Evaluating the potential of hydroponic fodder production – Implications for smallholder and communal farmers in water-limited agro-ecological areas in the Northern Cape Province of South Africa

Report to the

Water Research Commission

by

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EXECUTIVE SUMMARY

Background

Livestock production in arid and semi-arid regions is increasingly challenged by unpredictable rainfall, recurrent droughts, and poor-quality rangeland forage. These environmental factors, exacerbated by climate change, contribute to reduced livestock productivity, increased disease prevalence, and poor reproductive performance. To mitigate these issues, alternative fodder production systems, such as hydroponic fodder, have been explored as sustainable solutions. This study evaluates the feasibility of hydroponic fodder as a supplementary feed source by examining its growth performance, nutritional value, cost-effectiveness, and impact on livestock condition and methane emissions. The main aim of the projects was achieved through the following objectives:

1. To identify the best fodder species to use in a hydroponic fodder flow programme in the cold winter months and hot summer months in a net covered structure and a plastic covered structure, and to determine the quantity and nutritional quality of the different hydroponically produced fodders and relating these to the requirements of different livestock species.
2. To determine the impact of different water sources on the growth and quality of hydroponically produced fodders
3. To determine the impacts of feeding hydroponic fodder to small stock on livestock condition, gut microbiome and methane emission.
4. To evaluate the effects of supplementing barley fodder sprouts on feed intake, weight gain, and rumen microbial composition of weaned indigenous goat kids.
5. To determine the quantity and nutritional quality of the different hydroponically produced fodders and relate these to the requirements of different livestock species.
6. To determine the cost-effectiveness of the hydroponic system as a fodder flow program for smallholder and communal farmers.

PROJECT METHODOLOGY

Hydroponic barley, maize, oats, sorghum, and wheat were assessed for their growth characteristics and nutritional composition. While barley and oats produced the highest fresh biomass, barley exhibited the lowest dry matter content due to higher water retention. Despite this, all species contained sufficient crude protein to meet livestock maintenance requirements, with barley and wheat also meeting the nutritional needs of highly productive livestock. Most mineral nutrients were present at adequate levels, except for calcium, sodium, and copper, which were deficient across all species.

The study also examined the effects of different water sources on hydroponic barley growth. Municipal and borehole water proved to be suitable irrigation sources, producing fodder with adequate protein and mineral content. Distilled water yielded the highest dry matter production, while nutrient-enriched water enhanced crude protein levels. This indicates that resource-poor farmers can successfully use locally available water sources without compromising fodder quality.

Structural efficiency was another critical aspect of the study. Plastic-covered structures consistently yielded higher biomass than net-covered structures, despite similar water use. While plastic structures maintained higher mid-morning and early afternoon temperatures, supporting better sprout growth, net-covered structures allowed greater airflow, reducing the risk of fungal contamination. These findings highlight the benefits of plastic structures for winter fodder production in Namaqualand, where seasonal grazing limitations impact livestock productivity.

Feeding hydroponic barley to Meatmaster lambs significantly improved feed intake and body weight compared to a control diet of *Eragrostis curvula* hay. Methane emissions per unit of feed intake were reduced by 34–52%, demonstrating the potential of hydroponic fodder in mitigating the environmental impact of livestock production. Furthermore, the gut microbiome composition shifted, with changes in bacterial abundance linked to improved rumen fermentation efficiency. These results suggest that hydroponic fodder can enhance feed utilization while simultaneously reducing greenhouse gas emissions.

The economic viability of hydroponic fodder production was also assessed. A small-scale hydroponic fodder unit (3m x 5m) was found to be financially feasible, with a payback period

of just over two months under optimal conditions. While manual watering was cost-effective, it was labour-intensive, and automation is recommended for long-term sustainability. Given its ability to provide an immediate solution for fodder shortages, hydroponic production presents a viable option for communal farmers in Namaqualand.

KEY FINDINGS

Chapter 2:

- Barley and oats showed the best growth in hydroponic systems, but barley had high dry matter loss.
- All species met basic livestock protein/phosphorus needs; barley and wheat suited high-production herds.
- Different water sources (borehole, municipal) did not compromise fodder quality, making it viable for resource-poor farmers.

Chapter 3:

- Plastic covered structures outperformed net covered ones in yield and water use efficiency (WUE), especially in winter.
- Hydroponics is a water saving solution for fodder production in arid regions.

Chapter 4:

- Seasonal forage quality in Namaqualand rangelands was consistently low in minerals, risking livestock health.
- Interventions like feed supplementation and drought management are needed.

Chapter 5:

- Barley sprouts reduced methane emissions per feed intake in lambs and altered rumen bacteria for better efficiency.

Chapter 6:

- Barley sprouts increased goat kids' feed intake (17–18%) but not significantly their weight gain.

- Rumen health remained stable, but *Anabaena* (toxin producing bacteria) contamination risks need investigation.

Chapter 7:

- Hydroponics is cost-effective for smallholders but requires careful timing (avoid extreme temps) and management.
- Integration with other fodder sources improves resilience to climate variability.

RESEARCH PRODUCTS

Except for the knowledge and skills that were collected and developed by the project team members, the most important research products were:

- Training materials and demonstration models on hydroponic fodder production, used during community workshops.
- Practical guidelines to support smallholder and communal farmers in adopting hydroponic fodder production technologies.
- These research products contributed to:
    - **Knowledge transfer** among farmers in targeted communal areas.
    - **Community capacity building** through hands-on engagement and skills development.
    - **Farmer participation and interest**, particularly in Leliefontein (Paulshoek) and Concordia, where farmers requested to be shown the full production process.

CONCLUSION AND RECOMMENDATIONS

Hydroponic fodder represents a sustainable, water-efficient supplement for livestock in arid regions, demonstrating clear benefits for feed quality, animal performance, and environmental sustainability. To realize its full potential, scaling up production must be prioritized through optimized plastic-covered structures with enhanced ventilation to prevent contamination, alongside automated irrigation systems to improve efficiency. While the technology offers climate-smart solutions for resource-constrained farmers, critical challenges, including contamination risks and seasonal management requirements, must be systematically addressed. Strategic implementation through targeted farmer training and supportive policies will be

essential to facilitate widespread adoption. With these measures in place, hydroponic fodder can evolve from an innovative alternative to a mainstream component of resilient livestock production systems, effectively balancing productivity with sustainability in water-scarce environments.

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LIST OF ABBREVIATIONS/ACRONYMS

ADF	Acid detergent fibre
ANOVA	Analysis Of Variance
ARC	Agricultural Research council
ARC-AP	Agricultural Research Council - Animal Production
ASV	Amplicon Sequence Variants
AZEF	Arid Zone Ecology Forum
CP	Crude protein
DDM	Digestible dry matter
DFE	Digestible forage energy

DOM	Digestible organic matter
FDR	False Discovery Rate
LMD	Laser Methane Detector
ME	Metabolizable energy
NDF	Neutral detergent fibre
NE_G	Net energy for gains/growth
NE_L	Net energy for lactation
NE_M	Net energy for maintenance
RWX	Relative water Content
FM	Fresh Mass
TWU	Total water used
WUE	Water Use Efficiency
DM	Dry matter
OUT	Operational Taxonomic Units
PCoA	Principal Coordinate Analysis
TDN	Total digestible nutrients
VFA	Volatile fatty acids
CRD	Complete randomised design
FCR	Feed conversion ratio
ADG	Average daily gain

UNITS OF MEASUREMENTS

m	meter
cm	centimeter
Mm	milimeter
l	liter
ml	milliliter
g	grams
mg/kg	milligrams per kilogram
g/kg BW	grams per kilogram of Body Weight
g/day	grams per day
g/ml	grams per milliliter
mg/l	milligrams per liter

mg/dL	milligrams per deciliter
mmol/L	millimoles per Liter
Ppb	Parts per billion
(ppm)2	parts per million
g/g DM	gram per grams of Dry Matter
Mcal/kg DM	Megacalories per kilogram of Dry Matter
MJ/kg DM	MegaJoules per kilogram of Dry Matter
g/DMI	grams per Dry Matter Intake
mS/m	milliSiemens per meter
°C	degree Celsius

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Approximately 80% of South Africa's land surface is classified as semi-arid to arid (Palmer & Ainslie 2006). Of this, approximately 82% are used for agricultural activities of which only 14% receive sufficient rainfall for arable crop production. The remainder of the agricultural land is used for extensive livestock production, forestry, and wildlife/nature conservation (Palmer & Ainslie 2006; Jordaan et al. 2013). Under these semi-arid and arid conditions, the most extensive agricultural activities are livestock farming under rangeland conditions where livestock make use of the natural veld (Jordaan et al. 2013). However, along with low annual precipitation, these semi-arid and arid rangelands are, in many instances, also subjected to recurrent droughts, cyclic long-term droughts, extreme temperatures and marginal edaphic conditions (Jordaan et al. 2013). During these dry periods, and to an extent, also as a result of inadequate fodder flow planning, inadequate supply of good quality feed during the dry season is one of the most limiting factors affecting extensive livestock production (Palmer & Ainslie 2006; Jordaan et al. 2013; Muller et al. 2019). This is especially true for smallholder and communal farmers where a continuous challenge to improving smallholder livestock productivity has been low commercial offtake, which is often less than 10% of total herd size, and significantly lower successful laming percentages in communal farming areas.

In the water-limited agro-ecological areas of Namaqualand in the Northern Cape Province, dryland fodder in the form of low input cereal crops are grown on cleared patches within the rangelands, where crop residues make an important contribution to livestock diets on both commercial and communal farming areas, especially during dry periods (Palmer & Ainslie 2006). In general, however, the nutritional quality of these crop residues is poor, mainly due to its low digestibility, protein, and available carbohydrate content (Brand et al. 2000; Brundyn et al. 2005). In many instances, in these dry rangelands, these croplands are left uncultivated and unmanaged primarily due to a lack of forage species suitable for these marginal agro-ecological conditions, increased variability in rainfall and stray equines. An example of this can be found in the communal rangelands of Namaqualand in the Northern Cape province of South Africa (Samuels 2013). Within the Leliefontein communal area, approximately 12% of the communal rangelands has been demarcated for cultivating crops and forages. This equates

to approximately 23 050 hectares of land that has been divided into 559 sowing plots (Samuels 2013). Over the years, these sowing plots have been left uncultivated, unmanaged, and fallow, which in turn, has resulted in only 3742 hectares (or 16%) of available croplands being used per annum (Samuels 2013). When these sowing plots are left uncultivated and unmanaged for prolonged periods, it has been shown that various non-palatable plant species such as *Galenia africana* (Kraalbos), *Hermannia amoena* (Jeukbos) and *Dicerothamnus rhinocerotis* (Renosterbos) occupy these spaces. Furthermore, even when these old croplands are uncultivated, during the winter rainy season, the cropland areas that has not been taken over by non-palatable species, are covered with ephemeral plants, which is an immensely important feed resource for livestock, but in the absence of a good rainy season, these ephemerals are less abundant and result in forage shortages for communal livestock farmers.

The absence of the ephemeral forage source in the wet season (during droughts) and a general lack of good quality forage during the dry and drought periods (Müller et al. 2019) have in the past resulted in serious consequences for livestock production as many animals succumb to hunger. This, in turn, has had negative economic impacts on these rural communities, which are often found to be food insecure, and live well below the poverty line (Ntombela 2017). Similar scenarios of unproductive fodder flow systems can be found in other less studied agro-pastoral areas such as the Steinkopf and Concordia and Paulshoek communal areas within Namaqualand.

The inclusion of a carefully planned fodder flow programme during times of natural feed shortages, therefore, has the potential of significantly enhancing smallholder and communal livestock productivity, which in turn, has the potential to unlock opportunities necessary for providing better incomes and sustainable livelihoods. We therefore propose the implementation of a hydroponic fodder production program within these areas where rainfall variability is the main factor influencing the production of feed for livestock, for supplementary feeding during the dry season. These systems, which will either make use of a water-harvesting system to capture water during the wet season or other water sources such as boreholes or grey water, will be able to produce fodder during the dry season. The benefits of a hydroponic fodder flow system, as opposed to a sown fodder system, are that the water requirements/usage is minimal, approximately 2% to 3% of that water used under field conditions to produce the same amount of fodder (Al-Karaki & Al-Hashimi 2012). It does not require large areas of arable land, and therefore, the capital and fixed asset costs i.e., fences, tractors, ploughs,

planters, and harvesters, are minimal. This, in turn, reduces the amount of labour needed to produce fodder, and therefore, also labour costs. These hydroponic fodder systems also require low operational costs once the system has been established, with the only expenses coming from purchasing the seeds, and the chemicals needed to clean the system. However, using a hydroponic fodder production system, for every 1 kg of seed used, approximately 7 to 10 kg of feed can be produced (depending on the fodder species used), and this can be done within 7 to 10 days. An example of the cost-effectiveness of such a system can be seen using the following example. A 25 kg bag of sorghum seeds, priced at approximately R400 to R600 can produce up to 250kg of green feed. If lower quality seeds are used, seeds can be obtained for approximately R3500 to R5000 per ton, which can produce up to 10 000 kg of green feed. When this is compared to a 250kg bale of grass hay, which, during the dry season, could cost up to R1000 and lucerne hay, up to R1700, depending on the markets, it is easy to see the impact that hydroponic fodder production can have on carrying livestock through the dry season. Additionally, within the Namaqualand rangelands, farmers and herders are often situated far from towns and areas where good quality hay can be purchased, making the use of the natural veld or the production of their own feed often the only options for many of these farmers.

An added benefit of hydroponically produced fodder within these dry agro-ecological areas is that, unlike feeding the grains directly to the animals, which contains approximately 85% to 87% dry matter (13% to 15% water), hydroponically produced fodders contain approximately 80% to 85% water. This is extremely important when you are in a water-limited environment where water for the animals is scarce. It has also often been noted that there is a 2% to 4% increase in the crude protein content in hydroponically produced fodder (when a nutrient solution is applied after sprouting), as opposed to the pure grains. All these features of the hydroponic fodder production system make it one of the most important agricultural technologies currently available for green fodder production, especially in water-limited agro-ecological regions. Furthermore, preliminary results from a hydroponic fodder production system set up at the ARC Irene campus show that crude protein content of hydroponically produced sprouts (without adding liquid fertiliser) ranged between 10% for sorghum and 38% for lucerne. Taking into consideration that previous studies from the Leliefontein communal area showed that on average, during the dry season livestock consumed diets that contained crude protein content of only 3% to 6% (Müller et al. 2019), it is easy to see how feeding these

hydroponic fodders could significantly improve the supply of fodder within these water-limited agro-ecological areas.

Although seemingly a viable option that can significantly improve livestock production in water-limited agro-ecological areas in South Africa, unfortunately, these hydroponic fodder production systems have not been evaluated effectively under the variable bioclimatic conditions in South Africa. Several farmers have indicated issues with perfecting the fodder flow program. Some of the issues include the fact that there is no clear indication as to which fodder species would be better adapted to winter or summer rainfall areas, and which species would produce the highest quality fodders in the shortest time under these conditions. In the summer rainfall areas, various issues during the dry season could impede the success of the fodder flow program, especially when the goal is to use low-cost hydroponic feed production systems where temperature and humidity cannot be controlled. For instance, the dry season within summer rainfall areas falls within the cold winter months and with temperature being the major determinant of seed germination rate, this could significantly influence the time in which these fodders are produced. In the winter rainfall regions, however, the dry season falls within the summer months, which would benefit seed germination rate and the time taken to produce the fodders (Hu et al. 2015). Within the winter rainfall regions, however, the high temperatures coupled with high levels of humidity in the closed hydroponic system (i.e., using a plastic-covered structure) can result in various other issues such as pathogens (mould and fungi) entering the system and influencing the quality of the fodders produced.

To address some of these issues and identify any further potential issues, we propose to test two low-cost hydroponic production systems, one using a net structure (allowing constant air flow) and one using a plastic structure (reduced air flow and increased humidity). These structures will be used to evaluate the potential of different fodder species for the production of hydroponic feeds using the two types of structures, and to determine the cost effectiveness of producing these hydroponic fodders during both cold winter months in the summer rainfall areas, and hot summer months in the winter rainfall areas. This work will form the basis to determine which type of structure would do best under the different dry seasons found in South Africa and would inform future efforts to address dry season feed gaps in water-limited semi-arid to arid agro-ecological areas. For the current report, we specifically aim to determine which structure type is best suited for the summer rainfall areas, where the dry season is in the cold winter months.

1.2 PROJECT AIMS AND OBJECTIVES

This overall project aimed to identify the most suitable low-cost hydroponic fodder production system to address dry season feed gaps within both winter and summer rainfall areas. We aimed to do this by addressing the following objectives:

1. To identify the best fodder species to use in a hydroponic fodder flow program in the cold winter months and hot summer months in a net covered structure and a plastic covered structure, and to determine the quantity and nutritional quality of the different hydroponically produced fodders and relating these to the requirements of different livestock species.

2. To determine the impact of different water sources on the growth and quality of hydroponically produced fodders

3. To determine the impacts of feeding hydroponic fodder to small stock on livestock condition, gut microbiome and methane emission.

4. To evaluate the effects of supplementing barley fodder sprouts on feed intake, weight gain, and rumen microbial composition of weaned indigenous goat kids.

5. To determine the cost-effectiveness of the hydroponic system as a fodder flow programme for smallholder and communal farmers.

1.3 SCOPE AND LIMITATIONS

Hydroponic fodder production involves the use of water as the growing medium. Hydroponic fodder has the potential to be produced in low-cost structures. Using locally bought seeds, this technology could be a cost-effective means to improve livestock production in areas with adverse bioclimatic conditions. However, mould, bacteria, and fungi are a few issues that affect yield production. Mould and spoiling occur occasionally if there is no proper drainage or if the trays are not inclined. Growth is slow during the winter months compared to the summer months.

CHAPTER 2: DETERMINING THE NUTRITIVE VALUE OF DIFFERENT CEREAL CROPS AND THE IMPACT OF DIFFERENT WATER SOURCES ON THE GROWTH AND QUALITY OF HYDROPONICALLY PRODUCED BARLEY FODDERS

2.1 INTRODUCTION

Livestock production systems, particularly in arid and semi-arid regions, are often constrained by the seasonal availability and nutritional quality of natural pastures (Saha et al. 2018). In response to these challenges, hydroponically produced fodder has emerged as a viable alternative to supplement conventional feed resources, ensuring year-round availability of high-quality forage (Naik et al. 2015). Hydroponic fodder production involves growing cereal crops such as barley (*Hordeum vulgare L.*), maize (*Zea mays*), oats (*Avena sativa*), sorghum (*Sorghum bicolor*), and wheat (*Triticum aestivum*) under controlled conditions without soil, and or, using nutrient-enriched water solutions (Fazaeli et al. 2012). This method has gained attention for its ability to produce nutritionally rich feed within a short growth cycle, typically 7 to 10 days, while utilizing significantly less water than traditional forage production (Tranel & Rosenkrans 2018).

Among the various cereal crops evaluated for hydroponic production, barley has been widely recognized for its superior yield and high digestibility, making it a preferred choice for livestock feed (Cuddeford 1989). However, the nutritional composition of hydroponic fodder can be influenced by several factors, including seed type, growth duration, environmental conditions, and water quality (Kide et al. 2015). Water availability and quality are particularly critical in hydroponic systems, as they directly affect germination rates, biomass accumulation, and the mineral content of the produced fodder (Gebrehawariat et al. 2018). In water-scarce regions such as Namaqualand, Northern Cape, alternative water sources, including borehole water and municipal tap water, are often used for agricultural purposes, yet their impact on hydroponic fodder production remains poorly understood.

This study aims to evaluate the nutritive value of different hydroponic cereal fodders and assess the impact of different water sources on the growth and nutritional composition of hydroponically grown barley. The first experiment focuses on comparing the production

potential and nutritional quality of barley, oats, maize, sorghum, and wheat, with an emphasis on growth characteristics, dry matter yield, and mineral composition. The second experiment investigates how different water sources – borehole water, municipal tap water, distilled water, and a nutrient-enriched water solution – affect the growth and nutritional attributes of hydroponic barley fodder. Given the crucial role of crude protein and essential minerals in livestock nutrition (Meissner 2000), the findings from this study will contribute valuable insights into optimizing hydroponic fodder production to enhance livestock productivity in water-limited environments.

2.2 METHODS

In experiment 1 (Figure 2.1), we aimed to evaluate the production potential and nutritional quality of different hydroponic fodder species. Barley, oats, maize, sorghum and wheat seeds were obtained from local seed distributors. Thereafter, four replicates of 238g, 257g, 192g, 273 g and 262g of barley, maize, oats, sorghum and wheat seeds respectively, were weighed and washed with a 1% bleach solution to minimize any intrusion of fungi. The seeds were first measured using a 500 ml jar for uniform volume estimation, and later weighed using a digital scale, which accounts for the differences in weights. For experiment 2, only barley seeds were used. In this experiment we aimed to evaluate the impact of different water sources on the production potential and nutritional quality of hydroponic fodders produced. After washing, the seeds were spread open in aluminium trays (32 cm Length, 26 cm Width and 6 cm Height) and placed in glasshouses with natural light regimes.

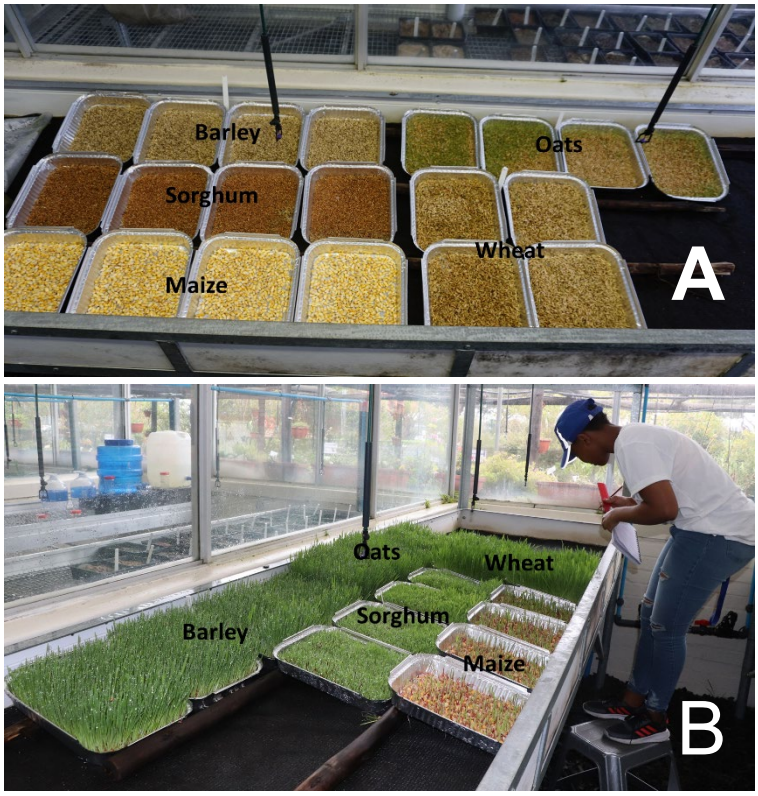


Figure 2.1 A & B: Evaluation of production potential of hydroponic fodder species, including barley, maize, oats, sorghum, and wheat.

