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Coopworth hogget and lamb liveweight gain on regenerative and conventional dryland pastures

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A dissertation

submitted in partial fulfilment

of the requirements for the Degree of

Bachelor of Agricultural Science with Honours

at

Lincoln University

by

Breanna M. Holt

Lincoln University

2024

Disclaimer:

The data for this dissertation were collected as part of the Regenerative Agriculture Dryland Experiment (RADE) at Lincoln University. The candidate was responsible for all of the data collation and analyses.

Abstract of a Thesis submitted in partial fulfilment of the requirement for the Degree of Agricultural Science with Honours

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by

Breanna. M. Holt

Regenerative systems have been proposed as a potential greenhouse gas mitigation strategy for New Zealand agricultural systems. They focus on a holistic approach which encompasses, plant, animal, soil and community health. Regenerative agriculture principles claim to naturally increase carbon storage, soil fertility and biodiversity while producing the equivalent harvestable product of conventional systems. This dissertation reports on the liveweight gain of Coopworth hoggets and lambs grazing conventional and regenerative dryland pastures under high (20 mg/kg) and low (10 mg/kg) Olsen P giving four treatment groups: high conventional (HC), low conventional (LC), high regenerative (HR) and low regenerative (LR).

The research period was within the establishment phase of the ongoing regenerative agriculture dryland experiment at Lincoln University. Four 2-ha farmlets, of 20 paddocks each, were established between 10 December 2021 and 16 March 2023. Grazing management and pasture species were the main attributes under investigation. Animals under regenerative management grazed multi-species forages (>8 species), under high intensity, short duration, with high residual, rotational grazing. Whereas, conventional grazing management was rotational, with duration and rotation length based on pasture cover.

Differences in animal liveweight gain (LWG), were explained by the pasture production and quality for each of the two Coopworth flocks (ewe hoggets and then ewe lambs) which grazed between 11 September 2022 and 3 August 2023. The first ewe hogget flock grazed between 11 September 2022 and 3 March 2023. These animals were replaced with new season ewe lambs from 3 March to 3 August 2023.

Conventional treatments produced the greatest LWG. The Coopworth hoggets and lambs grazed on conventional pastures accumulated 42 to 60 (hoggets) kg LWG/ha and 15 to 28 (lambs) kg LWG/ha more than those on RA treatments. This difference was attributed to greater crude protein content

(20% CA, compared with 15% RA) and lower neutral detergent fibre (40% CA, compared with 46% RA) due to increased legume in the lucerne-based conventional diet. This meant animals met their daily intake requirements sooner which enabled increased total intake, due to increased rate of rumination. Pasture production and quality were affected by water stress in this summer dry rainfed environment. Pastures were shown to be water stressed from 13 November 2022, when 157 mm actual soil moisture deficit was reached, until March 2023. During autumn and winter 2023 pasture grew based only on rainfall. Soil water had not recharged until July 2023. There was no effect on pasture quality or legume production during the experimental period due to Olsen P treatments, however, further research over time is required to confirm these results.

Keywords: disappearance method, diverse pastures, estimated intake, nutritive value, selectivity, theoretical ME requirements, water use efficiency, *Bromus catharticus* L., *Cichorium intybus* L., *Dactylis glomerata* L., *Festuca arundinacea* L., *Medicago sativa* L., *Plantago lanceolata* L., *Trifolium subterranean* L., *Trifolium repens* L., *Trifolium pratense* L., *Lolium multiflorium* L.

Acknowledgements

Firstly, I would like to thank my family and Jack for your endless support, love, advice and encouragement throughout my university journey and life. Thank you for believing in me on all the days I didn't. I wouldn't be half the person I am today without you. Particular thank you to Mum for reading all my "books".

To my flatmates and friends, thank you for the support, love, fun and providing sanity throughout my university journey. I can't wait to see what you all achieve as the next chapter begins and appreciate you all immensely.

To Dr. Anna Mills, thank you so much. This project definitely would not have been completed without your help. Thank you for your patience, wisdom, help and support, you truly are a legend.

To Malcolm Smith, thank you for your guidance, stories and jokes over the last two years, you are an inspiration.

To Dr. Alistair Black, thank you for your help and guidance throughout my project. I appreciate the time you put into helping me with my project.

To Dr. Mariana Andreucci, over the past two years you have taught me so much and become someone I aspire to. Thank you for your guidance and support - it doesn't go unnoticed.

Finally, I would like to thank my supervisor, Prof. Derrick Moot. You have had a significant impact on my time at Lincoln as a person and as a student. You have encouraged me to step outside of my comfort zone on many occasions, thank you… I definitely needed the push. I am very grateful for the opportunities you have presented me, along with your time, support, guidance and advice. Your dedication, enthusiasm and extensive knowledge are inspiring. I look forward to working with and learning from you in the next three years.

This report includes animal liveweight, yield and botanical composition data from the Lincoln University RADE experiment. This experiment forms part of the Whenua Haumanu programme (https://www.massey.ac.nz/about/colleges-schools-and-institutes/college-of-sciences/our-research/themes-and-research-strengths/whenua-haumanu/), funded by the Ministry for Primary Industry (MPI). Whenua Haumanu is a partnership between Massey University and the MPI through the Sustainable Food and Fibre Futures fund. Programme delivery partners include Lincoln University, AgResearch, Manaaka Whenua and the Riddet Institute. We thank M. Smith for managing the technical team responsible for field measurements.

