.

6.6 MAJOR FINDINGS

With regards to germination of the seed of *Hordeum* vulgare Sv13 it was found that 1-hour soak in conjunction with an 8 hourly irrigation interval to be most beneficial in breaking seed dormancy and causing radicle emergence to occur. This would benefit the small-scale farmer in reducing the time spent pre-soaking the seed before placing it into the hydroponic chamber. More importantly when looking at water saving techniques it can be concluded that the seed responded more positively to a drier climate and therefore less water during the initial germination period of 48 hours. It can also be concluded that irrigation can be reduced to every 8 hours during the initial 2-day germination phase of the seed, thereby further saving water. The number of leaves at harvest (germination percentage) also responded most favourably to a shorter pre-soaking time of 1 hour. Unfortunately, the same cannot be said for the amount of water required to achieve the same result as the seeds responded most positively to an increase in irrigation, favouring the 2 hourly irrigation interval. The recommendation to a prospective grower, when focusing on germination, would therefore be to soak the seed for 1-hour, before placing into a hydroponic growing chamber. Thereafter, for the first 48 hours, to irrigate the seed every 8 hours. Once radicle emergence has occurred to increase irrigation to every 2 hours in order to produce the highest germination rate.

Average leaf height and tallest leaf measurements were used to determine the growth of the seeds into a seedling forage mat. It is important to note that a higher average leaf height is more beneficial as it indicates that the growth within the entire container was more substantial compared to a tallest leaf, which is a single entity within the seed tray. Although important to note, root mat expansion is not the most important factor when determining overall growth of the seedlings. Tallest and average leaf height most favoured a shorter initial soaking period and an irrigation interval of 2 hours. It can be concluded that a shorter soaking time is required to produce a favourable growth, with the highest means being derived from a 1-hour soaking treatment, reducing the time required in the soaking process. The same can be said for the tallest leaf height recorded as far as soaking treatments are concerned. Considering that a higher average height in the seedlings is more beneficial to a potential grower it can be concluded that the irrigation interval can be increased to every 8 hours, which reduces the amount of water required to produce a seedling mat. The wet

weight of the seedling mat, post-harvest responded most favourably to a 1-hour soaking treatment in conjunction with a 4 hourly irrigation interval.

To conclude, when focusing on the germination of the seed of *Hordeum vulgare* Sv13, the small-scale grower would need to pre-soak the seed for a period of 1-hour, in a 20 % solution of sodium hypochlorite (bleach), before placing the seed into the growing chamber. Irrigation for the initial 48-hour period of germination should be set to every 8 hours using 1245 ml of water per irrigation interval. Once the initial 48-hour period of germination is complete the irrigation interval will need to be changed to irrigate every 2 hours in order to produce the highest leaf count, tallest leaf and average leaf height, nitrogen and protein percentages in the seedlings.

6.7 RECOMMENDATIONS

With regards to germination it must be noted that the seed was not exposed to an initial dark treatment once soaking was completed. Additional testing would be required to ascertain if the seed would respond in the same manner to soak and irrigation treatments and produce the same results, if exposed to an initial dark photoperiod of 48 hours. Without light exposure it is assumed that the seed would require less water to break seed dormancy and cause radicle emergence to occur. All treatments were irrigated using flood irrigation where the tray was filled with 1245 ml of water at each irrigation interval. It would be interesting to note if this amount of water could be reduced without there being negative effects on the overall germination of the seed. The same argument could be applied to the growth of the seedlings to determine if a reduction in the amount of water per irrigation interval would have any negative effects on the overall growth and average height of the seedlings. Furthermore, it would be interesting to ascertain if spray irrigation would have any effect on the seed, both in radicle emergence, germination percentage and overall growth of the seed and seedling, considering that capillary action would ensure that all the seeds would remain moist in between watering. Further testing into spray irrigation would be required to determine if spraying the seed, instead of soaking at each irrigation interval, would affect the overall germination and growth of the seeds and seedlings. The amount of water given at each irrigation interval would also need to be examined to determine if a reduction would affect the outcome if allowing for capillary action to soak the seeds in their trays, between watering. All treatments were exposed to the same photoperiod of 16 hours light and 8 hours darkness. Irrigation continued according to the irrigation interval, irrespective of the photoperiod, which included watering during the dark phase. Further studies would be required to determine if the results would change, if only irrigated during the light phase of