The trays were punctured at the lower end to ensure that all excess water could run off after watering. Watering was done manually from above and seedling growth was measured daily for 10 days. For experiment 1, tap water was used and for experiment two, water samples were collected from a borehole as well as municipal taps within the Paulshoek area of Namaqualand in the Northern Cape. The samples were transported to the greenhouse and kept for watering of sprouts. Additionally, distilled water and a full-strength stock liquid fertilizer (Plant Food - Starke Ayers) were used as the controls for experiment 2. For both experiments, sprouts emerged from day five, from where daily height measurements from the bottom, middle and top of each tray were done using a ruler. After 10 days, the sprouts were removed from the trays and the fresh mass and dry mass were calculated. After determining the fresh mass, the sprouts were dried at 60 ˚C until a constant mass was achieved, after which the dry mass was measured. Thereafter, the water content (g/g) was calculated on a dry mass basis. The loss in dry matter content from seed to dry sprouts was also calculated and expressed at as % loss from seeds to sprouts. The dried sprouts were thereafter milled using a laboratory stainless steel blender, after which the milled samples were split for mineral nutrient analyses (N, P, K, Ca, Mg, Na, Fe, Cu, Zn and Mn) and determination of fibre content (NDF and ADF). Samples for

mineral nutrient content were shipped to the Western Cape Department Agriculture, Land Reform and Rural Development labs at Elsenburg, while the samples for fibre analyses were shipped to the Agricultural Research Council Analytical Labs at Irene. Results from the mineral nutrient analyses, specifically the N-content, was used to determine the crude protein content in the sprouts by multiplying the %N with 6.25 (Meissner 2000). The NDF and ADF values obtained were used to calculate the digestible dry matter (DDM), metabolizable energy (ME), total digestible nutrients (TDN), digestible forage energy (DFE), digestible organic matter (DOM), net energy for lactation (NE_L), net energy for maintenance (NE_M) and net energy for gain/growth (NE_G) using equations 1 – 8.

1. DDM (%) = 88.9 - (ADF × 0.779) (Rasby et al. 2008)
2. ME (Mcal/kg DM) = (1.01 x DFE) – 0.45 (Meissner et al. 2000)
3. TDN (%) = 87.84 - (0.7 × ADF) (Schroeder 2009)
4. DFE (Mcal/kg DM) = 0.04409 x TDN (Meissner et al. 2000)
5. DOM (%) = TDN ÷1.05 (Meissner et al. 2000)
6. NE_L (Mcal/kg DM) = 1.044 - (0.0119 x %ADF) (Rasby et al. 2008)
7. NE_M (Mcal/kg DM) = ((1.37 x ME) – (0.3042 x ME) + (0.051 x ME)) – 0.508 (Rasby et al. 2008)
8. NE_G (Mcal/kg DM) = ((1.42 x ME) – (0.3836 x ME) + (0.0593 x ME)) – 0.7484 (Rasby et al. 2008)

2.3 RESULTS AND DISCUSSION

The study addressed two main objectives and was structured accordingly. Experiment **1** focused on evaluating the production potential and nutritional quality of different hydroponic fodder species. **Experiment 2** aimed to assess the impact of different water sources on the production potential and nutritional quality of hydroponically grown fodder, using only barley seeds.

2.3.1 EXPERIMENT 1 – OBJECTIVE 1

The different forages were found to all start sprouting at day three. However, the sprouts were only long enough to take measurements from day six without disturbing the seeds (Table 2.1). Barley and oats produced larger sprouts, with taller leaves. Barley produced higher fresh mass yields at the end of the growing period, while oats produced similar yields to the other species

evaluated at the end of the growing period. Even though it had the highest fresh mass, barley had the lowest dry matter production by the end of the experiment. This was generally due to larger quantities of water being taken up by the sprouts, resulting in higher water content per gram of dry material. In all species evaluated, a significant loss in dry matter content from seed to sprouts was observed. Maize and sorghum had the lowest loss in dry matter from seed to sprouts (19%), while barley had the highest loss (31%). This coincides with the amount of water in the sprouts, and the water-use efficiency of the sprouts. The loss in dry matter, however, is a worrying result as all nutritional requirements for livestock is calculated on a dry matter basis. Significant differences in mineral nutrient content were found between some of the species evaluated (Table 2.2). All species evaluated contained high enough crude protein concentrations to meet the minimum requirements of 6% – 8% to maintain livestock condition (Meissner et al. 2000). Only barley and wheat contained crude protein content that is high enough for maintaining highly productive livestock herds with a minimum requirement of 13 – 14% (Meissner et al. 2000). All of the species evaluated contained high enough concentrations of Mg, P, K (with the exception of sorghum), Fe, and Zn to meet the minimum requirements of livestock (Meissner 2000). Only oats, sorghum and wheat contained high enough concentrations of Mn to meet the minimum requirements of livestock (Meissner 2000). None of the species evaluated contained Ca, Na and Cu in sufficient concentrations to meet the minimum requirements of livestock (Meissner 2000). Although some of the mineral nutrients were not in sufficient concentrations to meet the minimum requirements of the livestock, it is important to remember that the hydroponic fodders will not be used as a standalone feed but will be supplementary to the basal rangeland diets. Previous work done by the ARC: AP – RFS team in Namaqualand found that the diets of the livestock in Namaqualand generally contain sufficient concentrations of most of the mineral nutrients (Müller et al. 2019), and therefore the lack in some nutrients from the hydroponic feed should not have an impact on the health of the livestock. However, from these prior studies, it was clear that crude protein (CP) and phosphorus (P) are the major limiting factors in terms of mineral nutrient requirements. From the results obtained from these preliminary nutritional quality data, it is clear that the hydroponic fodders can close these gaps as both P and CP concentrations in all of the species evaluated were high enough to meet the minimum requirements of livestock (Meissner 2000; Meissner et al. 2000).

Table 2.1: Differences in the growth and morphology of barley, maize, oats, sorghum, and wheat hydroponic fodders.

	Sprout Height (cm) Day 6	Sprout Height (cm) Day 7	Sprout Height (cm) Day 8	Sprout Height (cm) Day 9	Final Sprout Height (cm)	Fresh Mass (g)	Dry Mass (g)	Water Content (g/g DM)	% Loss in DM from seed to sprouts
Barley	1.1 ± 0.3^{b}	2.9 ± 0.7^{b}	5.2 ± 1.4^{b}	6.9 ± 1.7^{b}	9.1 ± 1.5^{b}	722.6 ± 116.4^{b}	163.3 ± 6.9^{a}	3.5 ± 0.8^{b}	31.4 ± 2.9^{c}
Maize	0.2 ± 0.1^{a}	0.7 ± 0.1^{a}	1.5 ± 0.3^{a}	2.4 ± 0.4^{a}	4.3 ± 0.6^{a}	391.1 ± 30.2^{a}	208.5 ± 2.9^{c}	0.9 ± 0.2^{a}	19.0 ± 1.1^{a}
Oats	2.1 ± 0.7^{b}	2.8 ± 0.9^{b}	4.4 ± 1.3^{b}	5.8 ± 1.4^{b}	8.1 ± 1.8^{b}	409.5 ± 14.2^{a}	153.3 ± 6.8^{a}	1.7 ± 0.2^{a}	20.2 ± 3.6^{ab}
Sorghum	0.0 ± 0.0^{a}	0.1 ± 0.1^{a}	0.8 ± 0.1^{a}	1.1 ± 0.3^{a}	2.4 ± 0.6^{a}	433.3 ± 17.7^{a}	220.3 ± 1.8^{c}	1.0 ± 0.1^{a}	19.3 ± 0.7^{a}
Wheat	0.2 ± 0.2^{a}	0.9 ± 0.2^{a}	1.8 ± 0.3^{a}	2.8 ± 0.3^{a}	4.0 ± 0.4^{a}	448.1 ± 23.7^{a}	192.9 ± 2.6^{b}	1.3 ± 0.2^{a}	26.3 ± 1.0^{bc}
Significance	$F_{(4,20)} = 6.06$, $p = 0.004$	$F_{(4,20)} = 5.84$, $p = 0.005$	$F_{(4,20)} = 5.12$, $p = 0.008$	$F_{(4,20)} = 6.10$, $p = 0.004$	$F_{(4,20)} = 6.60$, $p = 0.003$	$F_{(4,20)} = 6.02$, $p = 0.004$	$F_{(4,20)} = 36.56$, $p = 0.010$	$F_{(4,20)} = 7.101$, $p < 0.001$	$F_{(4,20)} = 6.24$, $p = 0.004$

Table 2.2: Differences in the mineral nutrients of barley, maize, oats, sorghum, and wheat hydroponic fodders.

	CP (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
Oats	12.9 ± 1.5^{b}	0.4 ± 0.020^{b}	0.6 ± 0.12^{a}	0.08 ± 0.003^{d}	0.1 ± 0.006^{a}	184.5 ± 6.1^{c}	72.4 ± 5.4^{c}	0.7 ± 0.07^{a}	30.3 ± 1.1^{b}	38.3 ± 1.0^{d}
Barley	13.3 ± 0.4^{b}	0.4 ± 0.010^{b}	0.6 ± 0.09^{a}	0.05 ± 0.003^{c}	0.1 ± 0.004^{a}	236.8 ± 7.5^{d}	52.7 ± 4.9^{b}	0.8 ± 0.25^{a}	21.0 ± 2.4^{a}	15.1 ± 0.6^{c}
Sorghum	11.9 ± 0.1^{ab}	0.3 ± 0.003^{a}	0.4 ± 0.01^{a}	0.02 ± 0.003^{b}	0.2 ± 0.003^{b}	130.8 ± 5.5^{ab}	45.8 ± 2.2^{ab}	1.0 ± 0.05^{a}	20.4 ± 0.3^{a}	17.7 ± 0.3^{b}
Wheat	13.8 ± 0.5^{b}	0.3 ± 0.005^{a}	0.6 ± 0.06^{a}	0.05 ± 0.000^{c}	0.1 ± 0.000^{a}	133.8 ± 4.9^{b}	42.4 ± 3.1^{a}	2.1 ± 0.26^{b}	27.6 ± 2.2^{b}	42.0 ± 0.7^{e}
Maize	9.8 ± 0.3^{a}	0.3 ± 0.003^{a}	0.7 ± 0.16^{a}	0.01 ± 0.000^{a}	0.1 ± 0.000^{a}	129.3 ± 7.4^{a}	41.0 ± 1.3^{a}	1.5 ± 0.52^{ab}	16.9 ± 0.4^{a}	4.6 ± 0.1^{a}
Significance	$F_{(5,19)} = 4.58$, $p = 0.013$	$F_{(5,19)} = 29.87$, $p < 0.001$	$F_{(5,19)} = 1.23$, $p = 0.342$	$F_{(5,19)} = 17.62$, $p < 0.001$	$F_{(5,19)} = 35.00$, $p < 0.001$	$F_{(5,19)} = 55.03$, $p < 0.001$	$F_{(5,19)} = 11.96$, $p < 0.001$	$F_{(5,19)} = 3.94$, $p = 0.022$	$F_{(5,19)} = 12.64$, $p < 0.001$	$F_{(5,19)} = 69.14$, $p < 0.001$
Dry Season Veld	4.8 ± 0.3	0.07 ± 0.006								
Wet Season Veld	6.9 ± 0.4	0.10 ± 0.001								

2.3.2 EXPERIMENT 2 – OBJECTIVE 2

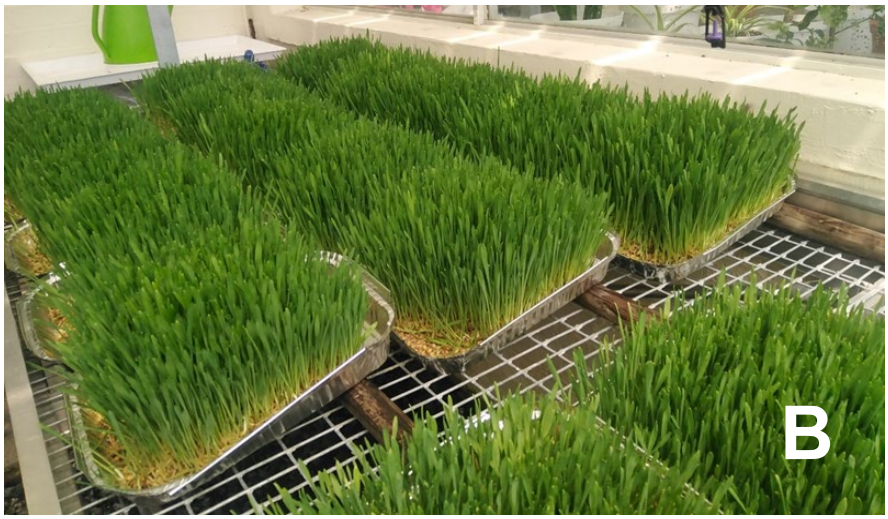
The water analyses from Namaqualand (Table 2.3), including both municipal and borehole sources, were found to be alkaline and saline, with pH values above the optimal range for hydroponic crops but still acceptable for use. Despite the high electrical conductivity and mineral concentrations, barley growth was not negatively affected. Essential elements such as sodium (Na), calcium (Ca), magnesium (Mg), and chloride (Cl) were present at high levels but did not stop plant growth. Most potentially toxic elements were within safe limits for irrigation, except zinc and selenium, which slightly exceeded guidelines but remain acceptable for short-term use.

Table 2.3: Mineral content of the water sources from Namaqualand.

	Groundwater	Municipal water
pH	8.5 ± 0.01	8.6 ± 0.04
E.C. (mS/m)	299.5 ± 56.01	243.5 ± 1.5
NO_3^- (mg/l)	0.3 ± 0.05	15.2 ± 0.05
NO_2^- (mg/l)	< 0.02 ± 0.0	< 0.02 ± 0.0
Cl- (mg/l)	750.3 ± 170.6	549.5 ± 3.5
F- (mg/l)	3.3 ± 0.2	4.6 ± 0.02
SO_4^{-2} (mg/l)	225.5 ± 42.4	204.0 ± 2.0
PO_4^{-3} (mg/l)	0.3 ± 0.0	< 0.1 ± 0.0
CO_3^{-2} (mg/l)	7.9 ± 1.4	12.2 ± 0.2
HCO_3^- (mg/l)	148.2 ± 4.5	145.2 ± 12.2
Na (mg/l)	304.2 ± 88.6	312.1 ± 1.1
K (mg/l)	6.0 ± 1.2	2.1 ± 0.01
Ca (mg/l)	155.9 ± 18.5	86.2 ± 0.1
Mg (mg/l)	92.1 ± 7.8	69.4 ± 0.07
Mn (ppb)	< 0.06 ± 0.0	4.4 ± 0.02
Cu (ppb)	< 0.7 ± 0.0	< 0.7 ± 0.0
Zn (ppb)	540.6 ± 305.3	303.7 ± 90.0
Mo (ppb)	2.8 ± 0.5	1.6 ± 0.03

The barley started sprouting at day three. However, the sprouts were only long enough to take measurements from day six without disturbing the seeds. Barley sprouts produced using the liquid fertilizers were found to be taller than those produced with the other water sources. However, early during sprout growth, the municipal water generally resulted in faster growth and taller sprouts. The taller sprouts produced towards the end of the growth period when grown with the fertilizers could be explained by the foliar uptake of larger quantities of mineral nutrients once the sprouts have established. This can be explained by the fact that seeds generally do not need externally applied mineral nutrients to germinate. They use internal storage reserves, and only after depletion are external sources of mineral nutrients required for the growth of the seedlings. The rapid increase in growth from day 9 to day 10 in plants that were watered using the liquid fertilizer can be explained

by the uptake of essential mineral nutrients once the seedlings have exhausted their internal reserves. Although the fertilizer applications resulted in larger sprouts, the sprouts produced using the liquid fertilizer had the lowest dry mass production. The rapid increase in growth could thus not only be explained by the addition of mineral nutrients but also due to the rapid increase in water uptake and storage, which resulted in a large amount of water stored per gram of dry material (Table 2.4). In all instances, there was a significant loss of dry matter content from seed to sprouts. Sprouts that were watered using deionised water had the lowest losses in dry matter, followed by sprouts watered with municipal and borehole water, while sprouts watered with the liquid fertiliser had the highest loss in dry matter from seeds to sprouts (Table 2.4). As mentioned above, the loss in dry mass is a significant finding as all nutritional requirements for livestock are calculated on a dry matter basis.



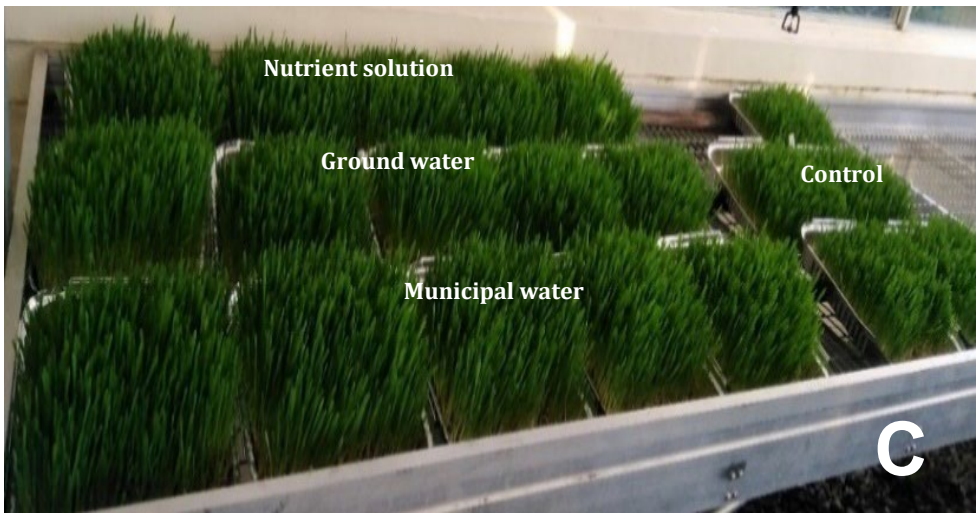


Figure 2.2 A, B & C: Illustration of the impact of different water sources on the production potential and of hydroponically grown barley fodder.

No differences were observed in the fiber content and digestibility of the barley sprouts produced using the different water sources (Table 2.5). Fibre adds bulk to livestock diets and is necessary for proper rumen function (Spencer 2018). The rumen of sheep and goat's functions best when the daily diet includes a high concentration of slowly degradable fibres (Spencer 2018). However, high fibre content decreases forage digestibility and intake, which could lead to deficiencies in protein, energy and mineral nutrients (Reinhard 2008; McDonald et al. 2010). The barley sprouts produced in this study contained low fibre content, especially ADF content. ADF is a measure of the plant components in forages that are the least digestible by livestock, e.g., cellulose and lignin. Due to this low ADF content, the sprouts produced can be regarded as highly digestible. When considering crude protein content, significantly higher crude protein contents were found in sprouts produced using the liquid fertilizer. In all instances and using any of the water sources, the CP content was high enough to maintain highly productive livestock herds which has a CP requirement of 13% – 14% (Meissner et al. 2000).

The different water sources used to irrigate the barley sprouts did not lead to significant differences in the energy content of the barley sprouts (Table 2.6; Figure 2.2). Because the ADF content in the sprouts is so low, the energy content of the sprouts is generally high. The metabolizable energy content of the barley sprouts ranged between 11.84 MJ/kg DM and 12.26 MJ/kg DM. Therefore, the barley sprouts, irrespective of the water source used for irrigation, had a ME content that is sufficient to meet the energy requirements of lambs up to 20 kg (3.9–10.5 MJ/kg DM) as well as 40–60 kg dry ewes (7.6–10.2 MJ/kg DM) (Meissner et al. 2000). However, the energy content of the barley sprouts, irrespective of the water source used for irrigation, was found to be insufficient to sustain pregnant

(14.5–17.7 MJ/kg DM) and lactating (15.5–19.4 MJ/kg DM) ewes (Meissner et al. 2000). In comparison to the nutritional quality of the natural veld, barley sprouts generally were of higher energy content. This is especially important when considering the net energy for lactation for ewes and the net energy for growth of lambs, which are the target periods for the fodder flow programme.

Sprouts produced from all water sources used contained sufficient concentrations of P, K, Mg, Fe, Zn, and Mn to meet the minimum requirements for livestock (Meissner et al. 2000) (Table 2.7). Cu concentrations were not high enough in the sprouts to maintain livestock condition, irrespective of the water sources used. However, the minimum requirement is 5 mg/kg of feed and the sprouts produced using the liquid fertilizer contained 4.4 mg/kg on the 10th day of growth. Ca concentrations were only sufficiently high in sprouts grown using the liquid fertilizer, although sprouts produced from the borehole and municipal water sources contained 1.6 mg/kg Cu, which is 0.2 mg/kg less than the minimum requirement levels for maintaining livestock condition. Na concentrations in sprouts produced using the municipal water and liquid fertilizers were below the required levels 400 – 1800 mg/kg, while the sprouts produced from the municipal and borehole water were higher than the levels required to maintain livestock condition. These concentrations, however, were within the tolerable levels of 5000 – 7000 mg/kg. During the 2015 – 2019 drought in Steinkopf, it was found that Zn concentrations in more than half of the plants consumed by livestock are below the recommended levels of 20 – 50 mg/kg, with concentrations as low as 5 mg/kg in certain of the key species grazed/browsed by the livestock. Therefore, the Zn concentrations found in the hydroponically grown fodders could reduce potential zinc deficiencies in livestock, especially during periods of drought.