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Chapter 1

Introduction

Globally, the food system has increasingly been criticised as being in a state of 'crisis' or 'broken' with concerns about synthetic chemical use, declining food quality, environmental degradation, animal welfare, and labour relations (Harwatt 2018). Soil health and biodiversity have deteriorated, and crop yields had plateaued (Giller *et al*. 2021). Accelerated production has led to soil erosion, degradation, and increased reliance on fossil fuels (Rhodes 2017). This situation has prompted a reassessment of agricultural practices and a growing interest in 'Regenerative Agriculture' (RA). Agriculture (food production) accounts for about 15% of global greenhouse gas emissions (Newton *et al*. 2020) and contributes significantly to land use change. At the same time, globally demand for food production continues to rise due to population growth and increased per capita demand (Newton *et al*. 2020).

In New Zealand, RA has gained traction for its reported potential to mitigate climate change and the environmental impacts of food production (Grelet et al. 2021). It is also claims to offer market and social benefits for producers. Pastoral agriculture is also the key economic driver in New Zealand, and in 2021 it contributed to 50% of the export value (Caradus et al. 2023). This system relies heavily on perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), particularly in high-fertility, summer-moist systems. However, these pasture species often struggle in the ~4 M hectares of hill country and dryland (rainfed) regions, which face additional challenges of acidic soils and limited phosphorus (Moir et al. 2016). Summer dry farming areas, have annual rainfall between 450-750 mm and high evapotranspiration rates, so require resilient pasture species such as cocksfoot (*Dactylis glomerata* L.), subterranean clover (*T. subterraneum* L.), and lucerne (*Medicago sativa* L.) to ensure high-quality feed and efficient livestock production (Mills & Moot 2010). Efficient growth of grazing livestock is crucial for early finishing lambs in these summer dry environments. This is required to ensure that breeding stock are maintained through summer which in turn can increase scanning and lambing rates and lamb survival (Moot et al., 2019).

Despite the growing interest in RA, there has been no comprehensive assessment of its effectiveness in New Zealand or globally. RA claims include improved soil fertility, carbon storage, and biodiversity through reduced synthetic chemical use and increased pasture diversity (Khangura et al. 2023, Tozer et al. 2023). This study aims to evaluate whether regenerative multispecies pastures can match or exceed the animal production performance of traditional dryland pastures (lucerne and cocksfoot/subterranean clover) in a grazed farmlet under low and high Olsen P levels. Measured animal performance is explained as a function of herbage availability, quality, and intake.

1.1 Aims and objectives

The aim of this research is to understand the factors which affect the liveweight gain of Coopworth hoggets that grazed on conventional or regenerative dryland pastures. To achieve this, several linked objectives were identified:

Objective 1: Describe the grazing management and basis for regenerative and conventional pastures, and how this relates to pasture quality and quantity.

Objective 2: Quantify the annual growth of Coopworth hoggets and lambs that grazed either conventional or regenerative pastures under high and low Olsen P.

Objective 3: Quantify herbage production in the period of grazing (kg DM/ha) for conventional and regenerative pastures under high and low Olsen P.

Objective 4: Quantify herbage intake using the disappearance method (kg DM/head/day) for the period of grazing and compare with theoretical intake methods for conventional and regeneratively managed pastures under high and low Olsen P.

Objective 5: Quantify feed conversion efficiency (kg LW/kg DM) of animals grazing conventional and regenerative pastures under high and low Olsen P.

Objective 6: Quantify nutritive quality (i.e. metabolisable energy, crude protein, fibre content, botanical composition) of conventional and regenerative pastures under high and low Olsen P.

This dissertation is presented in five chapters. Chapter 2 is a review of literature which relates to the management of dryland pastures, their production, quality and expected growth rates from grazing livestock. This review defines RA and compares it with conventional agriculture (CA). It also describes and assesses the effectiveness of the three main methods of estimating grazing animal intake, and the importance of Olsen P in pasture production. Chapter 3 is the materials and methods, which outlines the field measurements and analysis. Results from the experiment are presented in Chapter 4. Findings from the results are discussed in Chapter 5 to establish research conclusions.

Chapter 2

Literature review

2.1 Introduction

The rising interest in regenerative agriculture (RA) has recently extended to New Zealand as a prospective strategy to mitigate and lower greenhouse gas emissions (Grelet & Lang 2021, Grelet et al. 2021). Despite this growing attention, RA has so far been implemented on a small scale worldwide, and its outcomes have not been thoroughly quantified (Grelet et al. 2021). As a result, RA's claims remain largely unverified, which limits quantified comparison to conventional agriculture (CA) practices and production. To make meaningful comparisons between RA and CA concerning animal performance, particularly in relation to feed quantity and quality, it is essential to understand key factors, including differences in system practices, animal intake, energy requirements, and Olsen P (phosphorus) status.