the growing period. The experiment was conducted using only water to irrigate the seedlings and it would be interesting to note if the introduction of nutrients, during the growing phase, would have any effect in increasing the average leaf height of the barley seedlings during the growing process. Root mat expansion favoured a longer period in between irrigation and therefore a drier environment. The seeds were placed into perforated aluminium trays in the growing chamber. Perhaps, if the container were to be modified into having a mesh base, instead of a solid perforated surface, allowing for better drainage in between watering, the results of root mat expansion would be improved. Results also showed that root max expansion and overall wet weight of the seedlings preferred a 4 hourly irrigation interval. It would therefore be recommended to try a 3 hourly irrigation interval to determine if this would have any benefit or negative effects on the growth and weight of the seedling mat, post harvesting.

CHAPTER SEVEN

REFERENCES

REFERENCES

Abel-Caines, S. & Tierney, C. 2012. Sprouted barley fodder. Coulee Region Organic Produce Pool (CROPP) *Cooperative Organic Farming Technical Bulletin*, (10):1-5.

Al Ajmi, A., Ali Salih, A., Kadim, I. & Othman, Y. 2009. Yield and water use efficiency of barley fodder produced under hydroponic system in GCC countries using tertiary treated sewage effluents. *Journal of Phytology*, 1(5): 342-348.

Ali, S., Farooq, M.A., Yasmeen, T., Hussain, S., Arif, M.S., Abbas, F., Bharwana, S.A. & Zhang, G. 2013. The influence of silicon on barley growth, photosynthesis and ultra-structure under chromium stress. *Journal of Ecotoxicology and Environmental Safety*, 89:66-72.

Al-Karaki, G.N. 2010. Hydroponic green fodder: alternative method for saving water in dry areas. In *Proceedings of the" Second Agricultural Meeting on Sustainable Improvement of Agricultural and Animal Production and Saving Water Use*. September 2010. Sultanate of Oman.

Al-Karaki, G.N. 2011. Utilization of treated sewage waste water for green forage production in a hydroponic system. *Emirates Journal of Food and Agriculture*, 23(1):80-94.

Al-Karaki, G.N. & Al-Momani, N. 2011. Evaluation of some barley cultivars for green fodder production and water use efficiency under hydroponic conditions. *Jordan Journal of Agricultural Sciences*, 7(3):448-457.

Al-Karaki, G.N. & Al-Hashimi, M. 2012. Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholarly Research Network (ISRN) Agronomy*, 1:114-126.

Anker-Nilssen, K., Sahlstrøm, S., Knutsen, S. H. & Holtekjølen, A. K. 2008. Influence of growth temperature on content, viscosity and relative molecular weight of water-soluble b-glucans in barley (Hordeum vulgare L.). *Journal of Cereal Science*, 48:670-677.

Arora, S., Jood, S. & Khetarpaul, N. 2010. Effect of germination and probiotic fermentation on nutrient composition of barley based food mixtures. *Food Chemistry*, 119:799-784.

Baik, B.K. & Ullrich, S.E., 2008. Barley for food: characteristics, improvement, and renewed interest. *Journal of Cereal Science*, 48:233-242.

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

Bradbeer, J.W. 1992. *Seed Dormancy and Germination*. *Second Edition*. Glasgow: Blackie Academic & Professional.

Chaminuka, P., Udo, H.M.J., Eilers, K.C.H.A.M. & van der Zipp, A. 2014. Livelihood roles of cattle and prospects for alternative land uses at the wildlife/livestock interface in South Africa. *Land Use Policy*, 38:80-90.

Chung, H.J., Jang, S.H., Cho, H.Y. & Lim, S.T. 2009. Effects of steeping and anaerobic treatment on GABA (g-aminobutyric acid) content in germinated waxy hull-less barley. *Food Science and Technology*, 42:1712–1716.

Chung, T.Y., Nwokolo, E.N. & Sim, J.S. 1989. Compositional and digestibility changes in sprouted barley and canola seeds. *Plant Foods for Human Nutrition,* 39(3): 267-278.

Cuddeford, D. 1989. Hydroponic grass. *In Practice*, 11(5):211-214.