2.4 CONCLUSION

The results of these experiments highlight the potential of hydroponic fodder production as a viable supplementary feed source for smallholder and communal farmers in water-limited agro-ecological areas. All five species evaluated in Experiment 1 successfully sprouted by day three, with measurable growth from day six onward. However, barley and oats showed high growth performance, with barley producing the highest fresh mass yields. However, barley also showed the highest dry matter loss, which could limit its nutritional efficiency when considered on a dry matter basis, a critical factor for livestock feed formulation. In terms of nutritional quality, all fodder species met the minimum crude protein (CP) and phosphorus (P) requirements for maintaining livestock condition, with only barley and wheat meeting the higher CP requirements for highly productive herds. While deficiencies in calcium, sodium, and copper were observed across most species, these are unlikely to impact livestock health significantly due to their supplementation from natural veld forages.

Experiment 2 demonstrated that the use of different water sources has an impact on sprout morphology, dry matter content, and nutrient composition of barley fodder. Liquid fertilizer resulted in the tallest sprouts but also the highest dry matter losses, suggesting that growth was driven more by water uptake than nutrient accumulation. Despite this, sprouts from all water treatments maintained sufficiently high CP and metabolizable energy (ME) levels to meet the requirements of growing lambs and dry ewes. The water sources from Namaqualand, either borehole water or water from municipal taps, could be a good irrigation source and do not impact the quality of the feed produced. This is a significant finding, as many farmers in Namaqualand rely solely on groundwater for both livestock and minimal crop irrigation. Also, the crude protein content of the fodders produced using the Namaqualand water sources is still sufficient to support the nutritional needs of highly productive livestock herds and will be extremely valuable to the resource poor farmers. Also, given that the inclusion of the fertilizer would increase production costs and considering the resource constraints of many farming households, therefore, removing the fertilizer offers a more economically feasible approach.

Overall, hydroponically grown barley and other fodder species show promise as a nutrient-dense, fast-growing supplement to rangeland grazing systems. Importantly, they can help address the common nutritional gaps observed in Namaqualand, particularly in terms of crude protein, phosphorus, and zinc. With correct inclusion into livestock existing fodder flow programmes, hydroponic fodders can improve animal health and productivity, especially during periods of feed scarcity or drought.

Table 2.4: Differences in growth and morphology of barley hydroponic fodders grown with different water sources.

	Sprout Height (cm) Day 5	Sprout Height (cm) Day 6	Sprout Height (cm) Day 7	Sprout Height (cm) Day 8	Sprout Height (cm) Day 9	Final Sprout Height (cm)	Fresh Mass (g)	Dry Mass (g)	Water Content (g/g DM)	% Loss in DM from seed to sprouts
Deionised Water	1.80 ± 0.18^{b}	2.48 ± 0.25^{a}	5.83 ± 0.28^{a}	6.97 ± 0.45^{a}	9.53 ± 0.23^{b}	11.60 ± 0.45^{a}	956.0 ± 20.92^{a}	147.6 ± 1.81^{c}	5.48 ± 0.18^{a}	37.98 ± 0.76^{a}
Borehole Water	1.85 ± 0.04^{b}	3.53 ± 0.28^{b}	4.95 ± 0.26^{a}	6.20 ± 0.39^{a}	8.30 ± 0.39^{a}	14.27 ± 0.12^{b}	1264.8 ± 36.51^{b}	141.4 ± 1.77^{b}	7.96 ± 0.33^{b}	40.59 ± 0.74^{a}
Municipal Water	2.37 ± 0.15^{c}	5.31 ± 0.31^{c}	6.31 ± 0.61^{a}	7.33 ± 0.20^{a}	12.47 ± 0.52^{c}	14.13 ± 0.20^{b}	1404.0 ± 138.08^{b}	142.7 ± 1.60^{b}	8.84 ± 0.95^{b}	40.04 ± 0.67^{a}
Liquid Fertilizer	1.40 ± 0.07^{a}	3.31 ± 0.22^{ab}	6.00 ± 0.29^{a}	7.97 ± 0.53^{a}	8.90 ± 0.32^{ab}	16.80 ± 0.90^{c}	1360.3 ± 35.39^{b}	134.2 ± 4.03^{a}	9.18 ± 0.48^{c}	43.61 ± 1.69^{b}
Significance	$F_{(3,20)}$ = 10.27, p = 0.001	$F_{(3,20)}$ = 19.60, p < 0.001	$F_{(3,20)}$ = 2.27, p = 0.119	$F_{(3,20)}$ = 3.23, p = 0.050	$F_{(3,20)}$ = 23.57, p < 0.001	$F_{(3,20)}$ = 16.74, p < 0.001	$F_{(3,20)}$ = 7.39, p = 0.003	$F_{(3,20)}$ = 4.86, p = 0.014	$F_{(3,20)}$ = 8.83, p = 0.001	$F_{(3,20)}$ = 4.86, p = 0.014

Table 2.5: Protein content and digestibility of barley hydroponic fodders grown with different water sources.

	CP (%)	ADF (%)	NDF (%)	DDM (%)	TDN (%)	DOM (%)
Distilled Water	14.18 ± 0.2^{a}	17.1 ± 0.4^{a}	42.1 ± 3.0^{a}	75.6 ± 0.3^{a}	75.9 ± 0.3^{a}	72.28 ± 0.3^{a}
Borehole Water	14.38 ± 1.4^{a}	17.6 ± 0.6^{a}	41.8 ± 1.8^{a}	75.2 ± 0.5^{a}	75.5 ± 0.4^{a}	71.94 ± 0.4^{a}
Municipal Water	14.96 ± 0.6^{a}	18.3 ± 0.7^{a}	43.9 ± 1.6^{a}	74.7 ± 0.6^{a}	75.1 ± 0.5^{a}	71.49 ± 0.5^{a}
Liquid Fertilizer	18.75 ± 0.8^{b}	20.4 ± 1.4^{a}	48.2 ± 2.1^{a}	73.0 ± 1.1^{a}	73.6 ± 1.0^{a}	70.08 ± 1.0^{a}
Significance	$F_{(3,20)}$ = 6.02, p = 0.006	$F_{(3,20)}$ = 2.67, p = 0.082	$F_{(3,20)}$ = 1.83, p = 0.183	$F_{(3,20)}$ = 2.67, p = 0.083	$F_{(3,20)}$ = 2.67, p = 0.083	$F_{(3,20)}$ = 2.68, p = 0.082
Dry Season Veld	4.8 ± 0.3	41.5 ± 1.7	48.5 ± 1.9	56.8 ± 1.3	62.4 ± 1.5	59.4 ± 1.4
Wet Season Veld	6.9 ± 0.4	37.5 ± 1.2	45.8 ± 1.5	59.7 ± 1.0	63.2 ± 1.1	60.2 ± 1.1

Table 2.6: Energy content of barley hydroponic fodders grown with different water sources.

	DFE (Mcal kg^{-1} DM)	ME (Mcal kg^{-1} DM)	NE_L (Mcal kg^{-1} DM)	NE_M (Mcal kg^{-1} DM)	NE_G (Mcal kg^{-1} DM)
Distilled Water	3.35 ± 0.01^{a}	2.93 ± 0.01^{a}	0.84 ± 0.01^{a}	6.44 ± 0.03^{a}	2.46 ± 0.02^{a}
Borehole Water	3.33 ± 0.02^{a}	2.91 ± 0.02^{a}	0.83 ± 0.01^{a}	6.41 ± 0.04^{a}	2.44 ± 0.02^{a}
Municipal Water	3.31 ± 0.02^{a}	2.89 ± 0.02^{a}	0.83 ± 0.01^{a}	6.36 ± 0.05^{a}	2.42 ± 0.02^{a}
Liquid Fertilizer	3.24 ± 0.04^{a}	2.83 ± 0.05^{a}	0.80 ± 0.02^{a}	6.21 ± 0.10^{a}	2.35 ± 0.05^{a}
Significance	$F_{(3,20)} = 2.79$, $p = 0.074$	$F_{(3,20)} = 2.68$, $p = 0.082$	$F_{(3,20)} = 2.87$, $p = 0.069$	$F_{(3,20)} = 2.73$, $p = 0.078$	$F_{(3,20)} = 2.46$, $p = 0.100$
Dry Season Veld	2.8 ± 0.06	2.3 ± 0.07	0.6 ± 0.03	5.1 ± 0.1	1.8 ± 0.07
Wet Season Veld	2.8 ± 0.05	2.4 ± 0.05	0.6 ± 0.02	5.2 ± 0.1	1.8 ± 0.05

Table 2.7: Mineral nutrient content in barley hydroponic fodders grown with different water sources.

	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)
Distilled Water	0.42 ± 0.01^{a}	0.57 ± 0.02^{a}	0.05 ± 0.002^{a}	0.15 ± 0.002^{a}	227.2 ± 12.2^{a}	79.41 ± 3.7^{a}	1.62 ± 0.3^{a}	23.57 ± 1.0^{a}	16.32 ± 0.3^{a}
Borehole Water	0.50 ± 0.02^{b}	0.60 ± 0.03^{a}	0.16 ± 0.009^{b}	0.26 ± 0.013^{bc}	3876.8 ± 320.2^{b}	89.07 ± 4.4^{a}	3.79 ± 0.2^{b}	29.22 ± 0.2^{b}	18.35 ± 0.6^{b}
Municipal Water	0.49 ± 0.02^{b}	0.63 ± 0.03^{a}	0.16 ± 0.008^{b}	0.24 ± 0.008^{b}	4035.4 ± 246.2^{b}	94.39 ± 8.6^{a}	3.79 ± 0.1^{b}	31.69 ± 2.0^{bc}	16.53 ± 0.5^{a}
Liquid Fertilizer	0.67 ± 0.02^{c}	1.46 ± 0.03^{b}	0.31 ± 0.018^{c}	0.27 ± 0.009^{c}	287.4 ± 62.7^{a}	244.54 ± 19.7^{b}	4.39 ± 0.1^{c}	33.31 ± 1.4^{c}	36.70 ± 1.0^{c}
Significance	$F_{(3,20)} = 46.03$, $p < 0.001$	$F_{(3,20)} = 235.4$, $p < 0.001$	$F_{(3,20)} = 96.90$, $p < 0.001$	$F_{(3,20)} = 34.17$, $p < 0.001$	$F_{(3,20)} = 109.20$, $p < 0.001$	$F_{(3,20)} = 50.18$, $p < 0.001$	$F_{(3,20)} = 51.30$, $p < 0.001$	$F_{(3,20)} = 10.56$, $p < 0.001$	$F_{(3,20)} = 230.6$, $p < 0.001$
Dry Season Veld	0.07 ± 0.006								
Wet Season Veld	0.10 ± 0.001								

CHAPTER 3: DETERMINING THE GROWTH POTENTIAL AND WATER USE EFFICIENCY OF PLASTIC VS NET COVERED STRUCTURES

3.1 INTRODUCTION

It was noted that small-scale farmers in the drought prone agro-ecological areas of Namaqualand in the Northern Cape Province of South Africa, especially during the dry seasons, often have to deal with severely reduced livestock productivity due to a lack of good quality and nutritious feed for the livestock (Samuels et al. 2016, Müller et al. 2019, Schroeder et al. 2020). In most of these water-limited areas, planting fodders for use during the dry season as supplementary feed is not possible due to the increase in rainfall variability and a reduction in the overall amount of rainfall in the wet season. This, in turn, does not allow for productive fodder stands and often leads to reduced livestock productivity and in severe cases, during drought conditions, significant livestock mortality largely as a result of the insufficient quantities of good quality feed for the livestock. This, in turn, negatively affects the socio-economic and cultural standing of farmers in communities that are already primarily living below the poverty line (Ntombela 2017). This chapter compares the water consumption efficiency and growth potential of agricultural structures covered with a net with those covered with plastic. Although both kinds of structures offer protection against adverse weather conditions and pests, they have rather different effects on plant growth and water management. Although plastic structures offer a better-regulated microclimate, which frequently speeds up growth and extends growing seasons, they can also result in higher water use because of decreased air circulation (Hanan 1999). On the other hand, net-covered structures promote natural cooling and improved air flow, which may increase water efficiency but at the expense of growth conditions, particularly in extreme weather (Kacira et al. 2000). Therefore, understanding the differences is important when it comes to selecting the most suitable structure based on the environmental factors, crop needs and available resources.

3.2 MATERIALS AND METHODS

A trial was established in June 2024 where a comparison was made on the growth potential and water use efficiency of barley sprouts grown in a plastic covered structure (6.5 mm thick, 200 micron UV-resistant clear greenhouse plastic) versus a net-covered structure (40% shade net). In each structure type, 6 replicates of 220 g dry barley seeds were soaked in water for 24 hours before planting in plastic trays. During this time, the sprouts were watered four times a day (07:30, 10:30, 13:30 and

16:30) with 400 ml of water and at each watering, the corresponding temperature in the structure was recorded. The trays containing the seeds were placed in a second tray, which allowed us to capture the excess water running from the trays. At each watering, the amount of water used (TWU) in the trays and the amount of water running out of the trays were quantified using equation 1. The sprouts were allowed to grow until a complete mat was formed, noting the daily seedling heights, leaf width and fresh mass at the end of the period. The trays were harvested at the end of the trial and after fresh mass (FM) determination, the plant material was oven dried until a constant mass was achieved (DM). These results were thereafter used to calculate the relative water content (RWC), which was expressed as grams of water per gram of dry mass. At the end of the trial, the total water used was calculated as the sum of water given minus the water running out of the trays over the trial period. This was used as a means to calculate the water use efficiency of the sprouts grown in the different structures using equation 3.

Equation 1: TWU (ml/tray) = Total fresh water added to the tray (ml) – Total water drained from the tray (ml)

Equation 2: RWC (g/g DM) = [FM (g) – DM (g)] ÷ DM (g)

Equation 3: WUE (g/ml) = FM (g) ÷ total water used (ml)

The results obtained were statistically analyzed in SPSS v. 21 using an independent sample t-test to determine whether any significant differences ($p < 0.05$) were observed between sprouts grown in the plastic and net covered structures.

3.3 RESULTS AND DISCUSSION

In the summer rainfall areas of Namaqualand, various issues during the dry season could impede the success of the fodder flow programme, especially when the goal is to use low-cost hydroponic feed production systems where temperature and humidity cannot be controlled. For instance, the dry season within summer rainfall areas falls within the cold winter months and with temperature being the major determinant of seed germination rate, this could significantly influence the time in which these fodders are produced as well as the biomass produced. This means that the correct structures for these conditions should be identified to maximize growth and production. Results from the current trial indicated that temperature in the two structures (Figure 3.1) did not differ in the mornings (7:30) or late afternoons (16:30). However, it was clear that the net covered structures warmed up faster than the plastic covered structures later in the mornings ($t(1,12) = 2.357$, $p = 0.025$) but as the day progressed, the plastic covered structures were warmer ($t(1,12) = 2.101$, $p = 0.044$). This may be due

to the fact that as the morning temperatures increased, the net structures allowed for warmer air to come into the structure while in the plastic structure, as the day time temperatures increased, the structure was able to maintain heat better, compared to the net covered structure which allows for air to freely flow through the structure.

When considering the growth of the sprouts in winter in these two structures it was clear that at the end of the experimental period, the plastic covered structures produced significantly more biomass, both as fresh mass (Figure 3.2: $t_{(1,12)} = 2.463$, $p = 0.035$) and dry mass (Figure 3.3: $t_{(1,12)} = 2.337$, $p = 0.001$). However, there was a significantly greater ($t_{(1,12)} = 4.337$, $p = 0.001$) loss in dry matter content from seeds to sprout in the net covered structures (Figure 3.4), even though the total biomass produced was less.

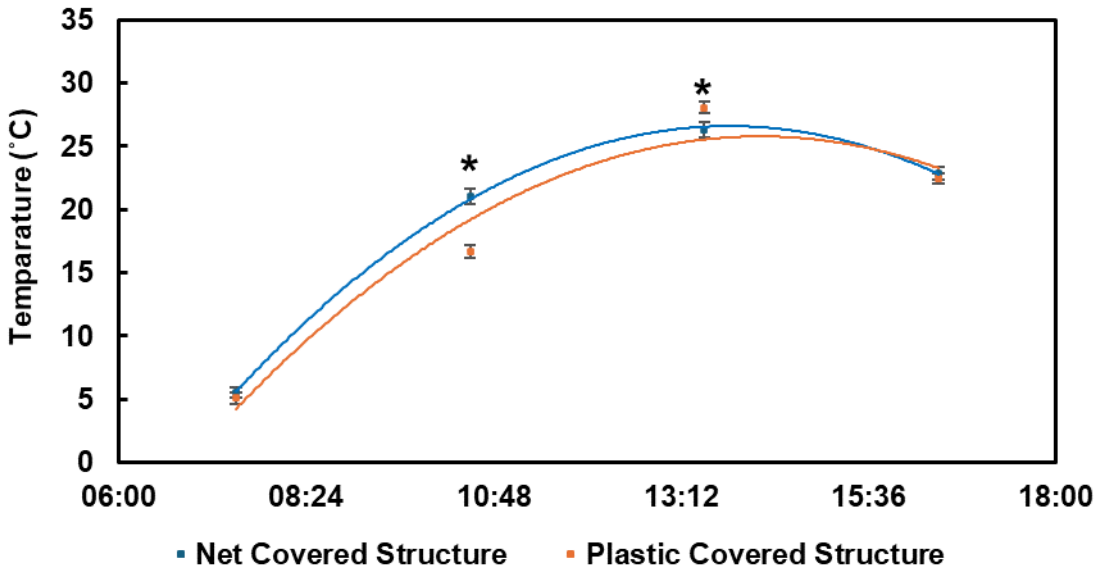


Figure 3.1: Changes in temperatures in plastic vs net covered structures. * indicates significant differences in the temperatures between plastic and net covered structures.

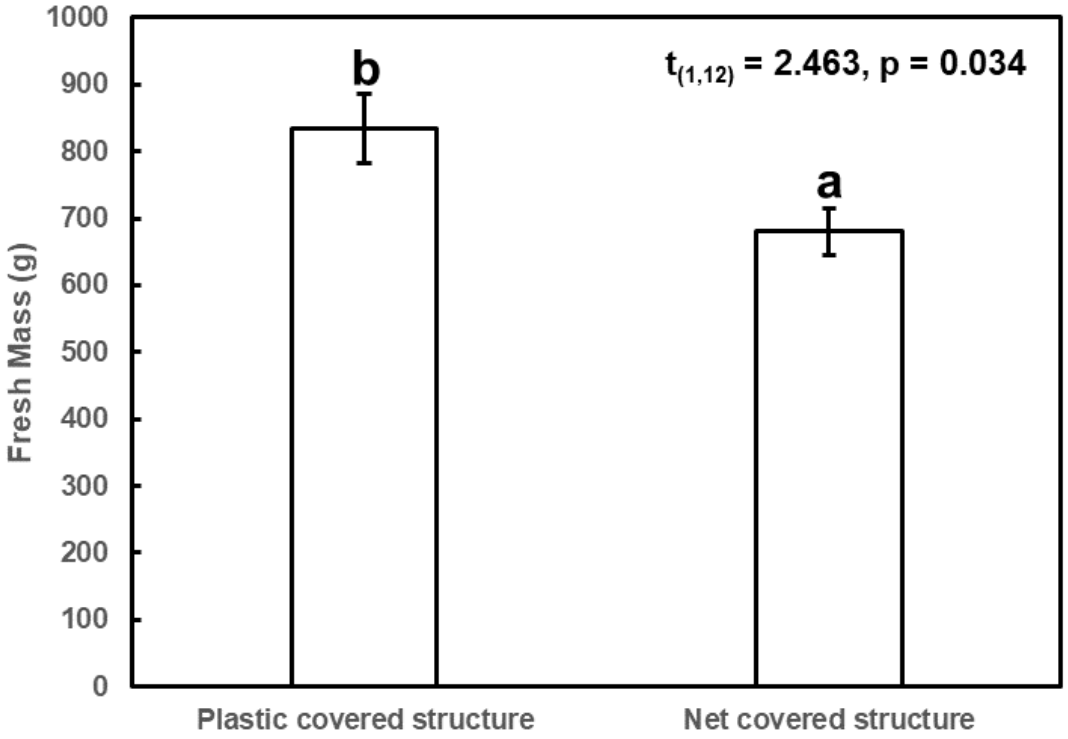


Figure 3.2: Hydroponically produced sprout fresh mass (g) in plastic and net covered structures. Significant differences ($p < 0.05$) in sprout mass between plastic and net covered structures are indicated by different lower case letters.

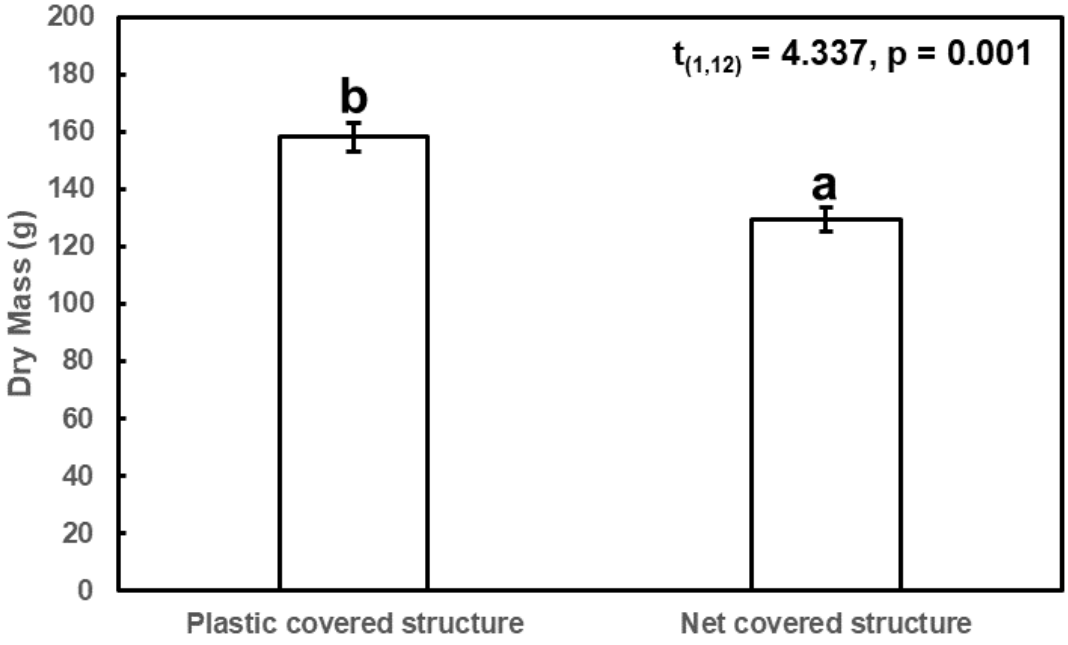


Figure 3.3: Hydroponically produced sprout dry mass (g) in plastic and net covered structures. Significant differences ($p < 0.05$) in sprout mass between plastic and net covered structures are indicated by different lower case letters.