This review provides insights to the movement toward RA and the current limitations of the practice. It will define RA as an agricultural system, outline its principles—both globally and within New Zealand—and explore the proposed role and production of diverse pastures. Conventional approaches to managing pastures, such as lucerne and cocksfoot/subterranean clover under dryland conditions, will also be reviewed with respect to pasture productivity and animal performance. Understanding animal performance and liveweight gain involves evaluating feed quantity versus quality and how these factors influence intake. Direct measurement of animal intake in the field is challenging. Therefore, researchers often rely on estimation methods such as the disappearance method, n-alkane markers, and theoretical calculations (Nicol & Brookes 2017, Waghorn et al. 2017, Akdağ & Ocak 2019). These methods can be used to explain to the impact of diet on liveweight gain, including feed utilisation and selectivity. Olsen P levels may play a critical role in RA versus CA outcome. Legume production is typically greater with higher Olsen P, as it enables the legume to compete with grasses (Scott 1973, Maxwell et al. 2013, Moir et al. 2016). Therefore, Olsen P may potentially influence pasture quantity, quality, and, consequently, grazing livestock performance.

2.2 Regenerative Agriculture

Regenerative Agriculture has been linked to agriculture since the late 1970s but only gained broader recognition in the 1980s through the Rodale Institute in the US (Giller et al. 2021). The term surged in popularity in the 1980s, and by 2016, RA saw a significant rise in adoption due to endorsements from organisations, multinational companies and charitable foundations such as Greenpeace, Kellogg's,

Patagonia, and IKEA Foundation (Giller et al. 2021). Robert Rodale (1983) defined RA as a practice which enhances soil biological production, minimises environmental impacts, while also enhancing biological and economic stability. Harwood, (1983) - an agronomist and director at Rodale Institute in 1983 – expanded on this definition to include integration of all farm system components. He emphasised the importance of the biological balance and the maximisation of desired biological relationships in the system. Regenerative agriculture's primary intent is to improve soil health, restore degraded soils, enhance water quality and use efficiency, as well as enhance vegetation (pasture or crop) production and land productivity (Rhodes 2017). In this, the practice aims to increase soil organic carbon (SOC), to build new soil, improve soil structure, health, fertility, increase crop yields, water retention and aquifer recharge. However, despite the growing attention around RA from different stakeholders, the term is not well defined or proven to achieve any of its desired outcomes.

A review by Newton et al. (2020) found diverse interpretations of RA. This revealed many definitions based on various processes and outcomes. Processes focused on practices, for example, cover crops, integration of livestock, reducing or eliminating tillage. Whereas outcomes focused on objectives such as, soil health, carbon sequestration and increased biodiversity. Some defined it as a combination of the two. Newton et al. (2020) described the process-based definitions which implied that advocates/users are open-minded to possible outcomes of the practice. While outcome-based definitions refer to users which are open minded to practices, which may lead to desired outcomes. This uncertainty has created tensions among policymakers, researchers, and consumers regarding RA's implementation both globally and in New Zealand (Newton et al. 2020).

Regenerative Agriculture (RA) is claimed to boost food production sustainability and aid in global climate change mitigation (Newton et al. 2020, Grelet et al. 2021). It is also presented as a long-term, holistic approach to maximise food production while revitalising soil and facilitating carbon sequestration (Rhodes 2017). Market potential is also a common driver for the implementation of RA especially for New Zealand systems (Grelet et al. 2021). However, the lack of a clear definition for RA has hindered research and verification of its benefits, complicating efforts to study its adoption and impact (Newton et al. 2020). Additionally, the absence of a standardised definition can mislead consumers, leading to misunderstandings within the supply chain (Moon et al. 2017).

Grelet et al. (2021) explored RA within the New Zealand context, developing a framework to guide future research. Their study, conducted in 2020, involved 70 organisations and 200 participants, including farmers, researchers, and industry professionals. They highlighted that while some conventional New Zealand practices align with RA principles, scepticism remains due to the

undefined nature of RA. A secondary argument is that conventional practices may already incorporate some regenerative principles. Table 2.1, adapted from Grelet et al. (2021) compares conventional New Zealand systems with RA principles, noting that synthetic fertiliser and chemical use are main areas of incompatibility. The principles of regenerative agriculture are further discussed in Section 2.2.1.

Table 2.1: Compatibility of common conventional management practices in NZ systems with instructional RA principles (#4 learn together, #5 failure is part of the journey, #8 maximise photosynthesis year-round, #9 minimise disturbance, #10 harness diversity) (Adapted from (Grelet et al. 2021)

Conventional practice or management strategy	Compatibility with RA principles
Pastoral Farming Systems	
Rotational grazing with year-round perennial pastures	Compatible # 8 and #9.
Mixed grass and legume perennial pastures	Compatible #10.
NZ rotational grazing has low GHG and water footprints per kg of product, and NZ farmers are known for innovation.	Compatible #4 & #5.
Set stocking, short rotations, or severe grazing (low residual)	Incompatible with #8 – suppresses growth, exposes bare soil.
High use of synthetic fertilizers and herbicides	Incompatible with #9 – disturbs soil microbiome.
Tillage for cropping and monoculture pastures	Incompatible with #9 and #10 – leads to low diversity and soil loss.
Arable Farming Systems	
Increasing adoption of no-till practices	Compatible with #9.
Diverse crop rotations with livestock integration	Compatible with #10.
Winter cover and catch crops reduce fallow periods, though some bare soil remains	Partial compatible/incompatible with #8.
Monoculture cropping with high fertilizer and pesticide use	Incompatible with #10 – reduces diversity, disrupts soil microbiome.