Dean-Drummond, C.E. 1982. Mechanisms for nitrate uptake into barley (*Hordeum vulgare* L. cv. Fergus) seedlings grown at controlled nitrate concentrations in the nutrient medium. *Plant Science Letters*, 24: 79-89.

DEAT (Department of Environmental Affairs and Tourism), 2006. *World Congress of International Council of Local Environmental Initiatives*. South Africa. https://www.environment.gov.za/sites/default/files/strategic_plans/2003_2006.pdf [22 March 2016].

Deininger, K.W. & Byerlee, D. 2011. *Rising global interest in farmland: can it yield sustainable and equitable benefits*? Washington, D.C. : World Bank. http://siteresources.worldbank.org/DEC/Resources/Rising-Global-Interest-in-Farmland.pdf [15 December 2014].

Driver, A., Sink, K.J., Nel, J.N., Holness, S., Van Niekerk, L., Daniels, F., Jonas, Z., Majiedt, P.A., Harris, L. & Maze, K. 2012. *National Biodiversity assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report*. Pretoria: South African National Biodiversity Institute and Department of Environmental Affairs.

Dung, D.D., Godwin, R. & Nolan, J.V. 2010. Nutrient content and *in sacco* degradation of hydroponic barley sprouts grown using nutrient solution or tap water. *Journal of Animal and Veterinary Advances*, 9(19):2432-2436.

DWAF (Department of Water Affairs and Forestry), 2002. *Proposed First Edition National Water Resource Strategy*, Pretoria.
https://www.dwa.gov.za/Documents/Policies/NWRS/Default.htm [22 March 2016].

DWAF (Department of Water Affairs and Forestry), 2004. *National Water Resource Strategy, Pretoria.*
*h*ttps://www.dwa.gov.za/iwqs/wrmais/National_Water_Resource_Quality_strategy_ed01_dr05_final.pdf [22 March 2016].

Dymek, K., Dejmek, P., Panarese, V., Vicente, A.A., Wadsö, L., Finnie, C. & Galindo, F.G. 2012. Effect of pulsed electric field on the germination of barley seeds. *Food Science and Technology*, 47:161-166.

El-Deeba, M.M., El-Awady, M.N., Hegazi, M.M., Abdel-Azeem, F.A. & El-Bourdiny, M.M. 2009. Engineering factors affecting hydroponics grass-fodder production. In The 16th Annual Conference of the Misr Society of Ag. Eng., Agricultural engineering and variables of the present epoch. *Biological Engineering*, 25:1647-1666.

El-Morsy, A.T., Abul-Soud, M. & Emam, M.S.A. 2013. Localised hydroponic green forage technology as a climate change adaptation under Egyptian conditions. *Journal of Agricultural and Biological Sciences*. 9(6):341-350.

Emam, M.S.A., 2016. The sprout production and water use efficiency of some barley cultivars under intensive hydroponic system. *Middle East Journal of Agriculture Research*, 5:161-170.

Fayed, A.F., 2011. Comparative study and feed evaluation of sprouted barley grains on rice straw versus *Tamarix Mannifera* on performance of growing Barki Lambs in Sinai. *Journal of American Science*, 7(1):954-961.

Fazaeli, H., Golmohammadi, H.A., Shoayee, A.A., Montajebi, N. & Mosharraf, S.H. 2011. Performance of feedlot calves fed hydroponics fodder barley. *Journal of Agricultural Science and Technology*, 13:367-375.

Fazaeli, H., Golmohammadi, H.A., Tabatabayee, S.N. & Asghari-Tabrizi, M., 2012. Productivity and nutritive value of barley green fodder yield in hydroponic system. *World Applied Sciences Journal*, 16(4): 531-539.

Fedina, I., Velitchkova, M., Georgieva, K. & Grogorova, I. 2005. UV-B-induced compounds as affected by proline and NaCl in *Hordeum vulgare* L. cv. Alfa. *Environmental and experimental Botany*, 54:182-191.

Frayne, B., Pendleton, W., Crush, J., Acquah, B., Battersby-Lennard, J., Bras, E., Chiweza, A., Dlamini, T., Fincham, R., Kroll, F., Leduka, C., Mosha, A., Mulenga, C., Mvula, P., Pomuti, A., Raimundo, I., Rudolph, M., Ruysenna, S., Simelane, N., Tevera, D., Tsoka, M., Tawodzera, G. & Zanamwe, L. 2010. The State of urban food insecurity in Southern Africa. http://www.afsun.org/wp-content/uploads/2013/09/AFSUN_2.pdf [24 March 2016].