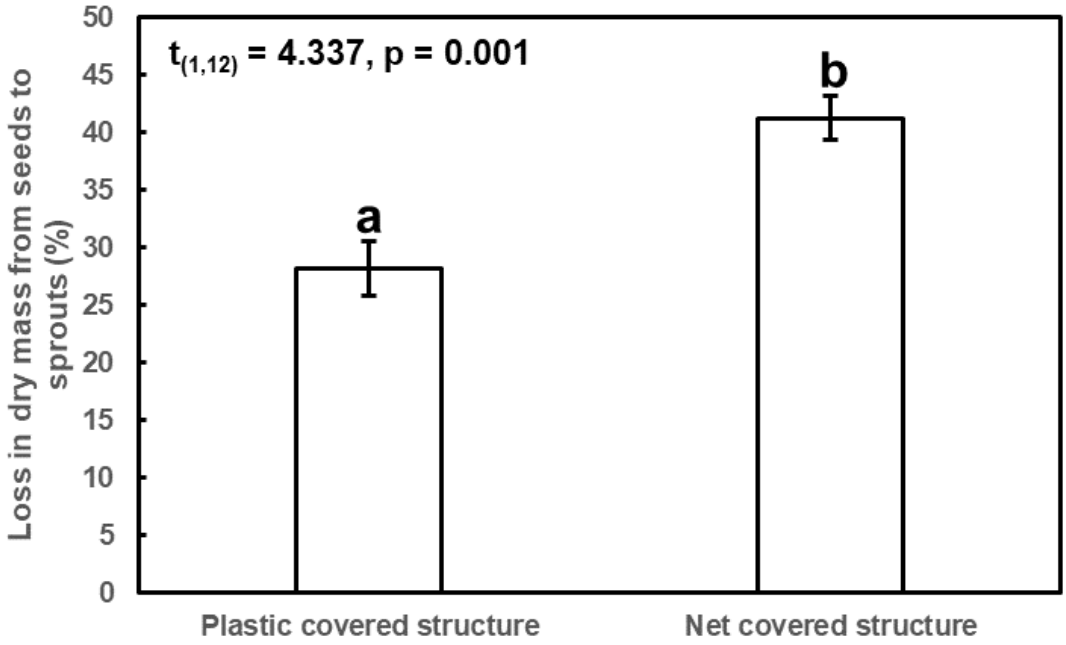


Figure 3.4: Loss in dry mass (%) from seed to sprout in plastic and net covered structures. Significant differences ($p < 0.05$) in the percentage loss of dry mass between plastic and net covered structures are indicated by different lower case letters.

Furthermore, the plastic covered structures also produced longer sprouts (Figure 3.5: $t_{(1,12)} = 7.047$, $p < 0.001$) than the sprouts produced in the plastic covered structures. This was a trend that was observed throughout the trial period (Figure 3.6). However, even though the biomass produced and sprout height in the plastic covered structures were significantly higher than in the net covered structures, the leaf width (Figure 3.7) of the sprouts produced in the net covered structures were significantly more than those of the sprouts grown in the plastic covered structures ($t_{(1,12)} = 2.290$, $p = 0.004$). This may be due to the net covered structures allowing more light to penetrate the structure, which meant that sprouts did not have to grow longer to access better light. When considering the water used (Figure 3.8) to produce these sprouts, no differences in water use were observed between the plastic and net covered structures ($t_{(1,12)} = 1.864$, $p = 0.094$). No differences were also found in the moisture content of the sprouts produced ($t_{(1,12)} = 1.174$, $p = 0.865$) between the net and plastic covered structures (Figure 3.9).

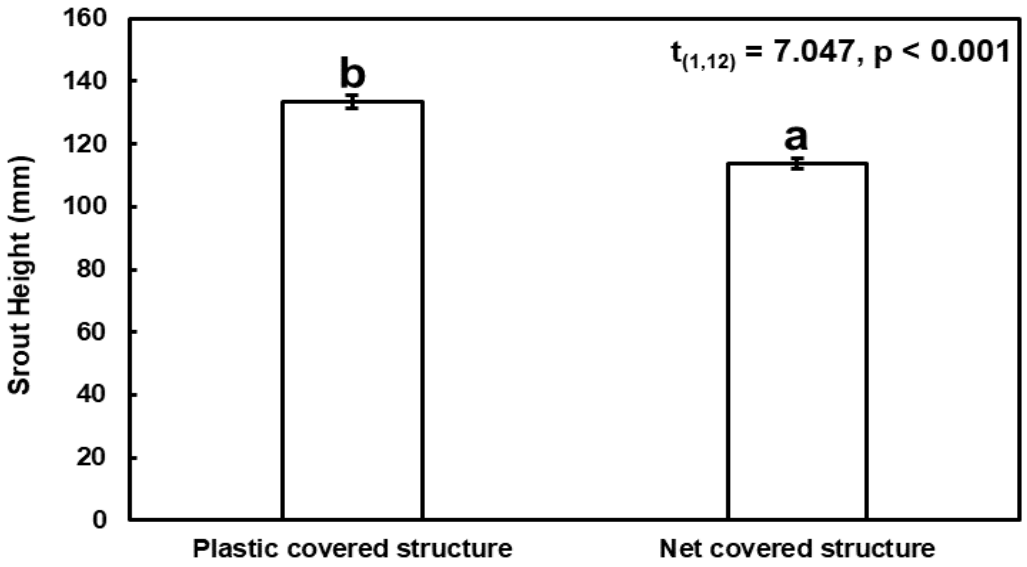


Figure 3.5: Hydroponically produced sprout height (mm) in plastic and net covered structures. Significant differences ($p < 0.05$) in height between plastic and net covered structures are indicated by different lower case letters.

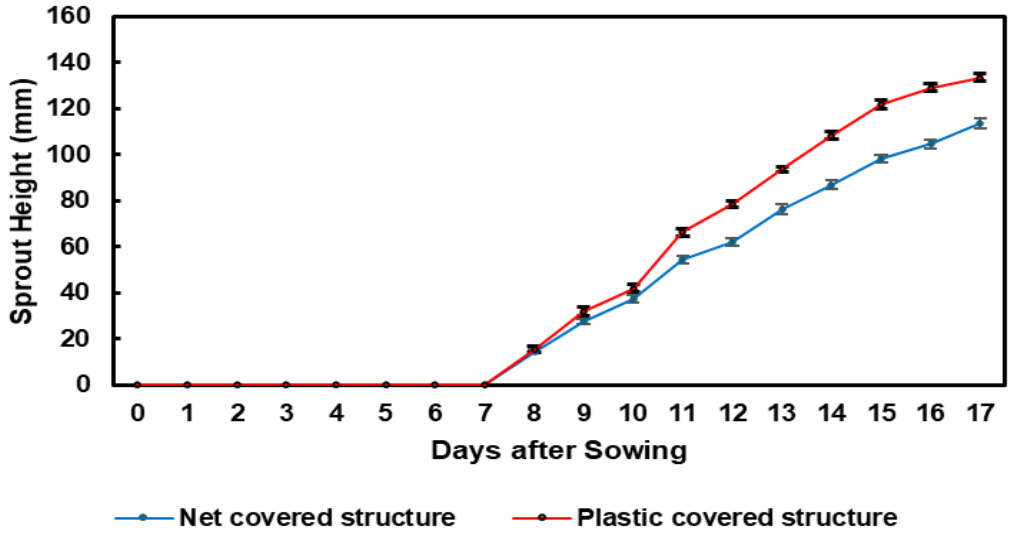


Figure 3.6: Growth (mm) of hydroponically produced sprout height in plastic and net covered structures.

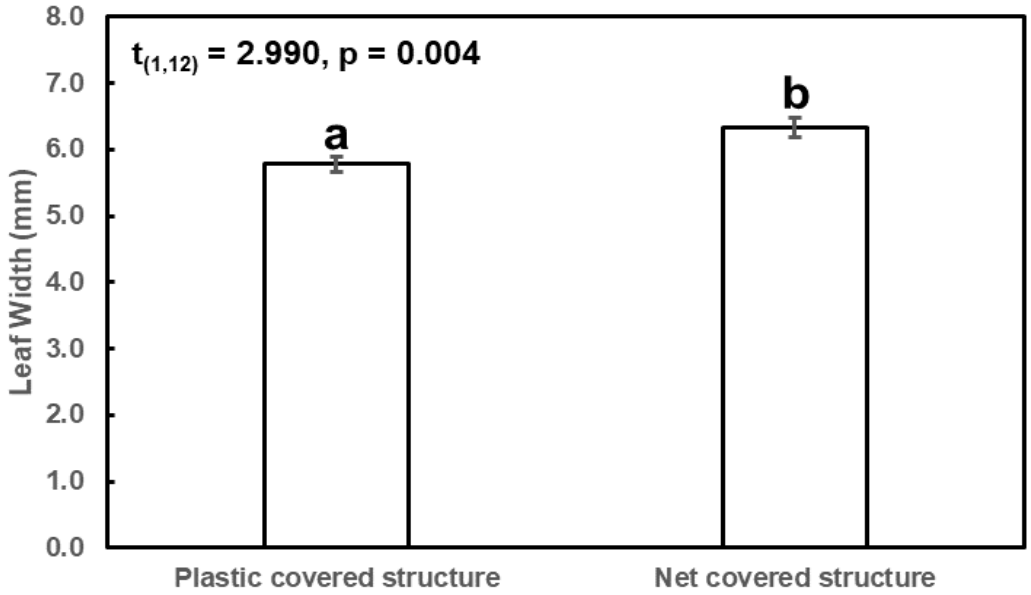


Figure 3.7: Leaf width (mm) of hydroponically produced sprout in plastic and net covered structures. Significant differences ($p < 0.05$) in leaf width between plastic and net covered structures are indicated by different lower case letters.

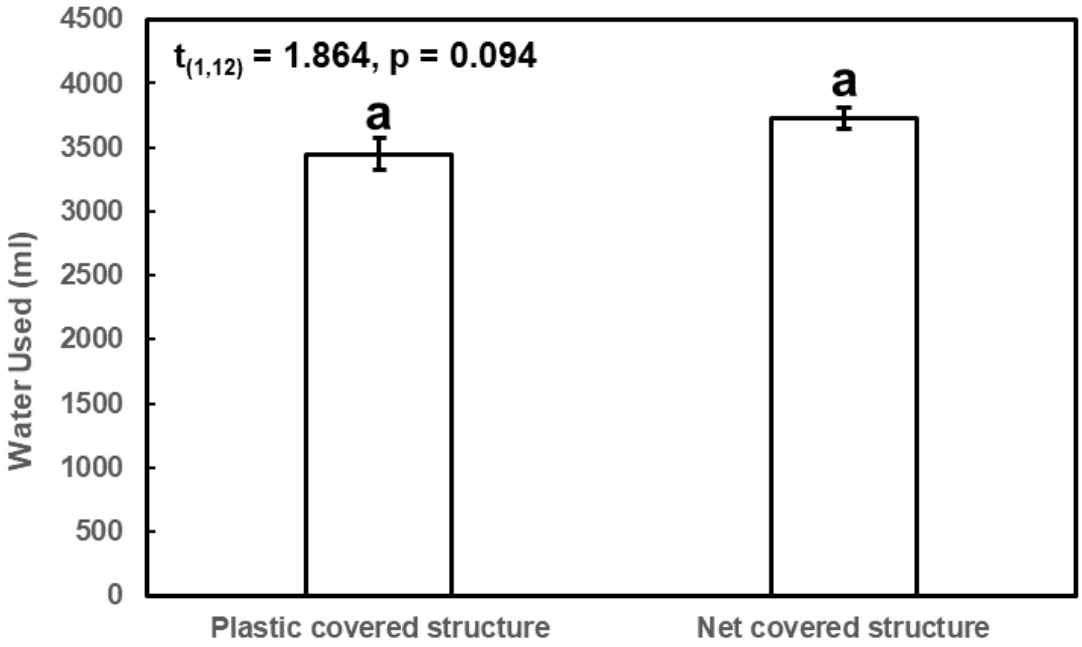


Figure 3.8: Water used (ml) for sprout production in plastic and net covered structures. Significant differences ($p < 0.05$) in water use between plastic and net covered structures are indicated by different lower case letters.

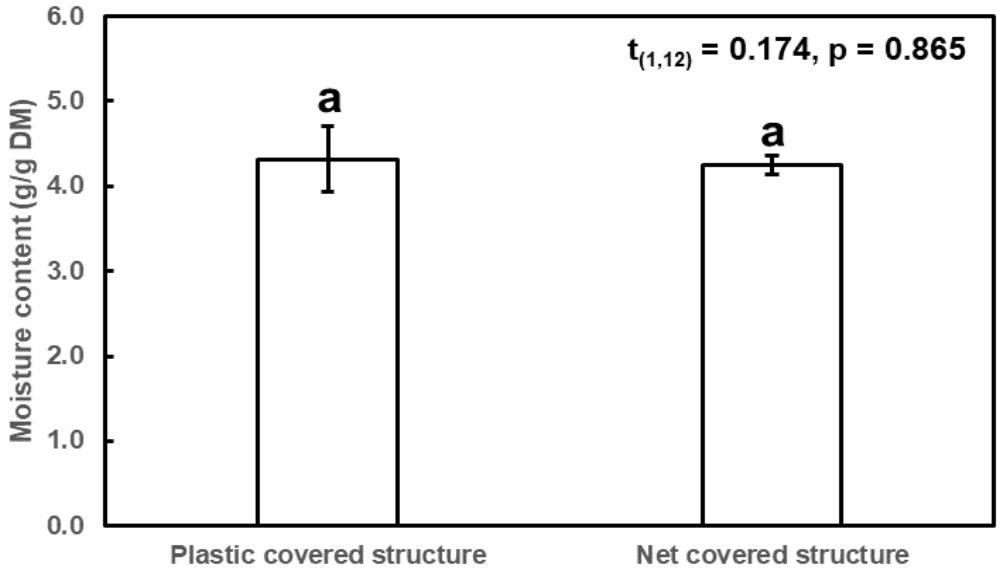


Figure 3.9: Moisture content (g/g DM) of sprout production in plastic and net covered structures. Significant differences ($p < 0.05$) in water use efficiency between plastic and net covered structures are indicated by different lower case letters.

At the end of the trial, the water use efficiency of the sprouts grown in the plastic vs net covered structures were determined (Figure 3.10). The results from the current study show that the sprouts produced in the plastic covered structure were more water use efficient compared to those grown in the net covered structure ($t(1,12) = 4.781$, $p < 0.001$).

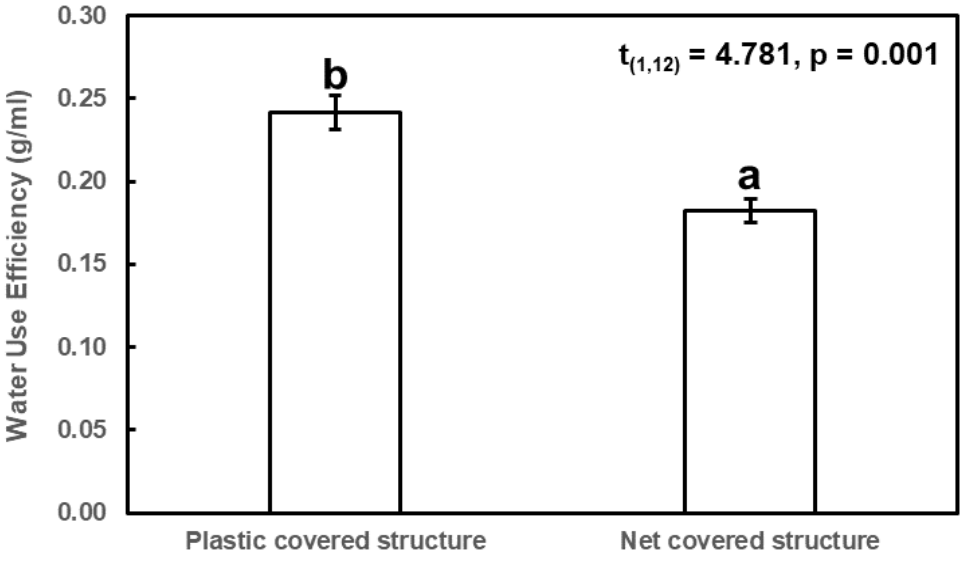


Figure 3.10: Water Use Efficiency (g/ml) of sprout production in plastic and net covered structures. Significant differences ($p < 0.05$) in water use efficiency between plastic and net covered structures are indicated by different lower case letters.

3.4 CONCLUSION

This study aimed to evaluate the effects of plastic-covered and net-covered structures on the growth performance and WUE of hydroponically grown barley fodder in an uncontrolled environment. This is to determine the best suitable structure (a net covered structure vs a plastic covered structure) to use in a hydroponic fodder flow program in the cold winter months and hot summer months of the Namaqualand region. The results showed that hydroponic fodder can be grown successfully in both winter and summer seasons. With plastic-covered structures are indicated to be more effective in terms of yield, dry mass, and water use efficiency compared to net-covered structures. The plastic structures provided better temperature regulation, which enhanced growth during the colder winter months. Furthermore, the study highlighted the water-saving potential of hydroponic systems, offering a sustainable solution for livestock feed production during dry seasons when water resources are limited. These findings highlighted the importance of hydroponic systems in maximizing resource efficiency and enhancing the availability of fodder in regions with limited water resources.

CHAPTER 4: THE NUTRITIVE VALUE AND QUALITY OF FORAGE PLANT SPECIES CONSUMED BY LIVESTOCK IN DIFFERENT SEASONS IN THE SEMI-ARID RANGELAND OF NAMAQUALAND, SOUTH AFRICA

4.1 INTRODUCTION

Livestock plays a crucial role in the sociocultural, economic, and nutritional well-being of people, households, and communities as it provides meat, milk and other products (Samuels 2006; Koohafkan & Stewart 2008; Cooke et al. 2024). Forage plants are the primary source of nutrients for livestock and occur in rangelands, and for this reason, rangelands are considered one of the least expensive sources of feed for livestock (Njidda 2010; Ismail et al. 2014). From an environmental perspective, rangelands are important as they provide vegetation cover and soil protection, which guarantees the long-term economic viability of animal feed (Abdullah et al. 2013). However, rangelands are under climatic stresses due to extended dry seasons, reduced amount and frequency of rainfall and temperature extremes; and these result in significant variations in the quality and quantity of the feed (Amiri &Mohamed Shariff 2012; Abdullah et al. 2013; New 2015).

The rangelands of Namaqualand, South Africa, support a wide variety of forage plants that are essential in maintaining livestock productivity in the region. However, the nutritional content of the forages varies with each season, thus affecting the overall livestock production and health (Snyman 2014; Du Toit et al. 2015). Livestock have different requirements for these nutritive components and depending on their developmental stages and these change over time (Simpson et al. 2004). These livestock requirements are affected by the nutrient content, quality and the digestibility of the plant, where some plants differ in their palatability and have developed defensive or structural compounds that limit the amount of plant matter that can be consumed (Distel et al. 2005). Furthermore, these requirements are not all met due to the challenge of feed supply to livestock, thus causing deficiencies.

To address feed deficiencies, it is important to be familiar and understand the nutritional quality of forages in rangelands and how they change seasonally. This will assist in identifying forages and proposing supplementation that best suit the requirements of the animals at a specific time, ultimately resulting in optimal livestock performance. Especially, minerals that are both essential for the growth of livestock and plants in large quantities (Abdullah et al. 2013). Therefore, the study aimed to evaluate the seasonal variation in the nutritional quality of the forage plant species available during the wet and dry season in the summer and winter rainfall regions in the Steinkopf communal area of Namaqualand.

4.2 MATERIALS AND METHODS

4.2.1 STUDY AREA

Steinkopf communal is located in Namaqualand, a semi-arid region of South Africa. The dominant land use in the area is livestock farming, where farmers use the Nama and Succulent Karoo biomes to sustain their livestock's daily feed requirements. The Succulent Karoo receives winter rainfall, and the Nama Karoo receives summer rainfall. With an average of ±150 animals per herd, this communal rangeland has approximately 50 000 small stock animals (sheep and goats) and they all rely on the rangeland for feed (Schroeder et al. 2019). These animals are kept in stock posts overnight and released every morning to feed, this is to prevent stock theft and predation (Samuels 2013).

4.2.2 OBSERVATIONS AND FORAGE PLANT COLLECTION

Plant samples were collected from the Steinkopf Communal Area in the Namaqualand Region of South Africa from a study conducted by Schroeder et al. (2019). Goat and sheep herds were followed at different times of the day to observe the plants they consumed. A focal animal was identified to represent the entire herd and these changed at different time intervals. The plant species they consumed or avoided but were within 2 m on either side of the animal, were identified and recorded. The observations and collection of plant samples were done in the dry and wet season of 2016 – 2017. Not all plant species available during the wet season were available in the rangeland during the dry season.

4.2.3 CHEMICAL ANALYSIS

The dried samples were submitted for analyses to determine the mineral nutrient content (P, K, Mg, Ca, Na, Fe, Cu, Zn, Mn and Al) at the Western Cape Department of Agriculture, Land Reform and Rural Development labs at Elsenburg using the dry ashing procedure as followed by Enders and Lehmann (2012). Acid detergent fibres (ADF) in the fodder samples were determined according to Van Soest et al. (1991) method at the University of Pretoria Analytical Labs. Nitrogen content was determined by the Kjeldahl's method and was further used to determine the crude protein (CP) content by multiplying the nitrogen content with a factor of 6.25 while the ADF values obtained were used to calculate the digestible dry matter (DDM), metabolizable energy (ME), total digestible nutrients (TDN), digestible forage energy (DFE), digestible organic matter (DOM), net energy for lactation (NEL), net energy for maintenance (NEM) and net energy for gain/growth (NEG) using equations 1 – 9.