Table 2.2 (Grelet et al. 2021) summarised the practices commonly adopted by RA practitioners, with bolded sections indicating those not typically used or advised in conventional New Zealand agriculture. Key differences include a greater diversity of species in forage and perennial pastures, reduced or eliminated use of synthetic fertilizers and chemicals, and an increased use of bio-stimulants or carbon-rich amendments to stimulate soil microbiome activity. However, many RA practices overlap with those in conventional systems. For example, Tozer et al. (2023) observed that several RA practices are already being implemented within New Zealand's conventional systems, such as the growing adoption of direct drilling.

In the survey by Grelet et al. (2021), the claim that "New Zealand is already regenerative" was found to be inaccurate. However, no published data from New Zealand's regenerative agriculture (RA) systems exist to directly compare with conventional practices, leaving RA claims unverified. New Zealand's conventional agriculture excels in several areas, contributing nearly 50% of export value (OECD 2019, Caradus et al. 2023). Pastoral systems have comparatively low greenhouse gas emissions per kilogram of milk (~1 kg CO_2e/kg milk) and meat (beef: ~10 kg CO_2e/kg live weight, sheep: ~5 kg CO_2e/kg live weight) due to year-round high-quality pasture grazing, unlike many northern hemisphere systems that rely on housed animals (Ledgard 2021). Since 1990, increased

lambing efficiency has reduced the lamb sector's carbon footprint by 22%. Additionally, New Zealand agriculture maintains relatively high soil carbon levels and demonstrates a commitment to preserving natural capital—such as mountains, rivers, and ecosystems—which contribute 30% of GDP (Grelet et al., 2021).

Table 2.2: Practices used by RA practitioners. The list is continually evolving. Practices in **bold** are <u>not used/advised</u> in conventional practice (Adapted from (Grelet et al., 2021).

Practice	Description	Purpose
Diverse cover crops	Arable - Short term, non-cash crops sown between cash crops. Include species with different plants functional traits **(>8 species).** Seed growers may be limited to 4-8 species to avoid cross-contamination risks.	Maintain photosynthesis – increase insect and microbe diversity and abundance. Protect soil from sun, wind and rain. Mobilise and cycle nutrients. Improve soil health (soil structure). Reduce pest/disease pressure in next crop.
Diverse forage crops	Usually, **>8 species** with different intended functions (e.g. animal nutrition, soil/plant health). Grazed: summer, autumn and winter.	Provide feed when demand exceeds pasture supply. Diverse diet – animals select for different nutritional needs. Habitat and food for beneficial insects/reduce pest pressure. In-fill species suppress weeds Reduce chemical/fertiliser requirements Increased litter protects soil from hooves. Some species regrow post grazing. Maintain/improve soil health.
Diverse perennial pastures	**16 to 40+ species** sown using **direct drilling** – perennial plant community with high functional diversity. Botanical composition and diversity change through time.	Increased resilience to climate variation Increased nutritional quality of forage More even growth rates year-round Maintain/improve soil health Reduce/eliminate leaching
Bale grazing	Placing bales throughout paddock while strip grazing in winter. Hay balanced with pasture. **Intentional bale 'wastage' creates fertiliser effect, improves soil health.**	Feed supplement during slow-growth winter period – replacing need for forage crops. Increased nutrient, carbon and seed inputs. Balanced protein, energy and fibre feed supply.
No-till and residue retention	Crops/pasture sown without cultivation. Retaining crop residues at soil surface.	Reduce soil disturbance Lower crop/pasture establishment cost Protect soil from wind, sun and rain Residue feeds worms/soil organisms.
Integrated pest management	Arable – promote beneficial insects, predate on crop pests.	Increase natural control of crop pests Reduce pesticide use.
Minimising synthetic fertiliser inputs	Multiple strategies: foliar application, increased nutrient cycling, increase N fixation, changing fertiliser source (natural)	Reduce negative impact on soil biota Reduce losses to waterways. Increased uptake efficiency Reduce input cost, maintain/improve profitability.
Minimising chemical inputs	Reducing/**eliminating** chemical inputs where practical. Such as: seed dressings, weed sprays, fungicides, insecticides, drenches, cleaning products, and/or **substituting with biological alternatives**.	Reduce impact on beneficial insects, soil and rumen microbiome. Minimised harm to insects, fish, animals, and people. Improve ecosystem resilience/pest outbreaks.
'Buffering' synthetic and chemical inputs	**Using C-based products such as humate-derived substances to chelate fertiliser and chemicals**	Increase input efficiencies, reduced rates. Support biological breakdown.
Inoculants, bio stimulant**s** and carbon-rich amendments	Inputs designed to enhance soil, plant, animal microbial function – either targeted or general. Common products: **Fish hydrolysate, seaweed derivatives, diluted seawater, compost, aqueous compost extracts, biochar**, isolated fungi/bacteria strains.	Increase/promote biological activity, soil biodiversity, soil functional diversity. Turn on quorum sensing genes. Optimise mobilisation of nutrients from complex/bound forms. Physiochemical immobilisation of excess minerals.
Mineral balancing and trace elements	Ensure sufficient soil minerals are available, so to not antagonise the ability of plants to uptake what they need. **Practitioners sometimes use Albrecht-Kinsey soil audit methodology to diagnose balancing requirements.**	Optimise elemental stoichiometry in soil and soil flocculation. Reduce/eliminate micronutrient deficiencies in plants and animals.
Timing interventions using the lunar calendar	**Some practitioners consider lunar/astral cycles to determine the timing of practices e.g. planting or harvest.**	Optimise plant growth, and quality of plant biomass at harvest.
Regenerative grazing management	**Adaptive multi-paddock grazing,** deferred grazing.	Increased carbon fixation (via increased photosynthesis). Promote carbon allocation below-ground (litter trampling/root exudate) Increase nutritional value of forage for animals Provide shelter to livestock from wind and sun exposure.