Fröhlich, M. & Kutschera, 1995. Changes in soluble sugars and proteins during development of rye coleoptiles. *Journal of Plant Physiology*, 146:122-125.

Frossard, R. & Oertli, J.J. 1982. Growth and germination of fungal spores in guttation fluids of barley grown with different nitrogen sources. *Transactions of the British Mycological Society*, 78(2): 239-245.

Garvin, D., Raman, H. & Smith, K. 2003. Barley. *Encyclopedia of Food and Culture*. http://www.encyclopedia.com/topic/barley.aspx#1-1G2:3403400063-full [1 June 2017]

Global Water Partnership (GWP) Technical Advisory Committee. 2000. *Integrated Water Resources Management. Technical Advisory Committee background papers No. 4*. Stockholm. http://www.gwp.org/Global/ToolBox/Publications/Background%20papers/04%20Integrated%20Water%20Resources%20Management%20(2000)%20English.pdf [January 2016]

Guiga, W., Boivin, P., Oumier, N., Fournier, F. & Fick, M. 2008. Quantification of the inhibitory effect of steep effluents on barley germination. *Process Biochemistry*, 43:311-319.

Hafsi, C., Russo, M.A., Sgherri, C., Izzo, R., Navari-Izzo, F. & Abdelly, C. 2009. Implication of phospholipase D in response of Hordeum vulgare root to short-term potassium deprivation. *Plant Physiology*, 166:499-506.

Harris, D. 1982. *Hydroponics: Gardening without soil*. Johannesburg: Centaur Publishers.

Hartmann, H.T., Kester, D.E., Davies, Jr., F.T. & Geneve, R.L. 1997. *Plant Propagation: Principles and Practices. Sixth Edition*. New Jearsey: Prentice-Hall, Inc.

Holden, S.T. & Shiferaw, B. 2004. Land degradation, drought and food security in a less-favoured area in the Ethiopian highlands: a bio-economic model with market imperfections. *Agricultural Economics*, 30(1), 31-49.

Holden, S.T. & Ghebru, H. 2016. Land tenure reforms, tenure security and food security in poor agrarian economies: Casual linkages and research gaps. *Global Food Security*, 10:21-28.

Jensen, H. & Malter, A. 1995. Protected agriculture a global review. *World Bank Technical Paper,* 253:156. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/1995/04/01/000009265_3970311122818/Rendered/PDF/multi_page.pdf [25 March 2016]

Kleinwächter, M., Müller, C., Methner, F.J. & Selmar, D. 2014. Biochemical heterogeneity of malt is caused by both biological variation and differences in processing: I. individual grain analyses of biochemical parameters in differently steeped *Hordeum vulgare* L.) malts. *Food Chemistry,* 147:25-33.

Lorenz, K. 1980. Cereal sprouts: composition, nutritive value, food applications. *Critical reviews in Food Science and Nutrition,* 13(4):353-385.

Metcalfe, S. & Kepe, T. 2008. Your elephant on our land: the struggle to manage wildlife mobility on Zambian communal land in the Kavango-Zambezi trans-frontier conservation area. *Environment and Development*, 17:99-117.

Merriam-Webster, 2016. *Subsistence farming*. http://www.merriam-webster.com/dictionary/subsistence%20farming [22 March 2016].

Mooney, J. 2005. Growing cattle feed hydroponically. *Meat and Livestock Australia*. http://www.foddersolutionsafrica.com/wp-content/uploads/2013/02/Growing-Cattle-Feed-Hydroponically.pdf [20 April 2016].

MOSES-Midwest Organic and Sustainable Education Service. 2012. http://mosesorganic.org/farming/farming-topics/livestock/sprouted-%20barley-fodder-a-revolution-in-animal-feed [22 April 2014].

Naik, P.K., Dhuri, R.B. & Singh, N.P. 2011. *Technology for production and feeding of hydroponics green fodder*. [Online]. India. Extension folder No.45/ 2011, ICAR Research Goa. [Accessed 19 November 2017]. Available from : http://www.academia.edu/5116703/Technology_for_production_and_feeding_of_hydroponics_green_fodder

Naik, P.K., Dhurri, R.B., Swain, B.K. & Singh, N.P. 2012. Nutrient changes with growth of hydroponics fodder maize. *Indian Journal of Animal Nutrition*, 29(2):161-163.