1. CP (%) = %N x 6.25 (Meissner 2000)
2. DDM (%) = 88.9 - (ADF × 0.779) (Rasby et al. 2008)
3. ME (Mcal/kg DM) = (1.01 x DFE) – 0.45 (Meissner et al. 2000)
4. TDN (%) = 87.84 - (0.7 × ADF) (Schroeder 2009)
5. DFE (Mcal/kg DM) = 0.04409 x TDN (Meissner et al. 2000)
6. DOM (%) = TDN ÷1.05 (Meissner et al. 2000)
7. NEL (Mcal/kg DM) = 1.044 - (0.0119 x %ADF) (Rasby et al. 2008)
8. NEM (Mcal/kg DM) = ((1.37 x ME) – (0.3042 x ME) + (0.051 x ME)) – 0.508 (Rasby et al. 2008)
9. NEG (Mcal/kg DM) = ((1.42 x ME) – (0.3836 x ME) + (0.0593 x ME)) – 0.7484 (Rasby et al. 2008)

4.3 RESULTS AND DISCUSSION

The aim of the study was to evaluate the impact of season on the nutritional quality of forage plants in the summer and winter rainfall regions of Namaqualand, South Africa. The results show that there is an interaction between each season and the species' nutritive values as observed Table 4.1. The crude protein concentrations of forage plants differed significantly ($p < 0.05$), with the wet season having the highest concentrations in each rainfall region. These results were similar to results published by Cooke et al. 2024 who reviewed the extent to which seasonality impacts ruminant production in Southern Africa and found prominent reductions of crude protein in grasses and browse species from the wet to dry season. While an exception for three browse species was recorded by Marius et al. (2021), where significant increases of at least 2.5 folds in crude protein from the wet season to the dry season were obtained. The reason for the increases is not clear; however, it is attributed to the sampling methodology. Literature has shown that growth and performance are generally improved by higher protein concentrations, while growth rates and lactation are impacted by eating less to un – palatable forage plant species which have reduced protein content (Ben Salem & Smith, 2008; Cooke et al. 2024)

4.3.1 DIGESTIBILITY AND ENERGY CONTENT

With regards to digestibility, significant differences ($p < 0.001$) were observed between the seasons and the hydroponically produced fodder. Within each region, there was an increase from the wet season to the dry season in terms of the Acid detergent fibre (ADF) (Table 4.2). The study's ADF values ranged between 43.1% – 45.1% in the wet season and 45.1% – 46.7% in the dry season, while the average ADF value of the hydroponically produced fodder was 13.8%. These results are similar

to the results published by Mahgoub et al. (2005) who observed ADF values to range between 35 – 50% in the semi-arid rangelands in Africa and Asia. Overall, the results suggest that the hydroponically produced fodder is the most digestible compared to the rangeland forages in with regions and seasons as forages with ADF values greater than 45% are categorized as low-quality forages (Ball et al. 2007). When considering dry matter, digestible dry matter (DDM) forages greater than 60% could be considered high-quality forages from an energy point of view (Reinhard 2008). Results from this study (Table 4.2) indicate no significant differences between the seasons, even though there was a reduction from the wet season (54.52%) to the dry season (53.27%). In terms of energy contents evaluated (DFE, ME, NE_L, NE_M and NE_G), significant differences *($p < 0.05$)* were observed between the seasons and the hydroponically produced fodder. Within the rainfall regions, there were reductions from the wet to the dry season. The metabolizable energy (ME) in the forages in the wet season (2.1 MJ/kg DM) and dry season (2.1 MJ/kg DM) as well as net energy for lactation (NE_L) values (0.5 and 0.5 MJ/kg DM in the wet season and dry season respectively) were insufficient to meet the energy requirements of lambs up to 20 kg (3.9 - 10.5 MJ/kg DM), 40 - 60 kg dry ewes (7.6 - 10.2 MJ/kg DM) as well as 40-60 kg lactating ewes (15.5 - 19.4 MJ/kg DM) (Meissner et al. 2000). The forage energy concentrations obtained are similar to the results obtained by Müller et al. (2021) and Ravhuhali et al. (2022) who observed a reduction in the concentrations from the wet to the dry season.

4.3.2 MINERAL NUTRIENT CONTENT

There were no significant differences in the mineral nutrients between the seasons even though some minerals had a different seasonal change in concentration (Table 4.1). Some minerals decreased from the wet to the dry season, such as K, Ca, Cu and P concentrations, while Zn, Fe, Mn and B concentrations were higher in the dry season. However, only Ca, Na, and Mn met the minimum nutritional requirements for livestock (Meissner et al. 2000). The reduction of P concentrations in the dry season is due to drought stress and is observed worldwide (He & Dijkstra, 2014). When conducting studies on Botswana and South Africa, Lukhele & Ryssen (2003); Moleele (1998) and Mthi et al. (2021) observed P concentrations to be below the recommended concentrations by NRC (2006) (0.15% DM) and this was due to the low concentration of P in the soil. Furthermore, this is worsened by the lack of rainfall in the dry season, which limits the movement of P in the soil and thus restricting its uptake by plants (Cooke et al. 2024).

4.4 CONCLUSION

The present study found that the concentrations of minerals in the Steinkopf communal rangeland were not significantly different between seasons. The reasons for the differences in the nutritive values between seasons in Steinkopf are unclear, but it could be because of the low minerals in the soils, spatial variation and climate factors (Cooke et al. 2024). Studies conducted by Scogings et al. (2015), Ophof et al. (2013) and Teka et al. (2012) who looked at the nutritional quality of forage plants in different seasons, have observed significant differences in P and N concentrations, changes in the quality and availability of forage plant species such as various dwarf shrubs and herbaceous plant species. The observed reduced and insufficient mineral concentrations in forage plants between the seasons raise the risks to livestock's overall health and sustainability. Therefore, it is necessary to address the challenge with various combinations of interventions, which may include but are not limited to drought management strategies, water conservation, and feed supplementation.

Table 4.1: The nutritive value of forage plants consumed by goats and sheep as affected by season.

Region	Season	Crude protein (%)	K (%)	Ca (%)	Mg (%)	Na (mg/kg)	Zn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	B (mg/kg)	Al (mg/kg)	P (%)
Winter Rainfall Region	Wet	7.6±0.6^{b}	1.7±0.2^{a}	1.7±0.4^{b}	0.5±0.1^{a}	10432.9±3244.7^{b}	26.3±3.9^{b}	313±86^{b}	5.3±0.4^{b}	237.4±75.2^{b}	22.5±1.5^{b}	206.6±31.8^{b}	0.1±0.01^{a}
	Dry	5.1±0.5^{a}	1.6±0.2^{a}	1.4±0.3^{b}	0.4±0.1^{a}	4349±1132.7^{b}	26.4±6^{b}	353±66^{b}	4.1±0.4^{b}	294.3±134^{b}	22.2±2.4^{b}	244.3±54.1^{b}	0.1±0.02^{a}
Summer Rainfall Region	Wet	6.7±0.5^{b}	1.4±0.2^{a}	2.1±0.5^{b}	0.4±0.1^{a}	14925.8±9050.5^{b}	9.3±0.9^{a}	296±73^{b}	4.1±0.5^{b}	106.2±49.9^{b}	22.3±2.8^{b}	181.9±40.3^{b}	0.1±0.01^{a}
	Dry	6.3±0.4^{ab}	1.3±0.1^{a}	2.1±0.4^{b}	0.3±0.05^{a}	13495.9±4519.3^{b}	16.3±2.4^{a}	379±77^{b}	4.6±0.4^{b}	117.4±36.8^{b}	27.3±6.6^{b}	311.3±49.6^{b}	0.1±0.01^{a}
Hydroponic Barley Sprouts		13.3±0.4^{c}	0.6±0.1^{a}	0.05±0^{a}	0.1±0^{a}	236.8±7.5^{a}	21±2.4^{ab}	53±5^{a}	0.8±0.3^{a}	15.1±0.6^{a}	1.3±0.05^{a}	18.5±1.7^{a}	0.4±0.01^{b}
F $_{(4,120)}$		8,633	1,613	13,079	0,981	13,669	4,205	14,265	3,758	25,931	14,511	19,681	21,798
p		< 0.001	0,176	0,011	0,421	0,008	0,003	0,006	0,007	< 0.001	0,006	0,001	< 0.001

Table 4.2: The digestibility and energy content of forage plant species during the dry and wet season.

Region	Season	ADF (%)	DDM (%)	TDN (%)	DFE (Mcal kg−1 DM)	ME (Mcal kg−1 DM)	DOM (%)	NEL (Mcal kg−1 DM)	NEM (Mcal kg−1 DM)	NEG (Mcal kg−1 DM)
Winter Rainfall Region	Wet	45.1±1.9b	53.8±1.5a	56.3±1.3a	2.5±0.06a	2.1±0.06a	53.6±1.3a	0.5±0.02a	4.5±0a	1.5±0.07a
	Dry	46.7±2.0b	55.5±2.5a	57.8±2.3a	2.6±0.1a	2.1±0.1a	55.1±2.2a	0.5±0.04a	4.7±0.2a	1.6±0.1a
Summer Rainfall Region	Wet	43.1±1.9b	55.3±1.5a	57.7±1.3a	2.5±0.06a	2.1±0.06a	54.9±1.3a	0.5±0.02a	4.7±0.1a	1.6±0.06a
	Dry	45.1±1.4b	54.8±1.4a	57.2±1.3a	2.5±0.06a	2.1±0.06a	54.5±1.2a	0.5±0.02a	4.6±0.1a	1.5±0.1a
Hydroponic Barley Sprouts		13.8±1.3a	78.2±1.1b	78.2±1b	3.4±0.04b	3±0.04b	74.5±0.9b	0.9±0.02b	6.7±0.1b	2.6±0.05b
F $_{(4,120)}$		9,914	6,553	6,555	6,579	6,598	6,551	6,577	6,573	6,557
p		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

CHAPTER 5: THE IMPACTS OF FEEDING HYDROPONIC FODDER TO SMALL STOCK ON LIVESTOCK CONDITION, GUT MICROBIOME AND METHANE EMISSION

5.1 INTRODUCTION

Livestock production plays a critical role in global food security and rural economies, but it also presents challenges related to feed availability, methane emissions, and gut microbiome health (Bodas et al. 2012). Ruminants, such as sheep and goats, have a unique digestive system with four compartments. The largest of these is the rumen, which can hold about 10 litres in sheep and goats. The rumen is a complex and dynamic environment filled with a variety of microbes – bacteria (10^{10}–10^{11}), archaea (10^{8}–10^{9}), protozoa (10^{5}–10^{6}), and fungi (10^{3}–10^{4} organisms/mL) – that play a key role in fermentation (Huws et al. 2018; Mamuad et al. 2019; Li et al. 2022). These microbes break down complex compounds like carbohydrates into volatile fatty acids (VFAs) such as acetate, propionate, and butyrate, which are the main sources of energy for the animal (Mamuad et al. 2019; Danielsson et al. 2017; Guo et al. 2020). Due to this microbial fermentation, ruminants can turn fibrous, inedible plant material into usable energy, supporting growth and production (Mamuad et al. 2019; Doi & Kosugi 2004; Ahmad et al. 2020; Geber et al. 2015). This fermentation, however, also produces enteric methane gas, a potent greenhouse gas. Methane is generated when archaea microbes in the rumen use CO_2 and H_2 as substrates during fermentation (Danielsson et al. 2017; Judy et al. 2019; Theil et al. 2019; Vargas et al. 2020; Roque et al. 2021). It is about 25 times more harmful than CO_2 for the environment and can account for up to 12% of the animal's gross energy loss (Sahebi et al. 2021; Bowen et al. 2020). While rumen microbes are usually stable, their populations can change depending on diet and feeding strategies (Zhou et al. 2017; Qui et al. 2019; Balanche et al. 2019). Therefore, managing the diet is key to reducing methane emissions while maintaining animal productivity.

This study explored the use of hydroponically grown barley fodder sprouts as a supplement in the diet of Meat master lambs. These sprouts are grown without soil, using only water or a nutrient solution, and are ready to feed within 7 to 10 days (Bekuma 2019). Hydroponic systems are ideal for arid and semi-arid regions where land and water are limited (Agius et al. 2019). They can produce up to 29 to 38.03 kg/m² of fresh fodder in about 8 days (Getachew et al. 2020). Although sprouts have a high moisture content (over 80%) and contain helpful enzymes and nutrients for rumen microbes, they should not be used as the sole feed due to their low dry matter content, typically less than 20% (Salo 2019; Farghaly et al. 2019). This study aimed to determine the effects of supplementing barley

sprouts on enteric methane emissions, rumen fermentation, and microbial composition in Meat master lambs. It was hypothesized that these sprouts would influence rumen activity and methane emissions.

5.2 MATERIALS AND METHODS

5.2.1 GROWING HYDROPONIC BARLEY SPROUTS FOR FEEDING

The study was conducted at Agricultural Research Council - Animal Production (ARC-AP) experimental farm in Irene. The study protocol in using animals during the experiment was approved by ARC- AP, Animal Ethics Committee (Ref APAEC 2019/15). Barley (*Hordeum vulgare L.)* seeds used for hydroponic fodder sprouts production were purchased from Barenbrug SA Seeds (Pty) Ltd. Cape Town, South Africa, with a germination rate of roughly 80% – 89%. A portion of the storage house at ARC-AP, Nutrition Section, measuring 20 × 6.0 × 3.5 m (L × W × H), was used for hydroponic fodder sprout production. The portion of the house was cleared and nine metal stands, each measuring 89 × 46 × 215 cm (L × W × H), with five shelves each, were installed. Each of the metal stands could carry ten hydroponic plastic trays each measuring 41 × 28 × 5 cm (L × W × H), respectively. The metal stands were joined together to form a single row for stableness. Fodder sprouts were produced at room temperature with no other light other than natural sunlight. Hydroponic trays were washed with soap water and rinsed with tap water. Before planting, the trays were disinfected by soaking in a 1% sodium hypochlorite (NaClO) solution. The barley seeds (1 kg dry weight) were weighed into a separate container and soaked for 30 min in 10% NaClO solution (Badran et al. 2017) After that, the seeds were rinsed with tap water three times and soaked again overnight in tap water. On the following day, wet barley seeds (about 2.1 kg wet mass) were spread on the hydroponic perforated plastic tray with a thickness of about 2.5 to 3 cm. Trays were irrigated manually with tap water using a 12 L Knapsack spray three times daily, at 09:00, 13:00 and 16:00. At harvest, day seven, to be fed on day eight, sprouts per tray weighed between 5.5 to 6 kg fresh biomass. A day (day seven) before lambs' feeding, sprouts were removed from the tray and allowed to drip off access water, and then hand shredded into small pieces for easy consumption by lambs. After shredding, three representative samples (300 g each) of sprouts were weighed and oven dried to determine the dry-matter content of sprout and kept for chemical composition analysis.

5.2.2 STUDY ANIMALS AND EXPERIMENTAL DIETS

A total of 12 healthy and uncastrated male meat-master lambs, about 3 months of age, with the initial body weight of 23.3 ± 2.3 kg, were bought from a local supplier. Upon arrival at ARC-AP, animals

were treated for internal and external parasites. Animals were weighed and randomly assigned to three dietary treatments, resulting in four animals per treatment. The dietary treatments were *Eragrostis curvula* grass (hereafter referred to as grass hay) as a control diet (T1), grass hay plus 25% hydroponic fodder sprouts on a dry-matter basis (T2) and grass hay plus 50% hydroponic fodder sprouts on a dry-matter basis (T3). A total of 25% and 50% of the hydroponic barley fodder sprouts (hereafter referred to as sprouts) were calculated from the daily intake of grass hay per animal and were offered in addition to grass intake. However, because of the high moisture (>80%) content in sprouts, grass hay and sprouts were offered separately. All animals received a daily concentrate supplement of 300 g and water was freely available throughout the study period. The concentrate was made of hominy chops (50%), wheat bran (36%), soybean meal (12%), feed lime (1.5%), salt (0.5%) and premix (1 pack). Animals were offered 3% of their body weight, of which 1% was from the concentrate while the remaining 2% was from grass hay for T1 diet and grass hay and sprout for T2 and T3 diets. The concentrate was offered once a day in the morning, at about 08:00, and was completely consumed by all animals. Animals finished the concentrate; thereafter, the dietary treatment was offered per animal in a group. Animals were fed twice a day, at 08:00 and 16:00. Animals were maintained in their respective dietary treatment for 61 days, including 10 days for adaptation before data collection.

5.2.3 DATA COLLECTION

Feed intake and animal final body weight were recorded. Methane gas emission data were collected in all four animals per treatment, for nine consecutive days (i.e., from day 52 to 60). Methane data were recorded using the hand-held laser methane detector (LMD) machine (Crowcon Detection Instruments Ltd., Tokyo, Japan). The LMD equipment records methane concentration using a red laser beam pointed in the nostril of an animal, as described by Chagunda et al. (2009). Briefly, the methane gas was recorded by pointing a red laser beam at the nostril of the lambs to estimate methane gas concentration at a distance of 1 m away from the animal. The recorded methane data in part per million (ppm) were converted into g/day using equation 9 (Chagunda et al. 2009), and it was calculated into g/kg BW and g/kg DMI.

Equation 9: $M_{DG} = 0.000567 \times MTV \times TVr$ where MDG is the daily methane in grams after including the conversion factor, MTV is the methane (ppm) recorded from the animal's nostril using a hand-held LMD and TVr is the tidal volume of air when the animal was standing. Rumen fluid (both solid and liquid fractions) was collected before morning feeding on day 61. The rumen fluid was collected using an esophageal stomach tube following the procedure of Shen et al. (Shen et al. 2012). Briefly, the first 50 mL of rumen fluid was discarded due to possible salivary contamination.

The second 50 mL was collected into a 100 mL container per animal. After collection, rumen fluid was divided into two halves; one half was used for rumen fermentation and the other half was used for DNA extraction. The samples for DNA extraction were frozen and stored in a −80 °C freezer immediately until further analysis.

5.2.4 RUMEN FERMENTATION

Rumen fermentation was measured by the determination of ammonia–nitrogen and VFAs, as described by Wang et al. (2021). The rumen fluid was strained through three layers of cheesecloth. Then 4 mL of rumen fluid was acidified with 0.2 M HCl in a 1:1 acid: rumen fluid ratio and used to determine ammonia–nitrogen. In addition, another 5 mL of rumen fluid was acidified with 25% metaphosphoric acid in a 1:4 acids: rumen fluid ratio for the determination of VFAs.

5.2.5 DNA EXTRACTION AND AMPLICON SEQUENCING

Microbial DNA was extracted using the Macherey-Nagel ™ NucleoSpin™ DNA Stool kit, and 16S ribosomal RNA (16S rRNA) amplification and sequencing were performed according to the Illumina 16S protocol (16S Metagenomic Sequencing Library Preparation Guide). Briefly, the variable V3 and V4 regions of the 16S rRNA gene were amplified primers from Klindworth et al. (2013) from the samples, followed by library amplification and sequencing on the Illumina MiSeq instrument using V3 chemistry. The primer sequence was as follows: 16S forward primer = 5′ TCGTCGGCAGCGTCAGATGTGTATAAGAGACAGCCTACGGGNGGCWGCAG and 16S Reverse primer = 5′ GTCTCGTGGGCTCGGAGATGTGTATAAGAGACAGGACTACHVGGGTATCTAATCC. The PCR program was as follows: 95 ◦C for 3 min, 25 cycles of; 95 ◦C for 30 s, 55 ◦C for 30 s, 72 ◦C for 30 s and a final extension at 72 ◦C for 5 min, held at 4 ◦C. Generated data were evaluated for quality and used for downstream bioinformatic pipelines. Low-quality sequencing reads were filtered and trimmed to a consistent length with a maximum of 2 expected errors per read enforced (Edgar & Flyvbjerg 2015). This is done on paired reads jointly, after which amplicon sequence variants are inferred and downstream analysis is done using the DADA2 method (Callahan 2016). This method combines identical sequencing reads into “unique sequences” with a corresponding abundance value, followed by the identification of sequencing errors. Thereafter, the forward and reverse reads are merged, and paired sequences that do not perfectly overlap are discarded.

The resulting sequence table was inspected for chimeras, which were removed. Taxonomy was assigned to the final, filtered sequence table using the SILVA ribosomal RNA gene reference database (Quast 2012). The R package, phyloseq (McMurdie et al. 2013) was used to further analyze and graphically display the sequencing data, which was clustered into amplicon sequence variants (ASVs) with the protocol described above. The ASV table was agglomerated onto operational taxonomic units (OTUs) according to taxonomic classification and inspected at "phylum" level to remove any unclassified OTUs. The OTU table was normalized using the 'normalize function' and the 'median ratio" method implemented in MetalonDA R package (Metwally et al. 2018) which uses the DESeq2 "estimate size factors" function (Love et al. 2014). For this analysis, we added a pseudo count of 1 to the initial OUT table, running the normalization prior to rounding off the normalized table to the largest integer not exceeding the normalized value. Floor rounding was applied to negate the effect of the pseudo-count addition. The sequencing dataset was deposited at the National Center of Biotechnology Information (NCBI) Sequence Read Archive (SRA) database under BioProject ID: PRJNA865290.