Despite these strengths, conventional agriculture faces significant challenges. Annual soil loss is substantial, amounting to 192 million tonnes (Ministry for the Environment & Stats NZ 2018).

Approximately one-third of soils have excessive phosphorus levels, and nearly half exhibit low microporosity. Agricultural runoff contributes 95% of river nutrients, intensifying nitrate pollution (OECD 2017, 2019). Furthermore, 46% of lakes larger than one hectare have poor to very poor ecological health, and regions like Canterbury, Otago, Marlborough, and Hawke's Bay exceed sustainable water usage levels (Ministry for the Environment & Stats NZ, 2020). Agriculture is responsible for nearly half of New Zealand's emissions, and climate change is expected to worsen these issues with increased droughts, severe rainfall events, pests, diseases, and a temperature rise of 0.7–3°C by 2090 (Ministry for the Environment 2016, Grelet et al. 2021).

Regenerative Agriculture has often been associated with "sustainable farming" but distinguishes itself through a holistic approach that addresses environmental, economic, social, and cultural outcomes both within and beyond the farm. Regenerative agriculture claims to reduce greenhouse gas emissions by lowering methane production through optimised grazing, enhanced carbon sequestration and soil health, and maintained productivity with less environmental impact per unit of yield. Promotion of pasture diversity is believed to improve nutrition, disease management, and decrease the need for chemicals, through integration of natural ecosystem functions and adding value from farmer to consumer. The aim of RA practices is to be adaptable to specific environmental contexts, to optimise inputs while maximising outputs. However, a significant limitation of all these practices, is the lack of an evidence base to confirm whether their intended benefits are reliably achieved. Therefore, research is needed to assess the impacts of these practices on soil health, plant productivity, and animal performance, which is critical for evaluating their viability. Therefore, this study will focus on how RA management affects pasture production factors and how this affects the liveweight gain of grazing Coopworth hoggets and lambs.

2.2.1 Principles of Regenerative Agriculture

Globally, regenerative agriculture (RA) was defined by principles that varied by region. Moyer et al. (2020) from the Rodale Institute emphasised principles such as restoring degraded soils, promoting soil health, and carbon sequestration. In the US - where monocultures and limited crop rotation had historically led to issues such as the Dust Bowl of the 1930's - RA focused on improving soil health and diversifying practices.

Harwood (1983) outlined RA principles, which included: Producing highly nutritious food free of biocides. Relying on biological interactions and eliminating synthetic biocides. Increasing soil productivity and fertility. Enhancing nutrient-flow systems and reducing environmental impact. Avoiding synthetic fertilisers to maintain biological structure. Fostering a close relationship between the manager and the system. Utilising biological nitrogen fixation – legumes. Managing animal feed

and housing to avoid hormones and antibiotics. Generating increased employment. Balancing national planning with local self-reliance.

Moyer et al. (2020) identified similar principles: crop rotation diversification, cover crops, compost use, managed grazing, minimised tillage, and elimination of synthetic chemicals. In the UK, Jaworski et al. (2024) focused on minimising soil disturbance, increasing crop diversity, maintaining soil coverage, maintaining living roots, and boosting soil organic matter. Giller et al. (2021) emphasised minimising tillage, maintaining soil cover, carbon sequestration, biological nutrient cycling, plant diversity, livestock integration, avoiding pesticides, and encouraging water filtration.
While principles across the US and UK focused on soil health, diversity, carbon sequestration, and minimising synthetic inputs, they lacked specific, quantified goals for practitioners. For instance, there was no standard soil carbon percentage target for climate change mitigation.

Questions have been raised about whether RA introduces new practices to New Zealand given that New Zealand pastural systems have comparatively high soil organic matter levels and similarities between common practice and identified principles. To address this, Grelet & Lang, (2021) sought to identify principles which guide New Zealand RA farmers decision-making and practices, which offer a framework for those interested in adopting RA practices in New Zealand (Grelet et al. 2021)**.** Some of the principles have a focus on adoption and encouragement of the practice, while others have a direct focus on the biological/ecological function of the system. While the principles are not definitive, they provide guidance for farmers and growers. Grelet & Lang (2021) and Grelet et al. 2021) surveyed 21 leading RA practitioners and developed 11 context-specific principles outlined in Table 2.3.

The survey was conducted across focus groups across four sectors—dairy, sheep and beef, arable, and viticulture. Four from dairy, four from sheep and beef, seven from arable, and five from viticulture, including both farmers and advisors. From the principles identified there was a strong emphasis on the treatment of farms as living ecosystems, with requirement of time and energy invested to learn how nature functions (Grelet & Lang 2021).

Table 2.3: 11 principles of New Zealand Regenerative Agriculture, identified by focus group of 21 leading RA practitioners (Adapted from (Grelet & Lang 2021).