Naik, P.K., Gaikwad, S.P., Gupta, M.J., Dhuri, R.B., Dhumal, G.M. & Singh, N.P., 2013. *Low cost devices for hydroponics fodder production*. [Online] Indian Dairymen-The Spirit of the Dairy Industry. [Accessed 19 November 2017]. Available from: https://www.researchgate.net/publication/258241382_Low_cost_devices_for_Hydroponics_fodder_production

Naik, P.K., Dhuri, R.B., Karunakaran, M., Swain, B.K. & Singh, N.P., 2014. Effect of feeding hydroponics maize fodder on digestibility of nutrients and milk production in lactating cows. *Indian Journal of Animal Sciences*, 8:880-883.

Naik, P.K., Swain, B.K. & Singh, N.P., 2015. Production and utilisation of hydroponics fodder. *Indian Journal of Animal Nutrition*, 32(1): 1-9.

Naik, P.K., Karunakaran, M., Chakurkar, E.M., Swain, B.K. & Singh, N.P., 2016. Digestibility of nutrients in crossbred heifers supplemented with hydroponically sprouted maize grains. *Indian Journal of Animal Sciences*, 86(10):1210-1212.

National Department of Agriculture (NDA). 2004. *Trends in the agricultural sector 2003: directorate, agricultural information*. Pretoria. http://www.nda.agric.za/docs/statsinfo/Trends_2003.pdf [23 March 2016].

National Department of Agriculture (NDA). 2005. *Abstract of agricultural statistics 2005: directorate agricultural information*. Pretoria. http://www.daff.gov.za/docs/statsinfo/P110112005.pdf [23 March 2016].

Nonogaki, H., Basel, G.W. & Bewley, J.D. 2010. Germination – Still a mystery. *Plant Science*, 179: 574-581.

Nuutila, A.M., Hämäläinen, J. & Mannonen, L. 2000. Optimisation of media nitrogen and copper concentrates for regeneration of green plants from polyembryogenic culture of barley (*Hordeum vulgare* L.). *Plant Science*, 151: 85-92.

Pardo, E., Malet, M., Marı´n, S., Sanchis, V. & Ramos, A.J. 2005. Effects of water activity and temperature on germination and growth profiles of ochratoxigenic *Penicillium verrucosum* isolates on barley meal extract agar. *Food Microbiology,* 106:25–31.

Pattanaik, A.K., Verma, A.K., Jadhav, S.E., Dutta, N, & Saikia, B.N. (eds). 2015. *Eco-responsive feeding and nutrition: Linking Livestock and Livelihood*. India: Bytes & Bytes.

Peer, D.J. & Leeson, S. 1985_a. Feeding value of hydroponically sprouted barley for poultry and pigs. *Animal Feed Science and Technology*, 13: 183-190.

Peer, D.J. & Leeson, S. 1985_b. Nutrient content of hydroponically sprouted barley. *Animal feed Science and Technology*, 13:191-202.

Petterson, S. 1995. Low root zone temperature effects on net mineral nutrient uptake and distribution in barley (Hordeum vulgare). *Plant Physiology*, 145:459-464.

Ramakrishna, N., Lacey, J. & Smith, J.E. 1991. Effect of surface sterilisation, fumigation and gamma irradiation on the microflora and germination of barley seeds. *International Journal of Food Microbiology*, 13:47-54.

Resh, H.M. 1997. *Hydroponic Food Production*. Santa Barbara. Woodbridge Press.

Rockström, J., Lannerstad, M. & Falkenmark, M. 2007. Assessing the eater challenge of a new green revolution in developing countries. *Proceedings of the National Academy of Sciences of the United States of America*, 104(15): 6253-6250.

Rostami, H., Giri, A., Nejad, A.S.M. & Moslem, A. 2013. Optimisation of multiple shoot induction and plant regeneration in Indian barley (*Hordeum vulgare*) cultivars using mature embryos. *Saudi Journal of Biological Sciences*, 20:251-255.