5.2.6 DATA ANALYSES

Data on feed intake, weight gain, enteric methane emission and fermentation profile were subjected to analysis of variance (ANOVA) using SAS software (SAS 2002) All bioinformatic analysis was done using a RStudio environment (R Studio 2015) with R core ream, version 4.0.2, Veinna, Austria (R Core). Alpha diversity indices (i.e., Observed, Chaol, ACE, Shannon, Simpson, InvSimpson and Fisher) were tested for equal variances using the Bartlett test of homogeneity of variances available from the stats version 4.1.2 package implemented in R. Differences in alpha diversity values between the treatments for all the indices were calculated and visualized using the "ggbetweenstats" function available from the ggstatsplot v. 0.9.3 package. Alpha diversity value differences between treatments were tested using a one-way analysis of means and pairwise t-test after homogeneity of variances was confirmed with Bartlett's test. Benjamini–Hochberg (BH), which is the same as false discovery rate (FDR) in R, p-value adjustment was used for multiple comparisons. Principal coordinate analysis (PCoA) was performed using the ordinate function from phylose version 1.38.0 with "gower" distance metric specified (Oksanen et al. 2022). To determine whether the variation exists between the treatments compared to within the treatments, anosim analysis was conducted by R package vegan version 2.6.2 (Oksanen et al. 2022) and "gower" distance metric was used to measure dissimilarity between samples. For all other statistical tests, differences between the means were considered significant at $p \leq 0.05$ and a trend was declared at $0.05 < p \leq 0.10$. In case of significant difference between the means, LSMEANS procedure of SAS (SAS 2002) software was used to separate the

means. Pearson's correlation analysis was conducted to assess the relationship between the abundance of microbiota and volatile fatty acids, methane emissions and body weight using PROC CORR procedure of SAS program.

5.3 RESULTS

Data on performance in terms of daily feed intake, final body weight and enteric methane emission of meat-master lambs are shown in Table 5.1. Barley sprouts supplementation to meat-master lambs significantly ($p = 0.0186$) increased the feed intake and body weight of the meat-master lambs, while significantly reducing enteric methane emission. Animals in T2 and T3 (supplemented with barley sprout) ate 41% and 67% more feed, respectively, as compared to the T1 group. Similarly, animals in T2 and T3 were 11% and 17% heavier, respectively, than the T1 group. Supplementing meat-master lambs with barley reduced the methane yield per body weight ($p < 0.0264$) and per feed intake ($p < 0.001$) significantly. Methane gas emission on grams per feed intake was reduced by 34% and 52%, respectively, for animals in T2 and T3, as compared to the T1 group.

Table 5.1: Effects of supplementing meat-master lamb diets with barley sprouts on intake, body condition and methane emission.

Parameters	Treatments			SEM [1]	*p*-Value
	T1	T2	T3		
Intake (kg)	1.0 [c]	1.4 [b]	1.6 [a]	0.05	<0.0001
Initial body weight (kg)	23.2	23.3	23.5	1.16	0.9871
Final body weight (kg)	28.6 [b]	31.9 [ab]	33.5 [a]	1.12	0.0186
Methane (ppm) [2]	23.4	22.0	19.1	1.11	0.0608
Methane (g/day)	51.1	48.2	41.9	2.44	0.0608
Methane (g/kg BW) [3]	1.8 [a]	1.5 [ab]	1.3 [b]	0.11	0.0264
Methane (g/DMI) [4]	53.0 [a]	35.1 [b]	25.5 [c]	2.50	<0.0001

Table 5.2 shows the rumen fermentation profile of meat-master lambs influenced by barley sprouts supplementation. Barley sprouts supplementation significantly ($p < 0.0001$) decreased the levels of ammonia–nitrogen (NH3-N). Meat-master lambs that were in T2 and T3 had 42.8% and 48.5% less NH3-N, respectively as compared to the T1 group. There was no significant ($p > 0.05$) variation observed in total volatile fatty acid (FVA), butyric, isobutyric, valeric and iso-valeric acids concentration in the rumen fluid. Iso-butyric acid was not detected in rumen fluid of animals that were in T3. However, there was a significant ($p < 0.05$) decrease in acetic acid while there was a tendency ($p = 0.0536$) to increase propionic acid. Animals that were in T2 and T3 produced 8.2% and 7.5% less acetic acids as compared to animals that were in T1. Moreover, there was a significant (p

= 0.0286) decrease in acetic and propionic ratio observed in animals that were supplemented with barley sprouts. Animals that were fed in T2 and T3 had 24% and 26% lower acetic/propionic ratios, respectively as compared to animals in T1.

Table 5.2: Effects of supplementing barley sprouts on the ruminal fermentation profile of meat-master lambs.

Parameters	Treatments			SEM [1]	*p*-Value
	T1	T2	T3		
NH_3-N (mg/dL) [2]	19.4 [a]	11.1 [b]	9.8 [b]	0.66	<0.0001
Total VFA (mmol/L) [3]	68.9	68.3	60.1	5.90	0.5344
Molar proportion of VFA					
Acetate (A)	73.3 [a]	67.3 [b]	67.8 [b]	1.23	0.0286
Propionate (P)	16.5	20.1	20.8	1.04	0.0536
Butyrate	7.1	8.8	9.0	0.71	0.2068
Iso-butyrate	1.2	1.5	nd [4]	0.09	0.2671
Valerate	0.8	1.0	0.8	0.06	0.1276
Iso-valerate	1.2	1.3	1.0	0.18	0.4426
A:P ratio	4.5 [a]	3.4 [b]	3.3 [b]	0.28	0.0408

Rumen microbial composition of meat master lambs as influenced by barley sprout supplementation is indicated in Figure 5.1 and Table 5.2. A total of 272 OTUs were obtained from all the samples. The rarefaction curves suggest that sampling of the rumen environments has a sufficient sequencing depth across the treatments. A total of 24 phyla, 40 classes, 68 orders, 96 families and 166 genera were identified in rumen fluid collected from all three groups of animals that were fed different dietary treatments. There were no statistically significant ($p > 0.05$) differences detected in alpha diversity for Observed, Chaol, ACE, Shannon, Simpson, InvSimpson and Fisher. Figure 5.1 shows the relative abundance of bacteria at the phylum level above 1% at least one group. The most predominant bacterial phyla that were identified in the rumen fluid of meat-master lambs were Bacteroidota and Firmicutes and they constituted an amount of 73% of the total bacterial phyla identified. The relative abundance of Bacteroidota phylum was 37.3%, 14.9% and 29.1% in T1, T2 and T3, respectively, while that of Firmicutes phylum was 27.0%, 52.9% and 35.4% in T1, T2 and T3, respectively. There was an observed variation of these bacterial phyla abundancy among the treatments; however, the variation was not statistically significant ($p > 0.05$).

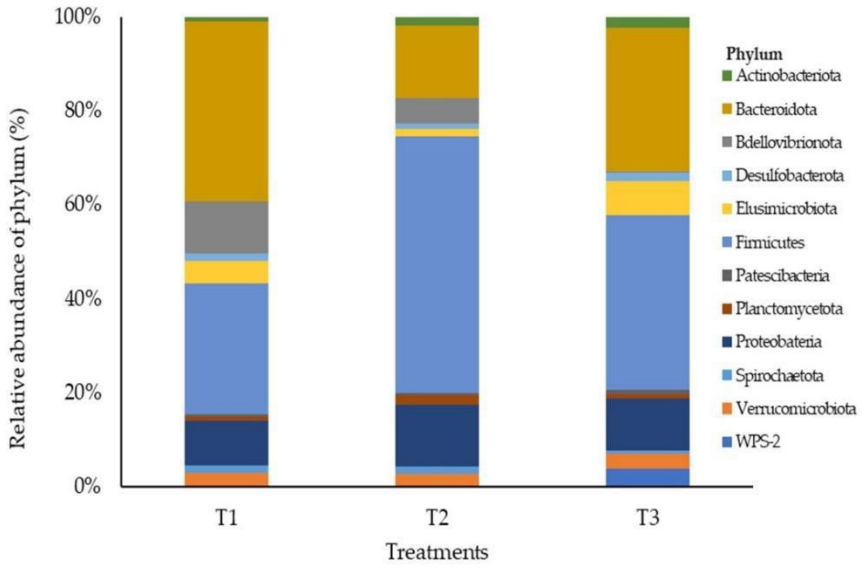


Figure 5.1: Bacterial relative abundance (>1% at least in one group) at phylum level as influenced by the sprout supplementation on meat-master lambs.

Table 5.3 shows the abundance of bacteria at the family level. There were 25 families with a relative abundance of above 1% at least in one of the groups. The most predominant bacteria that were detected in animals that were on T1 were p-2534-18B5 gut group (26.54%), Lachnospiraceae (7.90%) and Rikenellaceae (7.83%). On animals that were fed T2, the dominating bacteria were Erysipelatoclostridiaceae (24.67%) and Lachnospiraceae (10.96%). In animals that were fed T3, the predominant abundant bacteria were Prevotellaceae (26.24%), Lachnospiraceae (12.36%) and Selenomonadaceae (10.53%). The Prevotellaceae that dominated animals in T3 belonged to phylum Bacteroidota. There was a variation of these bacteria across the dietary treatments; however, the observed variation was not statistically significant ($p > 0.05$). A significant ($p < 0.05$) decrease in bacterial abundance as a result of sprouts supplementation was observed in Butyricicoccaceae (1.0, 0.2 and 0.1%) and Hungateiclostridiaceae (4.2, 0.8 and 0.7) in T1, T2 and T3, respectively. A decreasing trend ($p = 0.0924$) was observed in p-2534-18B5 gut group bacteria, with an abundance level dropping from 26.5% to 0.2% as the sprouts supplementation increases.

Figure 5.2 shows the differences in rumen microbial communities of meat-master lambs as influenced by the sprout supplementation. According to the principal coordinate analysis (PCoA), there is a distinct separation in the bacterial communities between the animals subjected to different dietary treatments. The PCoA showed that the rumen microbial differences accounted for a 29.1% variation in the animals in the T1 diet, distinguished from animals in the T2 and T3 diets by axis 1, while rumen microbial differences between the animals that were in T2 and T3 represent a 23.2% variation of axis 2. The ANOSIM analysis (Figure 5.3) confirmed that there was a significant ($p < 0.015$) dissimilarity

of rumen bacteria in animals on the T1 diet in relation to the other two groups (Figure 5.2). Correlation analysis was conducted to determine the correlation between the relative abundance of microbial bacteria, fermentation parameters, methane emission and body weight. There was a significant ($p < 0.0436$) negative correlation between phylum Acinobacteria and ammonia–nitrogen (NH3-N). Phylum Desulfobacterota had a significant ($p < 0.0065$) negative correlation with body weight and a significant ($p < 0.0124$) positive correlation with acetic and propionic ratios. Frimicute was positively corrected with valeric significantly ($p < 0.0402$). Patescibacteria negatively correlated with iso-butyrate and isovarate significantly with $p < 0.0034$ and $p < 0.0239$, respectively. Planctomycetota had a significant ($p < 0.0219$) positive correlation with valeric acid.

Table 5.3: Effects of sprouts supplementation on bacterial abundance at the family level on meat-master
lambs (>1% at least in one group).

Bacteria	Treatments			SEM [1]	*p*-Value
	T1	T2	T3		
Acholeplasmataceae	2.6	0.5	0.5	0.67	0.1097
Anaerovoracaceae	1.3	2.4	2.3	0.62	0.4303
Butyricicoccaceae	1.0 [a]	0.2 [b]	0.1 [b]	0.20	0.0388
Atopobiaceae	0.3	0.9	1.8	0.47	0.1529
Chitinophagaceae	0.5	1.9	1.0	0.93	0.5826
COB P4-1 termite group	3.3	0.1	0.2	1.05	0.1246
Desulfovibrionaceae	1.0	0.9	1.9	0.70	0.5806
Erwiniaceae	1.5	0.2	0.2	0.81	0.4529
Erysipelatoclostridiaceae	1.5	24.7	1.5	13.09	0.4084
Erysipelotrichaceae	0.7	1.2	2.6	0.55	0.1279
Hungateiclostridiaceae	4.2 [a]	0.8 [b]	0.7 [b]	0.64	0.013
Lachnospiraceae	7.9	11.0	12.4	2.44	0.4656
Moraxellaceae	1.2	1.3	0.5	0.68	0.7049
Oscillospiraceae	6.0	4.6	3.6	1.93	0.6761
Oxalobacteraceae	0.2	1.4	0.8	0.56	0.4259
p-2534-18B5 gut group	26.5	0.2	0.2	7.98	0.0924
Pasteurellaceae	1.7	1.3	1.9	0.89	0.8862
PeH15	2.7	5.5	0.2	3.16	0.5275
Pirellulaceae	1.0	1.9	0.6	0.46	0.1884
Prevotellaceae	1.5	5.9	26.2	12.10	0.3677
Rikenellaceae	7.8	0.8	0.8	3.96	0.4087
Ruminococcaceae	1.7	1.7	1.9	0.44	0.9587
Selenomonadaceae	0.9	4.6	10.5	3.90	0.2895
Spirochaetaceae	1.1	1.7	0.6	0.64	0.5574
Succinivibrionaceae	2.1	5.7	4.9	3.25	0.7317

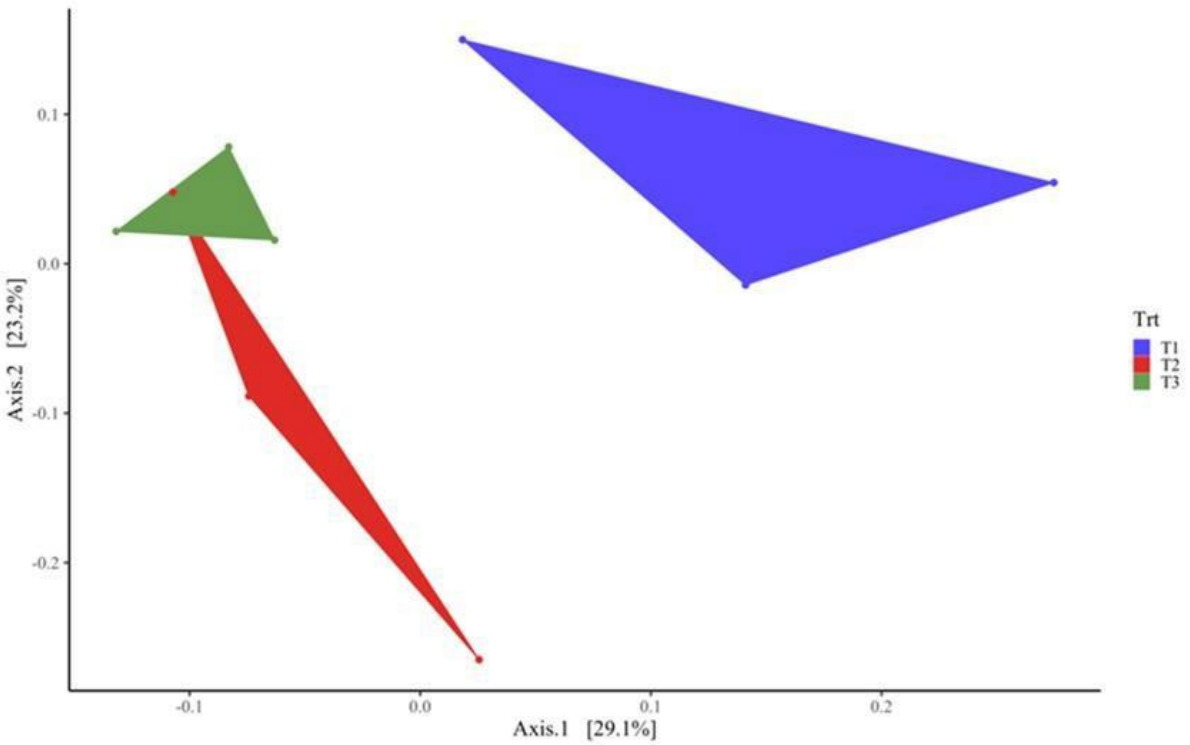


Figure 5.2: Principal coordinate analysis (PCoA) showing the differences in the bacterial community of meat-master lambs as influenced by sprouts supplementation.

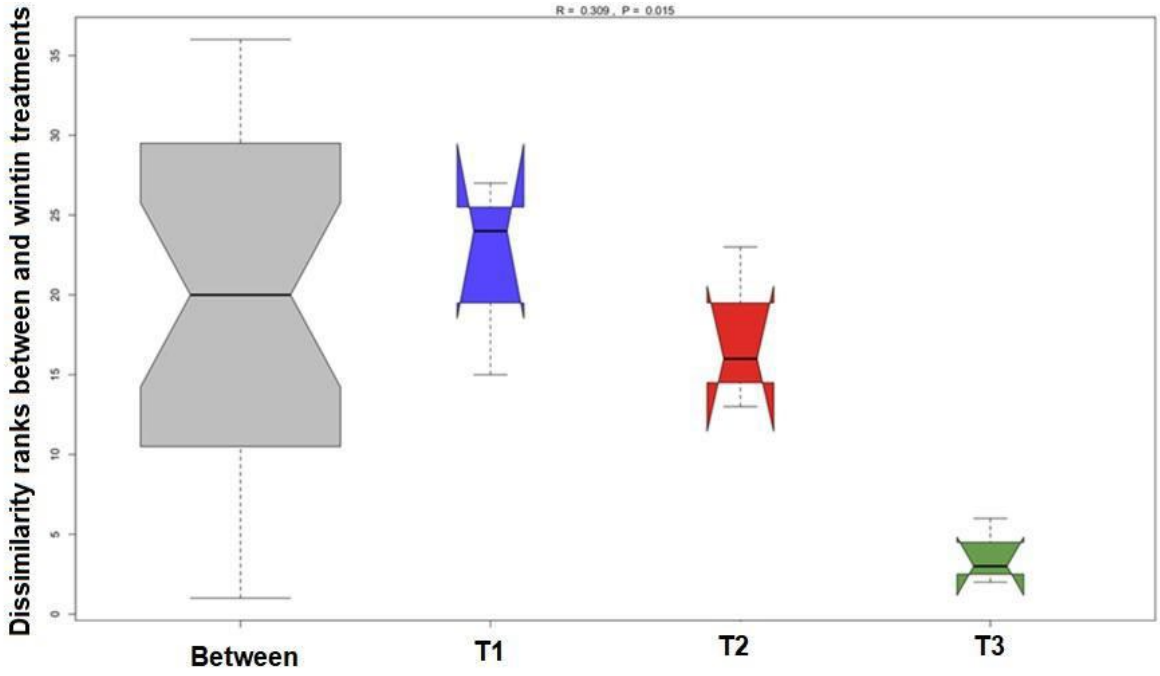


Figure 5.3: ANOSIM showing the dissimilarity between treatments.

5.4 DISCUSSION

The supplementation of hydroponic barley sprouts in the diet of meat-master lambs has shown significant benefits on methane emissions, nutrient utilization, and ruminal microbial composition. The observed reduction in methane gas emissions in animals fed T2 and T3 diets may be attributed to improved nutrient digestibility and increased availability of enzymes from the sprouts that support microbial activity in the rumen (Salo 2019; Farghaly et al. 2019). The T2 and T3 groups were heavier by 11% and 17%, respectively, compared to those in the control group (T1). Methane production is typically higher with fibrous feeds due to prolonged fermentation and accumulation of H_2 and CO_2, which are substrates for methanogenesis (Danielsson et al. 2017, Kumar et al. 2013; Swaison et al. 2018; Tiklebrhan et al. 2020). Animals in T2 and T3 groups, which produced less methane, exhibited greater body weight gains compared to the control group (T1), aligning with previous findings that associate reduced methane emissions with improved animal productivity (Congio et al. 2021).

Additionally, feed intake was higher in T2 and T3, yet methane output per kg of feed was lower, suggesting improved feed conversion efficiency (Li et al. 2022; Gaviria-Uribe et al. 2020; Min et al. 2020). A notable decline in ammonia–nitrogen (NH_3-N) levels was also observed with increased sprout supplementation, remaining within the optimal range for microbial growth (8.5–30 mg/dL) (McDonald et al. 2010). This reduction is likely due to lower protein fermentation in the rumen and increased microbial utilization of amino acids (Tiklebrhan et al. 2020; Panyawoot et al. 2022). The shift in volatile fatty acid (VFA) profiles, particularly a decrease in acetic acid and an increase in propionic acid, implies enhanced energy availability, since propionate is a major glucose precursor for ruminants (Den Besten et al. 2013; Ma et al. 2020). Consequently, animals in T2 and T3 showed improved weight gain, possibly due to the more favorable acetic-to-propionic acid ratio (Ma et al. 2020; Morgavi et al. 2013).

At the microbial level, supplementation influenced the relative abundance of bacterial phyla, shifting dominance from *Bacteroidota* (in T1) to *Firmicutes* (in T2 and T3), a change known to be associated with better energy absorption and feed efficiency (Li et al. 2022; Guo et al. 2020; Ahmad et al. 2020; Wang et al. 2012; Wang et al. 2020; Ley et al. 2006). This microbial shift may also explain the reduction in NH_3-N, given *Bacteroidota's* known role in protein degradation and NH_3-N production (Wang et al. 2020; Huo et al. 2014). Pearson's correlation showed a relationship between *Firmicutes* and valerate, supporting the idea that this phylum plays a key role in rumen metabolism (Ley et al. 2006).

5.5 CONCLUSION

According to this study, barley sprouts changed the bacterial composition and rumen fermentation in meat-master lambs' rumen. In animals fed barley sprouts, this has led to a decrease in methane output per kilogram of feed intake and a shift in bacterial relative abundance. As a result, this study showed that barley sprouts may enhance animal performance and efficiency while lowering methane yield per feed intake.

CHAPTER 6: EFFECTS OF BARLEY SPROUTS SUPPLEMENTATION ON GROWTH PEROFMANCE AND RUMEN MICROBIAL COMPOSITION OF INDIGENOUS GOAT KIDS

6.1 BACKGROUND

South Africa is an arid country with increasing water scarcity and thus becoming a limiting factor in agricultural farming systems for both livestock and crop farming. This is because of the increasing incidences of heat waves we are experiencing, which are associated with climate change. Southern Africa, including South Africa, is predicted to be drier as expected and to lose about 30% of available water because of increasing ambient temperature owing to climate change (ISS paper, 2010). On one hand, livestock farming is a vital agricultural commodity for global food security, because it provides about 17% and 33% of the global energy and protein consumption, respectively (Rosegrant *et al*., 2009). On the other hand, the world population is predicted to increase by 33.3% in 2050 (Thornton, 2010) and this will further increase the demand for animal-derived food (i.e., meat, milk and eggs). Consumption of animal derived food particularly meat and milk expected to increase by 37.5% and 41.8%, respectively in the developing countries by 2050 (Thornton, 2010). Therefore, the demand of green and nutritious forage as the main source of feed for livestock is expected to increase (Devendar *et al*., 2020). Available forage from natural pasture varies in both quantity and quality, especially during the dry season period, characterized by high fiber content, hence poorly digested (German *et al*., 2014; Bhatta *et al*., 2021). Therefore, feeding such forage to animals may lead to high enteric methane emissions and eventually poor animal performance. This is because enteric methane emissions account for about 12% of energy loss from the animals, hence it reduces production (Bowen *et al*., 2020). However, our study showed that supplementing hydroponic fodder sprout on sheep eating poor quality grass modified rumen microbial composition and hence reduced methane emission while improving nutrient use efficiency (Mpanza *et al*., 2022). However, little is reported on goat performance when they are supplemented with hydroponic fodder sprout. In ruminant animals, rumen microbes play a major role in the digestive system by enabling ruminant animals to utilize fiber to generate about 70% of the energy required by the animal (Newbold and Ramos-Morales, 2020). Nathani *et al*. (2015) reported that green or dry roughage fed to animals modulates rumen microbial compositions, by promoting the dominance of particular bacteria or the other.