1.	**The farm is a living system**	Understanding of how nature works to support holistic decision-making – whole system – soils, plants, animals, people, flora and fauna.
2.	**Make context-specific decisions**	Context varies between person, place and season to season, adaptation of system and practices to suit.
3.	**Question everything**	Active curiosity, question beliefs and test ideas.
4.	**Learn together**	Connect with like-minded peers, enhance learning and gain perspectives.
5.	**Failure is part of the journey**	Failure provides the best learning opportunities – push beyond comfort zone.
6.	**Open and flexible toolbox**	Try to use practices to improve ecosystem function, while maintaining other ideas for alterations
7.	**Plan for what you want; start with what you have**	Transitions take time, have clear goal, monitoring and planning
8.	**Maximise photosynthesis (year-round)**	Treat the farm like a solar panel – increased leaf area supports increased photosynthesis, increased food source for microbes and improved soil health.
9.	**Minimise disturbance**	Maintain soil cover and limit disturbance from chemical application, soluble fertiliser, machinery and livestock compaction.
10.	**Harness diversity**	Diversification of whole ecosystem – microbes, insects, plants, birds, livestock, and community.
11.	**Manage stock strategically**	Management of livestock to be a tool to build biological function and fertility in the soils.

It was recognised that each farm is unique, necessitating innovative and context-specific approaches. They also emphasised mindset, mental health, and community-building more than those in the US and UK. With a focus on attitudes and behaviours essential for managing complex systems. Therefore, practitioners are open to interpretation, and variation based on region, sector and value chain (Grelet & Lang 2021). An issue with this is that it makes RA practices difficult to benchmark against for production system comparison. Despite some criticism of the Grelet et al. (2021) white paper regarding its representation of RA scepticism, there was broad agreement on the need for robust scientific testing of RA claims (Wells 2021). However, the social aspect of RA makes it difficult to measure to be able to compare to conventional systems.

Therefore, the overarching goal, was to create a management system, which emulates natural ecosystems – flora and fauna. This involves the role of: soils - biological (microbes) and chemicals (nutrient cycling), plants and animals (Grelet & Lang 2021). Plants contribute to nutrient cycling, support microorganisms, regulate soil temperature, improve water infiltration, and reduced erosion. Diversity in livestock and wildlife (including birds, insects, and microorganisms) is promoted to enhance animal health, nutrient cycling, and pasture recovery through managed grazing rotations. Grazing practices are designed to ensure pasture recovery, maximise photosynthesis, maintain ground cover while protecting soil from erosion and extreme weather conditions.

Principles identified are to be used as a foundation for farm-level RA principles in New Zealand. Different people and organisations may evolve these principles for their own system or incorporate with other areas of focus such as economics. However, a notable limitation is the lack of quantified

benchmarks for practitioners to target and limited comparative data to evaluate RA against New Zealand CA systems. Further research into how RA management would affect pasture production and therefore animal performance is important to access the viability of the system.

2.2.2 Diverse pastures

Diversification of pastures and crops is a crucial component of RA principles. The RA grazing approach is described as a holistic planned grazing, or adaptive rotational grazing (Morris 2021). It involves the rotation of dense livestock herds, through multiple paddocks in short grazing periods to defoliate plants evenly. Followed by long recovery periods to promote regrowth. This method is believed to enhance soil regeneration and ecosystem services through hoof action, which integrates plant material into the soil, thereby boosting microbial activity, increasing forage grasses and forbs, and encouraging beneficial insects (Morris 2021). However, Morris (2021) noted that while RA management can be adapted to support a diverse range of biota, it does not universally promote biodiversity.

Research on diverse pastures has explored their potential to enhance water utilisation, drought tolerance, and carbon sequestration however, all research has been performed under conventional management. Rutledge et al. (2017) and Skinner et al. (2006) examined soil carbon storage under diverse pastures (8-11 species). Rutledge et al. (2017) found a higher net ecosystem carbon balance (NECB) of 254 g C m^2 over three years in diverse pastures compared to non-renewed ryegrass-white clover pastures, though diverse pasture remained a carbon source. This aligned with Cong et al. (2014) and Lange et al. (2015), who reported increased plant diversity enhanced soil carbon storage. In contrast, Skinner et al. (2006) observed soil organic carbon (SOC) remained unchanged or decreased under an 11-species mixture by 2-3 g/kg topsoil.

McNally et al. (2015), found that moderately diverse pastures had significantly greater root mass - up to 952 g/ha more, to 300 mm in summer compared with ryegrass-clover pastures. Diverse swards had nearly double the root mass between 100-300 mm depth when compared with ryegrass-clover, likely due to the deep taproot nature of lucerne and chicory (*Cichorium intybus* L.). This contributed an estimate of 1203 kg C ha^{-1} more to soil C inputs annually, excluding C inputs from rhizodeposition (including root exudates and cell sloughing) estimated to contribute 2.5 times that of root mass (Johnen & Sauerbeck, 1977). McNally et al. (2015) concluded that if these results were consistent across New Zealand soils, then moderately diverse pastures could increase soil C in grazed pasture systems. This research is provided to give context to research on diverse pastures however, similar data will not be presented in the following research.

Diverse pastures tend to lose diversity over time, as more competitive species dominate. Rutledge et al. (2017) saw an increase in the ryegrass component of the NewMix (8 species, diverse) from 19% to 46% between Year 2 and Year 4. In contrast ryegrass declined by ~10% in NewRye (renewed perennial ryegrass-white clover) and Control (non-renewed RG/WC) between Years 3 and 4. McNally et al. (2015) also experienced seasonal difference in diverse pastures, where RG made up a larger proportion of annual herbage, but in the spring increased to 31-41%, and dropped through summer/autumn. Whereas lucerne increased (14-20%) through summer. Rutledge et al. (2017) found that in summer, herbs (plantain and chicory) made up a larger proportion of the sward, up to 65%, while ryegrass dominated in the winter.