Ruel, M.T., Garrett, J.L., Morris, S.S., Maxwell, D., Oshaug, A., Engle, P., Menon, P., Slack, A. & Haddad, L. 1998. Urban challenges to food and nutrition security: a review of food security, health and caregiving in the cities. *Food Consumption and Nutrition Division Discussion Paper No. 51*. https://core.ac.uk/download/files/153/6289467.pdf [23 March 2016].

Saidi, A.R.M.A. & Omar, J.A. 2015. The biological and economical feasibility of feeding barley green fodder to lactating Awassi ewes. *Open Journal of Animal Sciences*, 5: 99-105.

Sampaolo, M., Sinha, S., Curley, R. & Setia, S. 2016. Subsistence farming. *Encyclopedia Britannica*. http://global.britannica.com/topic/subsistence-farming [22 March 2016].

Sang, N., Lee, G. & Xin, X. 2006. Municipal landfill leachate induces cytogentic damage in root tips of Hordeum vulgare. *Ecotoxicology and Environmental Safety*, 63:469-473.

Seckin, B., Turkan, I., Sekmen, A.H. & Ozfidan, C. 2010. The role of antioxidant defense systems at differential salt tolerance of *Hordeum marinum* Huds. (sea barleygrass) and *Hordeum vulgare* L. (cultivated barley). *Environmental and experimental Botany*. 69: 76-85.

Sigwela, A.M., Kerley, G.I.H., Mills, A.J. & Cowling, R.M. 2009. The impact of browsing-induced degradation on the reproduction of subtropical thicket canopy shrubs and trees. *South African Journal of Botany*. 75:262-267.

Singh, B.D., Singh, R.B., Singh, R.M., Singh, Y. & Singh, J. 1979. Effects of insecticides on germination, early growth and cytogentetic behaviour of barley (Hordeum vulgare). *Environmental and Experimental Botany*, 19:127-132.

Sneath, R. & Mcintosh, F. 2003. *Review of hydroponic fodder production for beef cattle: report 332*. [Online]. Australia. Department of Primary Industries. [Accessed 20 June 2014]. Available from: http://blogs.cornell.edu/organicdairyinitiative/files/2014/05/Hydroponicfodder-article-11wpnm0.pdf

Snow, A.M., Ghaly, A.E. & Snow, A. 2008. A Comparative Assessment of Hydroponically Grown Cereal Crops for the Purification of Aquaculture Wastewater and the Production of Fish Feed. *American Journal of Agricultural and Biological Sciences*, 3(1): 364-378.

SouthAfrica.info, 2016. *South African a*griculture. http://www.southafrica.info/business/economy/sectors/agricultural-sector.htm#.VvU6_eJ961s [23 March 2016].

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

Sung, H.G., Shin, H.T., Ha, J.K., Lai, H.L., Cheng, K.J. & Lee, J.H. 2005. Effect of germination temperature on characteristics of phytase production from barley. *Bioresource Technology*, 96:1297–1303.

Tamai, T., Shimada, Y., Sugimoto, T., Shiraishi, N. & Oji, Y. 2000. Potassium stimulates the efflux of putrescine in roots of barley seedlings. *Journal of Plant Physiology*, 157: 619-626.

UN-HABITAT, 2006. State of the World's cities report 2006-2007. *Earthscan*. http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2101&AspxAutoDetectCookieSupport=1 [23 March 2016].

Van Campenhout, L., Shen, H.Y., Iserentant, D. & Verachtert, H. 1999. The gas environment of germinating barley in various microbial states during malting. *Process Biochemistry*, 34:929-937.

Venter, G. 2010. *Successful Hydroponics: A comprehensive practical guide to scientifically based hydroponic crop production*. Unites States of America: Xlibris Corporation.

Walmsley, J. & Adamson, H. 1990. Gabaculine inhibition of chlorophyll synthesis in light and darkness in intact barley (Hordeum vulgare) seedlings. *Plant Science,* 68(1):65-70.

Yousfi, S., Wissal, M., Mahmouddi, H., Abdelly, C. & Gharsalli, M. 2007. Effect of salt on physiological responses of barley to iron deficiency. *Plant Physiology and Biochemistry*, 45:309-314.

Yousfi, S., Rabhi, M., Abdelly, C. & Gharsalli, M. 2009. Iron deficiency tolerance traits in wild (Hordeum maritimum) and cultivated barley (Hordeum vulgare). *Comptes Rendus – Biologies*, 332(6): 523-533.