Hydroponically produced fodder sprouts are the means of ensuring the availability of green fodder for animals even during the dry season. Hydroponic fodder production technology has been introduced as an option for green fodder production (Naik *et al*., 2013; Denvendar *et al*., 2020).

According to Devendra *et al*. (2020), hydroponic fodder sprouts are characterized by high sugar, minerals, crude fibre, vitamins, and total protein; modify amino acid profile; promote enzyme activity; and decrease dry matter and starch-based energy. Hydroponic sprout can be produced from a variety of seeds/grains such as wheat, cowpeas, maize, oats, barley and even from different grass species (Dhawale *et al*., 2018). Fodder sprout is best suited to arid and semi-arid regions where water is the major limiting factor on conventional forage production systems (Bakshi *et al*., 2017). For example, a hydroponic fodder production system utilizes about 2 L of water to produce 1 kg of fresh green fodder as compared to about 106 L of water required under a conventional system to produce the same quantity (Bakshi *et al*., 2017). The ability of hydroponic sprouts to generate 7 to 10 kg of green fodder within a week from grains is the most significant component of hydroponic fodder production (Gebremedhin, 2015; Farghaly *et al*., 2019). This study aimed to evaluate the effect of barley fodder sprout supplementation on indigenous goat kids' feed intake, weight gain, and rumen microbial composition. Therefore, this study was proposed to address the following objective: To evaluate the effects of supplementing barley fodder sprouts on feed intake, weight gain, and rumen microbial composition of weaned indigenous goat kids.

6.2 MATERIALS AND METHODOLOGY

The proposed study was conducted in at the Agricultural Research Council - Animal Production (ARC-AP) as an on-station research so that it was easy to collect samples such as rumen fluid for laboratory analysis. The study was conducted following the procedure of animal research ethics approved by the Agricultural Research Council Ethics Committee. In this study, twelve (12) male indigenous goat kids of the same age, weighing between 13.45 kg were used, selected ARC's small stock unit. Before they are used for the study they were weighed and treated for internal and external parasites. Animals were randomly assigned to one of three dietary treatments and housed in individual pens. The dietary experiments include control diets; group 1 were fed grass hay supplemented with 200 g pellets per animal per day, referred as T1, Group 2, T1 diet supplemented with 1% of body weight by barley sprout irrigated with tap water, referred as T2, and group 3 animals were fed T1 diet supplemented with 1% of body weight by sprout irrigated with fertilised water solution, referred as T3. Each group had four male goat kids on 4 months old. A Complete randomised design (CRD) was used as an experimental setup. Animals were adapted to their respective feed for 10 days before data collection. Animals were fed twice a day at 08h00 and 15h30 to minimise feed waste and high leftovers (Lima *et al*., 2023), with free access to clean water and the experiment lasted for 60 days, excluding 10 days of adaptation.

6.2.1 DATA COLLECTION

6.2.1.1 Animal performance

Animal weights were recorded at the beginning and at the end of the feeding and difference was used to determine weight gain during the study period. Feed intake by goat kids was recorded daily by weighing daily feed offered and refusals. Feed conversion ratio (FCR) and average daily gain (ADG) were calculated from feed intake divided by weight gain over study period and average weight gain dived by duration of the study, respectively.

6.2.1.2 Rumen fluid collection

Rumen fluid was on two animals per treatment at the end of the feed trial using a stomach tube, and to reduce salivary contamination, about 30 ml of the first collection was discarded and 100 ml of rumen fluid was 150 ml container per animal as described in Mpanza et al. (2022). The collected rumen fluid was used for DNA extraction as describe in Mpanza et al. (2022).

6.3 RESULTS

6.3.1.1 Growth performance as influence by fodder sprout supplementation

Figure 6.1 shows the animal performance in terms of feed intake as influenced by sprout supplementation. Animals that were in T2 and T3 showed a significant increase of feed intake as compared with animal that were not supplemented with sprouts. Animals that were in T2 and T3 showed a 17.2% and 18% increase of feed intake as compared to animals in T2 diet. The observed increase on feed intake could be a result of more feed available due to fodder sprout supplementation during the trial.

Table 6.1 shows animals' performance in terms of body weight gain, daily gain and feed conversion ratio of goat kids under different dietary treatments. Animals that were subjected to different dietary treatments gained weight during the study period; however, supplementing with fodder sprout did not lead to any significant ($p > 0.05$) effect on animals in terms of body weight gain, daily gain feed conversion ratio. However, animals that were on T2 and T3 diets showed a numerical increase in body weight as compared to animals in the T1 diet.

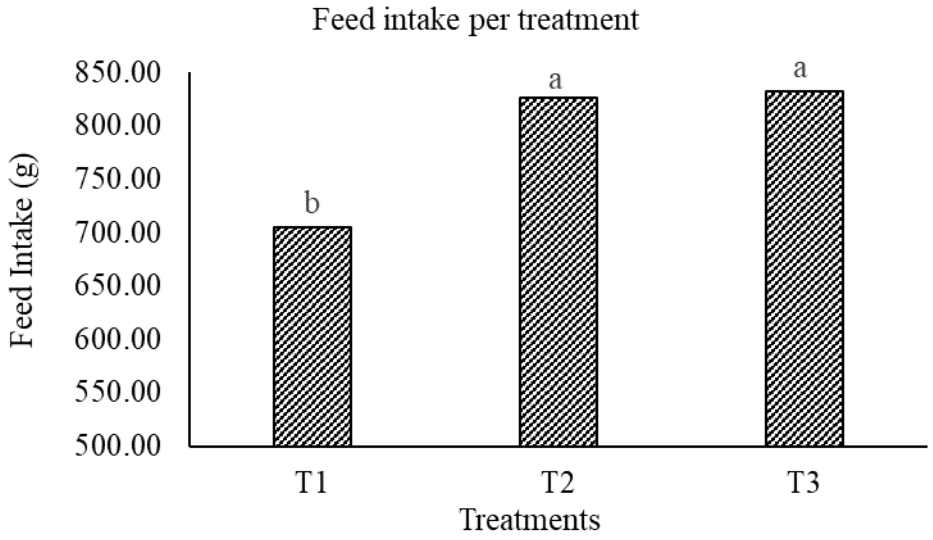


Figure 6.1: Feed intake by indigenous goat kids as influenced by hydroponic fodder sprout supplementation. T1 = Animals were fed grass hay and 200 g of pellets per animal per day; T2 = Animals were T1 diet and supplemented with sprout irrigated with tap water; and T3 = Animals were fed the T1 diet and supplemented with sprout irrigated with fertilised water. Letters a-b denote significant levels at $P \leq 0.05$).

Table 6.1: Goat kids' performance as influenced by fodder sprout supplementation

Parameters	Treatments				
	T1	T2	T3	SEM	*p*-Value
Initial Body Weight (kg)	13.25	13.25	13.75	1.228	0.9465
Final body weight (kg)	23.00	26.15	26.35	1.138	0.1974
Total weight gain (kg)	10.75	12.90	12.60	0.950	0.1526
Daily weight gain (kg)	0.26	0.32	0.32	0.024	0.1526
Feed conversion ratio	2.82	2.62	2.68	0.233	0.8262

The rumen pH indicated that animals were in good health since the pH was in range of the recommended level for healthy animals (Figure 6.2). There was no significant ($p > 0.05$) variation in rumen pH of goat kids due to dietary treatment. The rumen pH value recording for goat kids subjected to different dietary feeds represents a stable and healthy environment for normal rumen functioning. This range supports optimal microbial activity and feed digestion.

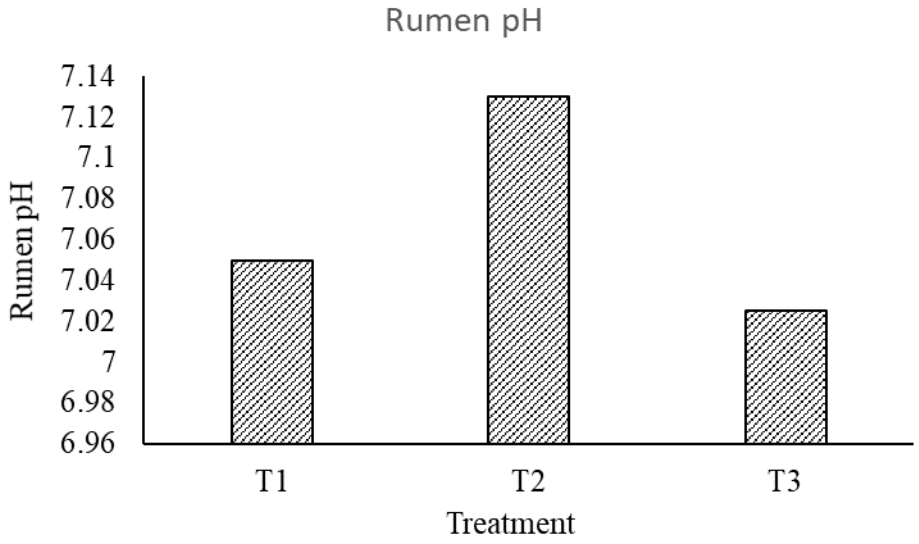


Figure 6.2: Rumen pH as influenced by dietary supplementation in goat kids

T1 = Animals were fed grass hay and 200 g of pellets per animal per day; T2 = Animals were T1 diet and supplemented with sprout irrigated with tap water; and T3 = Animals were fed the T1 diet and supplemented with sprout irrigated with fertilised water

6.3.1.2 Microbial composition as influenced by fodder sprout supplementation

Figure 6.3 shows the rumen bacterial composition of goat kids subjected to fodder sprout supplementation. The most dominant bacteria at the phylum level in the rumen of goat kids subjected to different dietary treatments were *Proteobacteria*, *Firmicutes*, *Bacteroidetes, Actinobacteria and Cyanobacteria*. However, it was observed that sprout supplementation resulted in a shift in bacterial composition between *cyanobacteria* and *actinobacteria*.

Figure 6.4 shows the bacterial composition of goat kids at the species level as influenced by fodder sprout supplementation. Bacteria *Anabaena sp.* YBS01 was the dominant bacteria at the species level in all animals irrespective of treatments; however, sprout supplementation improved the dominance of this bacteria on animals in T2 and T3 diets. Bacterial composition was further analysed at the genus level, and Figure 6.5 showed that Anabaena was the most dominant genera. And again, fodder sprout supplementation improved the dominance of the Anabaena genera.

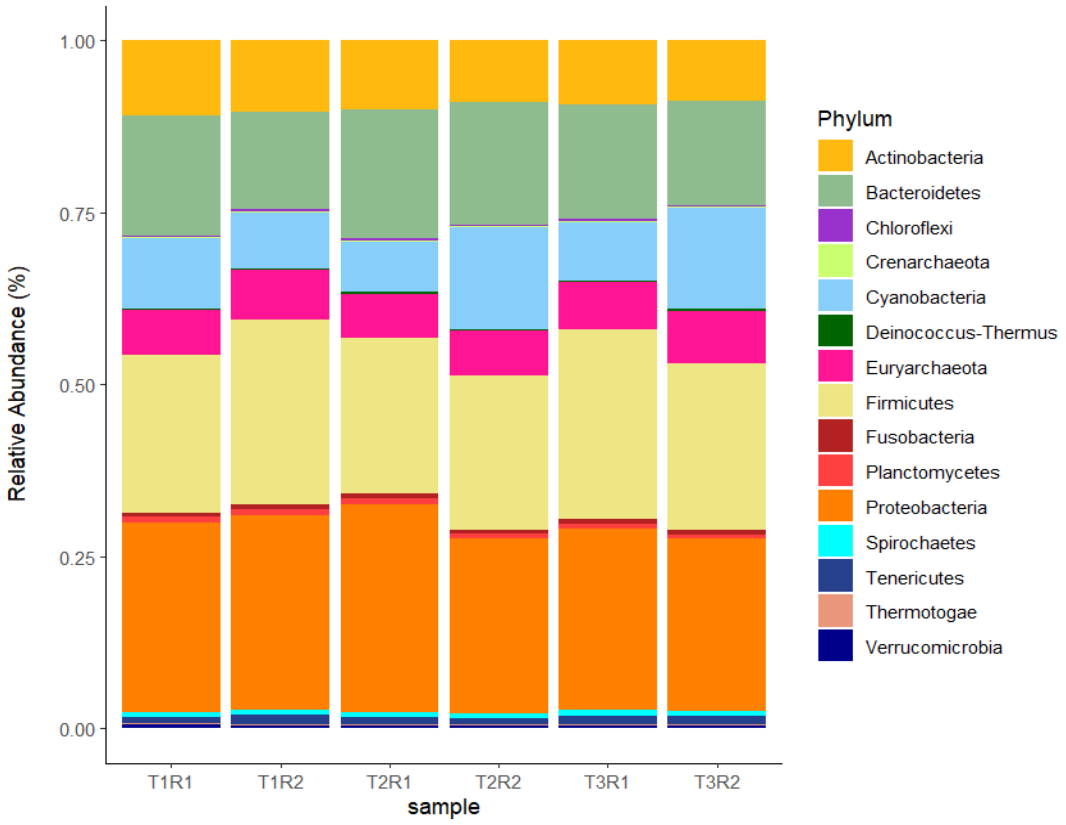


Figure 6.3: Microbial composition of goat kids as influenced by fodder sprout supplementation. T1 = Animals were fed grass hay and 200 g of pellets per animal per day; T2 = Animals were T1 diet and supplemented with sprout irrigated with tap water; and T3 = Animals were fed T1 diet and supplemented with sprout irrigated by fertilised water

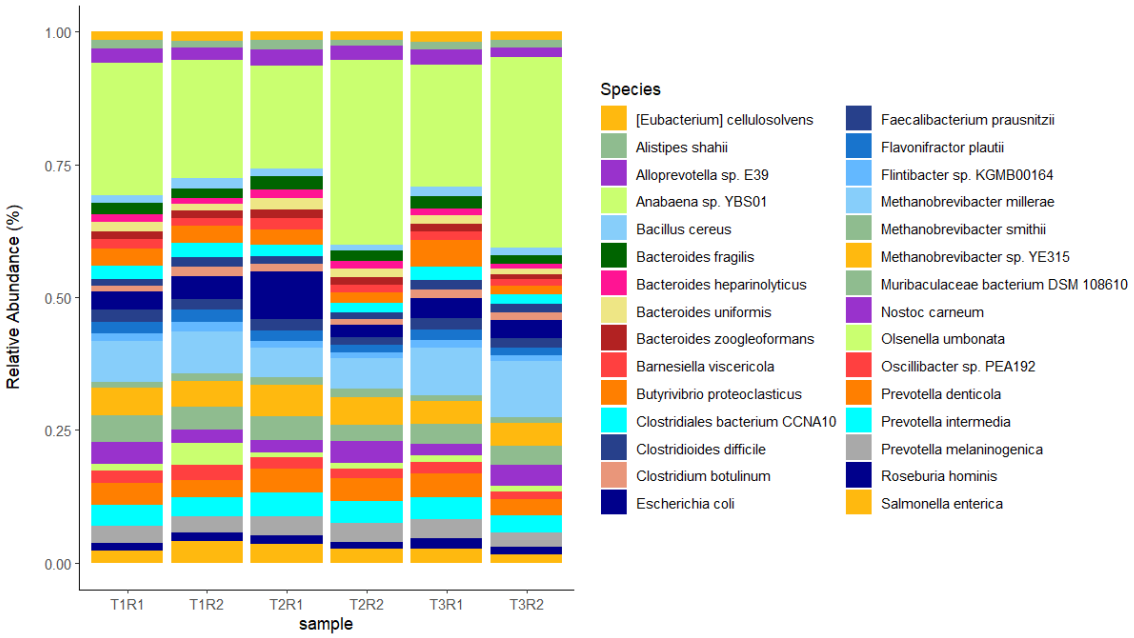


Figure 6.4: Bacterial composition at species level of goat kids as influenced by fodder sprout supplementation. T1 = Animals were fed grass hay and 200 g of pellets per animal per day; T2 = Animals were T1 diet and supplemented with sprout irrigated with tap water; and T3 = Animals were fed T1 diet and supplemented with sprout irrigated with fertilised water

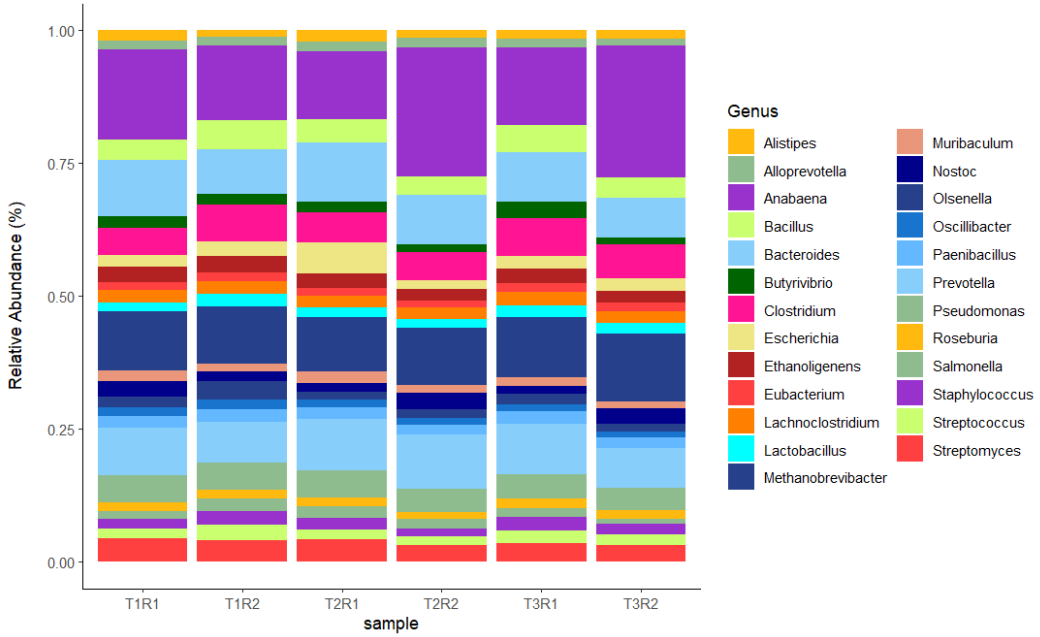


Figure 6.5: Bacterial composition at genus level on goat kids as influenced by fodder sprout supplementation. T1 = Animals were fed grass hay and 200 g of pellets per animal per day; T2 = Animals were T1 diet and supplemented with sprout irrigated with tap water; and T3 = Animals were fed T1 diet and supplemented with sprout irrigated with fertilised water.

6.4 DISCUSSION

The significant increase in feed intake due to fodder sprout supplementation did not lead to a significant body weight gain in animals that were on T2 and T3, although numerically, animals in T2 and T3 had higher body weight. These results are not in line with the results reported by Arif *et al*. (2023), who reported a significant increase in body weight of goat kids that were supplemented with fodder sprout. However, the discrepancies that were observed between the indigenous goats and Beetal goats are that the Beetal goats are a developed breed as compared with the indigenous breed (an underdeveloped breed). For example, Beetal goats are bred for milk or meat production, while South African indigenous goat is bred for adaptability to a harsh environment and disease resistance; therefore, their response to feed will not be the same. The pH value recorded in goat kids subjected to different dietary feeds in this study showed that animals adapted well to the feed. Hence, the rumen pH was in the range of normal pH that supports normal rumen microbial functioning (Jiyana *et al*., 2021). The pH level in the rumen has a major influence on rumen functioning and to the health of the animal (Baek et al., 2022; Lui *et al*., 2024).

The dominance of *Proteobacteria* phylum, known as facultative bacteria, in the rumen of animals that were subjected to different dietary feeds is common in growing goat kids. These bacteria are reported as the major carriers of antibiotic resistance genes in growing goat kids (Chai *et al*., 2024). Antibiotics are critically important for young animals. However, this study showed the presence of Anabaena sp. YBS01 and Anabaena at the species and genus level, respectively, in all animals, despite dietary treatments. The presence of these bacteria is alarming, because it regarded as bacteria that secrete toxins in the rumen of the animal (Belanche *et al*., 2023). This bacterium is produced by the phylum Cyanobacteria, which is the fourth most dominant bacterial after *Proteobacteria, Firmicutes* and *Bacteroidetes* (Figure 6.3 above). Therefore, the origin and ecological factors contributing to the prevalence of *Anabaena* spp. in the rumen microbiome remain unclear and warrant further investigation.

6.5 CONCLUSION

The study demonstrated that supplementing indigenous goat kids with hydroponic barley sprouts positively influenced feed intake, with T2 and T3 groups showing a 17–18% increase compared to the control. Although this did not translate into statistically significant weight gains, numerical improvements in body weight and feed conversion ratio suggest potential benefits for growth performance. Hydroponic fodder proved to be a viable option for arid regions, offering water-

efficient, high-quality feed while maintaining rumen health, as evidenced by stable pH levels across all treatments.

However, the unexpected dominance of *Anabaena* bacteria, a toxin-producing species, raises concerns about possible contamination in the hydroponic system or feed sources. Further investigation is needed to identify and mitigate contamination risks to ensure the safety and efficacy of hydroponic fodder. Despite this, the study highlights the promise of hydroponic sprouts as a sustainable feed supplement, particularly in water-scarce environments, warranting optimized production practices to maximize benefits for livestock productivity.