Research has found that diversity with two or more species can provide additional yield benefits known as the 'diversity effect' (Black et al. 2021). Where the inclusion of other species improves the outcome when compared with the monocultures on their own. A common example of this is mixing a grass with a legume, as the N fixation provides N to the grass, increasing yield. A challenge as mentioned above is maintaining diversity where the community of plants are all competing for the same things: light, water, and nutrients. Therefore, understanding how each plant species contributes and interacts in a plant community is important (Black et al. 2021). An important component for long term persistence in diverse pastures is the seeding rate for each species. A resilient pasture mix should use the ability of legumes to fix N to reduce reliance on N fertilisers. While use of a canopy made up of different leaf arrangements between grasses, legumes and herbs allow more efficient light capture. As a result of these components, yield and quality increase (Hay & Porter 2006, Black et al. 2021).

Nobilly et al., (2013) researched dairy cow performance under irrigated diverse pastures in Canterbury. They compared DM production, composition and nutritive value over two years. Pasture included simple two-species pasture mixes perennial ryegrass, high sugar ryegrass, or tall fescue with white clover, and diverse pastures (chicory, plantain, Lucerne, red clover, white clover, prairie grass and either ryegrass, high sugar ryegrass or tall fescue). Diverse pastures produced 1.6 t DM/ha more annually, due to a higher summer production, however, had slightly lower ME (12.0 compared with 12.2 MJ ME/kg DM – due to increased legume) and neutral detergent fibre (301 vs. 368 g/kg DM) – which was attributed the plantain/chicory component. Overall ME production was greater under diverse pastures; 202 (diverse), 185 (simple) GJ ME/ha. The research found that addition of legumes and herbs to simple pastures could enhance DM and ME production under irrigated conditions – comparable studies under dryland conditions are lacking.

As with Rutledge et al. (2017) and McNally et al. (2015), seasonal changes in botanical composition were also observed by Nobilly et al. (2013). In the simple pastures (HS, TF and RG), grasses are of a greater proportion (70-80%), while legumes sit between (10-30%). In diverse pastures (RGD, HSD, TFD) grasses made up 30-70% and by the end of the second year were between 40-60%, herbs made up a similar percentage, and legumes peaked at 20% in summer, and ranged between 5-20%.
The nutritive value of the diverse pasture was discussed by Nobilly et al. (2013) as presented in Figure 2.1. Information on the digestibility and quality of the pasture is important to help explain intake by grazing animals and liveweight change. From this it is likely that animals grazing simple pastures were able to consume less dry matter to meet ME requirements. However, the increased fibre content may have reduced their intake due to increased rumination time.

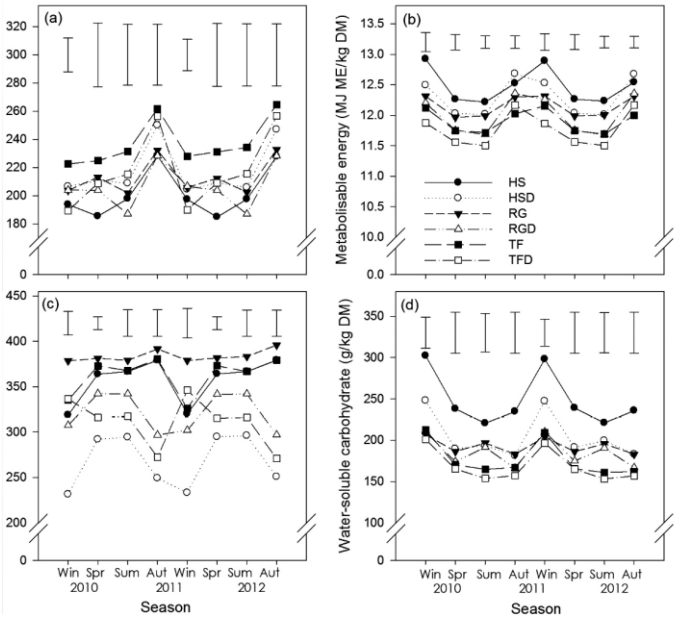

Figure 2.1: Seasonal pasture (a) crude protein (g/kg DM), (b) metabolisable energy (MJ ME/kg DM), (c) neutral detergent fibre (g/kg DM) and (d) water-soluble carbohydrate (g/kg DM) for all pasture mixes from June 2010 to May 2012 in Lincoln. HS = High sugar ryegrass-white clover, RG= ryegrass-white clover, TF= tall fescue-white clover, RGD= Ryegrass simple pasture with added herbs and legumes/diverse, HSD= high sugar ryegrass simple pasture with added herbs and legumes/diverse, TFD = tall fescue simple pasture with added herbs and legumes (From Nobilly et al., 2013)

Daly et al., (1996) compared a multi-species pasture with ryegrass-white clover at two dryland sites – Mid Canterbury, Winchmore Research Station (739 mm/yr rainfall), and Marlborough, Lower Awatere Valley at Dashwood (590 mm/yr rainfall). Over three years, pasture mass was cut using hand clippers, prior to grazing (visually assessed ~2500-3000 kg DM/hd) using adult ewes. Lower mass targets were used during summer/winter due to cold/dry resulting in cessation of growth. Grazing or topping reduced post-grazing residual to 2.5 cm within 1-3 days. Each site had four pasture treatments: ryegrass standard (RG), comprehensive multi-species pasture (CMSP), lucerne multi-species pasture (LMSP), and red-clover multispecies pasture (RMSP).