CHAPTER 7: DETERMINING THE COST EFFECTIVENESS OF THE HYDROPONIC SYSTEM AS A FODDER FLOW PROGRAM FOR SMALLHOLDER AND COMMUNAL FARMERS

7.1 PROJECT OVERVIEW

This cost-benefit analysis evaluates the feasibility of a low-cost hydroponic fodder production system for resource-poor farmers in Namaqualand. The goal is to provide immediate fodder solutions in the fodder gap, especially during critical periods when natural veld conditions cannot support pregnant or lactating ewes. This analysis considers economic viability, water efficiency, and production sustainability as key evaluation metrics.

The system under evaluation is a 3 x 5 meter wooden greenhouse with 80% shading cloth, a polycarbonate roof approximately 1 meter above the net, and seed trays placed on racks built using schedule 40 mm PVC pipes. Watering will be manual, using buckets and supplemented by a rainwater harvesting system connected to a 5 000-liter water tank. Manual watering is cost-effective but labour-intensive, making it less efficient compared to automated irrigation systems. In summer, high temperatures increase the risk of fungal outbreaks and root moulding, which require additional labour to manage. Conversely, in winter, manual watering may need to be adjusted to prevent excessive moisture retention, which can slow growth. These seasonal variations highlight the trade-offs between manual and automated systems in maintaining optimal growing conditions year-round. Automation could improve water distribution uniformity, reduce labour demands, and enhance overall system efficiency, although it would increase initial setup costs. The water tank will be placed on a cement block stand for stability.

7.2 GREENHOUSE SETUP DETAILS

- Dimensions: 3 meters (width) x 5 meters (length) x 2 meters (height)
- Trays: 53 cm x 27 cm x 3 cm plastic seed trays (216 trays total)
- Capacity: Each tray can produce approximately 7 kg of green barley fodder
- Total Production Capacity: 1,512 kg per cycle

7.3 PRODUCTION ASSUMPTION

Table 7.1: The production assumption of the proposed fodder system.

Scenario	Cycle Duration	Cycles per Month	Monthly Fodder Production
Best Case (Warm Conditions)	7 days	4	6 048 kg
Worst Case (Cool Conditions)	10 days	3	4 536 kg

FAO (2015)

7.4 SEASONAL CONSTRAINTS

Experiments have shown that hydroponic fodder production faces seasonal challenges. During summer, high temperatures lead to root moulding, fungal outbreaks, and an increase in fungus gnats inside the structure, making it difficult to maintain a consistent supply. In winter, barley growth slows significantly. Under a low-budget setup with no temperature control, the most viable production period is late in the dry season when ambient temperatures are cooler. This period coincides with increased demand for supplementary fodder, as climate change affects the timing of the first winter rains (Ntombela, 2017).

7.5 COST-BENEFIT ANALYSIS TABLE

A cost-benefit analysis involves comparing the total costs of production against the expected benefits (revenues or savings). This includes direct costs (seed, labour, structure) and indirect benefits (rainwater harvesting, reduced reliance on purchased fodder).

Table 7.2: The cost-benefit analysis of the proposed hydroponic fodder production system.

Category	Description	Cost (ZAR)	Best Case (4 Cycles/Month)	Worst Case (3 Cycles/Month)
Setup Costs:				
Greenhouse structure	Wooden poles, shade cloth, racks	6 000		
Polycarbonate roof	Roof panels and installation	12 000		
Rainwater system	Gutter pipes, drainage, 5 000L tank	8 000		
Tank base	Cement block stand	2 500		
Shelves	Schedule 40 mm PVC pipes	4 000		
Trays	216 trays @ R50 each	10 800		
Miscellaneous	Fasteners, tools, repairs	1 000		
Total Setup Cost		**44 300**		
Monthly Costs:				
Barley seed	108 kg per cycle @ R15/kg	1 620	6 480 (108 kg x 4 cycles)	4 860 (108 kg x 3 cycles)
Labour	3 hours/day @ R30/hour	420 per cycle	1 680	1 260
Miscellaneous	Repairs and maintenance	50 per cycle	200	150
Total Monthly Costs			**8 360**	**6 270**
Production and Revenue:				
Fodder production	1 512 kg per cycle		6 048 kg	4 536 kg
Revenue	Fodder @ R4 per kg		24 192	18 144

Rainwater value	3 000 liters per annum @ R1.50/L		4 500	4 500
Profit Analysis:				
Net Monthly Profit	Revenue - Monthly Costs + Water Value		**R20 972**	**R16 374**
Payback Period	Setup Cost / Net Profit		**~2.1 months**	**~2.7 months**

7.6 COMPARISON WITH IN-FIELD BARLEY PRODUCTION

Table 7.3: The comparison between the hydroponic barley fodder production and conventional fodder production.

Parameter	**Hydroponic Barley Fodder**	**In-Field Barley**
Water Use	3-4L per kg	120-150L per kg
Growth Time	7-10 days	90-120 days
Land Requirement	Minimal (small structure)	Large field
Risk Factors	Mold, heat stress in summer	Drought, pests, variability in rain
Yield Reliability	Consistent if controlled	Dependent on rainfall & soil quality

Hydroponic barley provides an immediate fodder solution during critical feeding gaps, whereas in-field barley is only viable under favourable rainfall conditions.

7.7 CONCLUSIONS AND RECOMMENDATIONS

Hydroponic barley fodder is an effective, rapid solution for resource-poor farmers in Namaqualand. However, production must be carefully timed to avoid extreme summer temperatures and slow winter growth. Climate change is delaying the onset of winter rains, increasing the reliance on supplementary feeding. While hydroponic fodder is more water-efficient than lucerne and in-field barley, it requires consistent management. Integrating hydroponic production with other fodder sources can improve resilience.

CHAPTER 8: GENERAL CONCLUSION

The studies presented across these chapters collectively underscore the potential of hydroponic fodder systems as a transformative solution for livestock production in water-scarce and resource-limited regions, particularly in arid areas like Namaqualand, South Africa. As climate change exacerbates water shortages and reduces the availability of natural forage, hydroponic fodder emerges as a viable, efficient, and scalable alternative to traditional feed sources. The findings highlight its benefits in terms of water conservation, nutritional supplementation, and methane mitigation, while also identifying key challenges that must be addressed to ensure its long-term viability and safety.

Nutritional and Environmental Benefits

Hydroponic fodder, particularly from barley and oats, demonstrated rapid growth and high crude protein content, meeting the nutritional requirements of livestock, even for high-production herds (Chapter 2). This is especially critical in regions where natural forage is deficient in essential minerals like phosphorus and zinc (Chapter 4). The ability to produce nutrient-dense feed with minimal water (as little as 2 litres per kg of fodder) makes hydroponics a game-changer for smallholder farmers facing erratic rainfall and prolonged droughts (Chapter 3). Additionally, the use of locally available water sources (borehole, municipal) without compromising feed quality further enhances its accessibility for resource-poor farming communities (Chapter 2).

Beyond nutrition, hydroponic barley supplementation showed promising environmental benefits by altering rumen microbial composition and reducing methane emissions per unit of feed intake in lambs (Chapter 5). This aligns with global efforts to mitigate livestock-related greenhouse gas emissions while improving feed efficiency. Similarly, goat kids fed hydroponic sprouts exhibited increased feed intake and stable rumen pH, suggesting better digestive health (Chapter 6). These findings position hydroponic fodder not just as a stopgap during droughts but as a sustainable component of climate-smart livestock farming.

Economic Viability and Practical Implementation

From an economic perspective, hydroponic systems offer a cost-effective fodder flow solution, particularly when integrated with existing feed strategies (Chapter 7). The reduced water requirements compared to conventional crops like lucerne make it an attractive option for small-scale

farmers. However, successful adoption depends on proper management – avoiding extreme temperatures (slow winter growth, summer heat stress) and ensuring consistent production cycles (Chapters 3, 7). The elimination of fertilizers in irrigation (Chapter 2) further lowers costs, though initial setup and training remain necessary investments.

Challenges and Risks

Despite its advantages, hydroponic fodder production is not without risks. The unexpected dominance of Anabaena bacteria, a toxin-producing species, in goat kids' rumen raises concerns about possible contamination in hydroponic systems (Chapter 6). This underscores the need for stringent quality control in seed sourcing, water treatment, and hygiene protocols to prevent microbial hazards. Additionally, while dry matter losses in barley sprouts did not negate their nutritional value, optimizing dry matter retention could further enhance feed efficiency (Chapter 2).

Another challenge lies in scaling up production while maintaining consistency. Plastic-covered structures improved yield and water use efficiency over net-covered ones (Chapter 3), but broader adoption requires adaptable designs for different climates. Seasonal forage deficiencies in rangelands (Chapter 4) also highlight the need for hydroponics to complement, not replace, natural grazing systems, ensuring year-round feed security without over-reliance on a single source.

Future Directions and Policy Implications

To maximize the benefits of hydroponic fodder, future research should focus on:

- Contamination Mitigation: Investigating sources of Anabaena and other pathogens to develop safer production protocols.
- Breed-Specific Responses: Evaluating hydroponic feed efficacy across different livestock breeds, particularly indigenous vs. commercial varieties.
- System Optimization: Refining low-cost, climate-resilient hydroponic designs (e.g., passive solar regulation) for smallholders.
- Farmer Training: Providing technical support to ensure proper implementation and troubleshooting.

Policy interventions could incentivize adoption through subsidies for initial setup costs, water-saving agriculture credits, or integration into national drought resilience programs. Collaborative efforts

between researchers, agricultural extensions, and farmers will be essential to tailor hydroponic systems to local needs.

Final Remarks

Hydroponic fodder represents a paradigm shift in livestock feeding strategies for arid regions, offering a sustainable, water-efficient, and nutritionally robust alternative to conventional forage. While challenges like contamination risks and dry matter losses require attention, the cumulative evidence supports its role in enhancing food security, reducing environmental impact, and improving livestock productivity. By addressing these limitations through targeted research and farmer education, hydroponic systems can become a cornerstone of climate-adaptive agriculture, empowering smallholder farmers to thrive in an era of increasing resource scarcity.

In conclusion, the integration of hydroponic fodder into livestock production systems is not merely an innovative experiment but a necessary evolution toward resilient and sustainable farming in water-limited environments. Its success will depend on balancing technological advancements with practical, locally adaptable solutions—ensuring that both livestock and farmers reap the benefits of this transformative approach.

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APPENDICES

CAPACITY BUILDING

1. STUDENT

One student (Miss Imanathi Kekaya) from the Department of Biodiversity and Conservation Biology at the University of the Western Cape was actively with the project during its course.

Most of this report will form part of Miss Kekaya's Master's degree in Biodiversity and Conservation Biology based on the results obtained from the trials conducted. The title of the "**A comparative analysis between the nutritive value of rangeland and hydroponic fodder for sustainable livestock production in the drylands of South Africa**". Miss Kekaya will be graduating in 2025 and is currently employed by the ARC in their internship program. Below Appendix A – F are abstracts and poster presentations Miss Kekaya has presented based on the results obtained from this project.

Appendix A: Abstract submitted to the Grassland Society of Southern Africa 2023 conference held at the Omaramba Holiday Resort and Conference Centre in the North West Province.

A comparative analysis between rangeland and hydroponic fodder nutritive value for sustainable livestock production in the drylands of South Africa.

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As climate change intensifies, increased rainfall variability and extended periods of droughts has been experienced within the Namaqualand region of the Northern Cape of South Africa. This has resulted in increased periods of feed shortages for livestock that are entirely dependent on the natural veld for their daily feed requirements. This, in turn, results in lower nutrient availability for animals, thus reducing weight gain and increasing diseases and pests. To address the issue of closing the ever-increasing feed gaps as well as addressing potential nutrient deficiencies due to poor and inadequate feed supply from the natural veld during especially the dry season, alternative fodder production

options are needed. Thus, feeding systems such as hydroponic fodder could be adopted to fill these gaps and improve the conditions of livestock during marginal times. Hydroponic fodder has been identified as an alternative technology that can be used to produce high-quality forage for livestock during the dry season, without requiring extensive land. Unfortunately, very little is known about the efficiency of these systems, especially low cost systems that can be used under extensive livestock production systems by resource poor farmers. The aim this study is therefore to evaluate the yield potential and nutritive quality of hydroponically produced fodders, and the cost effectiveness of implementing such systems in the arid zone of South Africa. To achieve this aim, the following objectives will be pursued:

1. To assess biomass production of different fodder species produced hydroponically 2. To assess the nutritional value of hydroponic forages and compare it to available dataset on rangeland species nutritional values from the Namaqualand region.

Maize (*Zea mays*), oat (*Avena sativa*), sorghum (*Sorghum sp.*), wheat (*Triticum sp.*), and barley (*Hordeum vulgare L.*) will be evaluated for their fodder yield and quality. This study will assist with achieving the production potential of livestock farming systems in the communal areas that experience fodder shortages during the drier months.

Appendix B: A presentation presented at the Grassland Society of Southern Africa 2023 conference held at the Omaramba Holiday Resort and Conference Centre in the North West Province.

Evaluating the nutritive value of hydroponic fodder for sustainable livestock production in the drylands of South Africa

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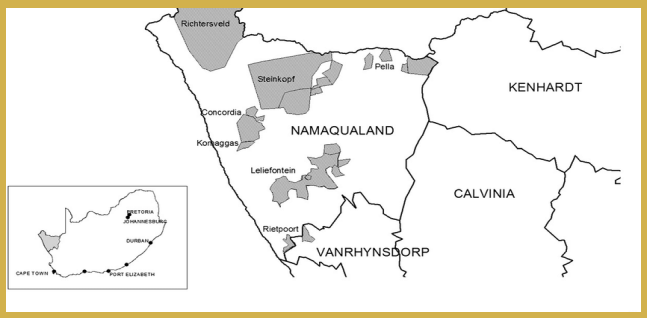
INTRODUCTION

Climate change in the Namaqualand region of South Africa has led to increased rainfall variability and droughts, causing feed shortages for livestock relying on the natural veld. This leads to lower nutrient availability, reduced weight gain, and increased diseases and pests. To address these issues and nutrient deficiencies, alternative fodder production options such as hydroponic fodder can be adopted. This technology can be used to produce high-quality forage for livestock during the dry season, without requiring extensive land or high capital input.

AIMS AND OBJECTIVES

- To evaluate the yield potential and nutritive quality of hydroponically produced fodders, as well as the cost effectiveness of implementing hydroponic systems in the arid zone of South Africa.
- To assess biomass production of different fodder species produced hydroponically.
- To assess the nutritional value of hydroponic forages and compare it to an available dataset on the nutritional values of rangeland species from the Namaqualand region.

STUDY AREA



Layout of the pilot study on Day 4.

Measuring plant growth on Day 8.

PROPOSED METHODOLOGY

- Maize (*Zea mays*), oat (*Avena sativa*), sorghum (*Sorghum sp.*), wheat (*Triticum sp.*), and barley (*Hordeum vulgare*) will be evaluated as the treatments.
- Seeds will be washed with tap water and soaked for 8 minutes with 1% bleach solution to minimize any intrusion of fungi.
- The seeds will be sprouted and grown in plastic containers in a glasshouse with natural day/night cycles and automated sprayer or manual irrigation for 10 days.
- The trays will be punctured at the lower end to ensure that all excess water can run off after watering.
- Plant growth (height) will be measured daily from roots to leaves.
- P, K, Mg, Ca, Na, Fe, Cu, Zn and Mn will be determined using dry ashing technique.
- The N-content will be converted to crude protein by multiplying by a factor of 6.25.
- Acid detergent fibre (ADF) and neutral detergent fibre (NDF) will be determined, and used to calculate the digestible dry matter (DDM), metabolizable energy (ME), total digestible nutrients (TDN), digestible forage energy (DFE), digestible organic matter (DOM) and net energy for lactation, maintenance and gain/growth.

STUDY IMPLICATIONS

- Hydroponic fodder farming provides a high quality, sustainable source of fodder, which can be available year-round and may lead to improved overall livestock condition.
- Moreover, this study will assist with achieving the production potential of livestock farming systems in the communal areas that experience fodder shortages during the drier months.

Appendix C: Abstract submitted to the Grassland Society of Southern Africa 2024 conference held at the Gariep Dam Resort in the Free State Province.

Hydroponic barley fodder: Bridging the fodder gap in arid rangelands of South Africa

Keywords: Water quality, hydroponic fodder, semi-arid rangelands

Kekaya, I. [1,2], Samuels, M.I.S.[1,2], Cupido, C.F. [2], Müller, F. [2] and Engelbrecht, A.[1]
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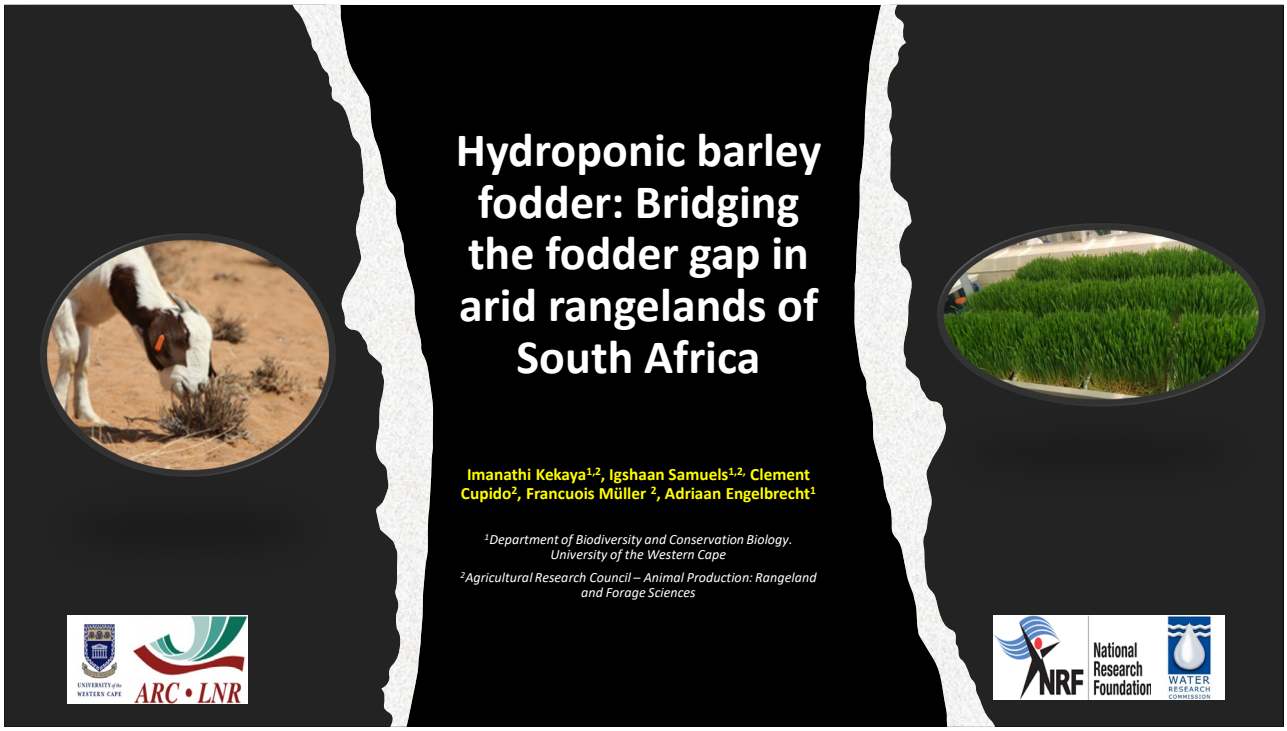
The effects of climate change on rangelands have caused a decline in forage quality and quantity. As a result, animals have less access to nutrients, which lowers weight gain and increases the prevalence of illnesses and pests. Therefore, alternative means of fodder production such as hydroponic fodder production systems need to be explored to bridge the fodder gap. The study aimed to evaluate the potential of implementing a hydroponic fodder system in the drylands of South Africa. The study assessed the effects of irrigating barley with borehole, municipal, nutrient solution and distilled water on its quantity and nutritional quality under a hydroponic system for green forage production. The seeds were sprouted and grown in aluminium containers in a glasshouse with natural day/night cycles and irrigated manually for 10 days. The study found that municipal water had a higher pH (8.6) and was less saline (243.5 mS/m) than borehole water (8.5). Fresh fodder yields ranged from 956 to 1404 g, while dry matter yield was highest in barley irrigated with distilled water. Crude protein content was highest in fodder irrigated with nutrient solution (18.75%), however, all the fodder had better crude protein content (14.18 - 18.75%) compared to natural veld forages (4.8 - 6.9%). Acid detergent fibre concentrations varied significantly between the water sources ($p < 0.05$), while neutral detergent fibre concentrations were not significantly different. Overall, the fodder energy concentrations were insufficient to meet the energy requirements of lambs, dry ewes, and other animals. However, the study found that hydroponic green barley fodder can be safely irrigated with water sources from Namaqualand, resulting in high yields. This, means that hydroponic fodder can be used as supplementary feed for livestock during the dry season. However, research is necessary to assess the effect of temperature on these fodders.

Appendix D: A presentation presented at the Grassland Society of Southern Africa 2024 conference held at the Gariep Dam Resort in the Free State Province.



Appendix E: An abstract submitted to the Arid Zone Ecology Forum (AZEF) 2024 Conference held at the The Barn in Calvinia.

Hydroponic barley fodder: Bridging the fodder gap in arid rangelands of South Africa

Keywords: Water quality, hydroponic fodder, semi-arid rangelands

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Appendix F: A presentation presented at the Arid Zone Ecology Forum (AZEF) 2024 Conference held at the The Barn in Calvinia

2. COMMUNITIES AND FARMERS ASSOCIATIONS

The project has contributed to community capacity building in the Leliefontein Communal Area (Paulshoek) by offering targeted training sessions on hydroponic fodder production. These sessions have equipped the local farmers with valuable knowledge and skills. In the Concordia Communal Area, previous engagements introduced the concept of hydroponic fodder production, sparking interest and enthusiasm among the farmers. They expressed a strong willingness to participate and requested to be guided through the full production process. To further strengthen community capacity, ongoing support and additional training sessions are needed across the various communal areas.

Appendix G: The invitation extended to the Paulshoek communal farmers, training and demonstration.

Acknowledgement: The late Mr. Sors Cloete of Paulshoek played a key role in championing the WRC hydroponic fodder project in his community. His energy, curiosity, and commitment to farming excellence will not be forgotten.