Figure 2.2 (Daly et al. 1996) shows annual DM production over the three-year period at the two sites. Pasture mass in the first year was not different, however, in the second year, MSP treatments

produced 2 t DM/ha more (P<0.05) than the RG treatment. As a result, MSPs pastures were concluded to be a viable option in summer dry systems offering increased DM production that RG/WC pastures. Pasture mass was not found to be different between diverse and renewed ryegrass-white clover by Rutledge et al. (2017) in Waikato, New Zealand. Whereas Skinner et al., (2006) reported a 43% increase in DM using diverse pastures in comparison to a cocksfoot and white clover mix in Pennsylvania, USA.

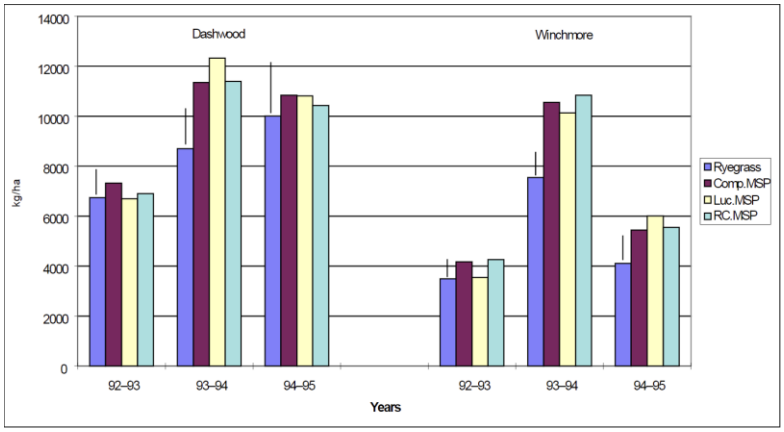

Figure 2.2: Annual dry matter production at Dashwood and Winchmore over a three-year period 1992-1995 (Daly et al. 1996).

Daly et al. (1996) did not investigate the long-term persistence of the MSPs or their effect on animal performance. However, the pastures with high legume component were expected to support higher animal performance. Therefore, LMSP was recommended as it maintained the highest legume proportion (40 and 21% at Dashwood and Winchmore respectively) in Year 3, compared with 18 and 17.8% for RMSP or 16.8 and 15.7% in RG, respectively (Daly et al. 1996).

All diverse pasture research done in New Zealand has been completed under conventional management, with no studies conducted under regenerative management or directly measuring livestock productivity on diverse pastures.

2.3 Dryland Conventional pastures

2.3.1 Lucerne pastures

Lucerne is a pasture species commonly used in rainfed; summer dry environments due to its deep taproot (Mills & Moot 2010). It is a high-quality feed, which has been shown to increase the productivity of farm systems with increased liveweight gain. The metabolisable energy content of lucerne averages ~11.0 MJ/kg DM. However annual ME production was reported as ~134 GJ/ha/yr and >500 kg N/ha/yr in a rainfed environment, with annual long term average rainfall of 624 mm. In this field study completed in Lincoln, Canterbury during 2007/08, lucerne pasture were found to produce between 833 – 1100 kg LW/ha/year (Mills & Moot 2010). Other species within the

experiment were found to have a lower ME yield, ~36.8 GJ ME/ha/yr and ~18.0 GJ ME/ha/yr for subterranean clover and ryegrass/white clover, respectively.

An example of liveweight increase through lucerne grazing, was Bog Roy Station. This is a 2860 ha high country station (Moot et al., 2019). Over a decade, the initial 60 ha area of established lucerne was extended by 30 ha per year from 2008 to 2018. In the first three years total lamb meat weaned increased from 91 to 130 t. By 2018, this had increased to 160 t, and ewe numbers increased by 900. Along with liveweight increase, lambing survival increased to 141% and lamb growth rates reached >270 g/hd/d by 2018. Average weaned lamb weight increased from 25 to 37 kg.

Lucerne grazing management is critical to achieving productivity in lucerne pastures (Moot et al., 2019). Winter management focuses on weed control and a late June/early July 'clean-up' graze, to promote vigorous, early spring growth. This hard grazing helps remove overwintering aphids without damaging new basal buds. This graze should be followed, 7-10 days after by an appropriate contact residual herbicide such as Paraquat or Atrazine (Moot et al., 2003). The stand should be then left to recover until spring defoliation. Weed control and timing of final grazing are crucial to the lucerne yield. Failure to correctly manage a lucerne stand during the winter can result in a 25% decrease in final yield and increase weed content by up to 50%, as found in a study at Ashley Dene, Lincoln University Research Farm, Canterbury (Moot et al. 2003).

Spring management should focus on maximisation of lamb or priority stock liveweight gain or yield for conservation (Moot et al. 2003). Increased temperatures and non-limiting light and water conditions promote growth - grazing rotation should be based on crop growth – not developmental stage. Where lucerne exceeds 30% of farm cover, early spring (September) grazing of ideally an older stand should begin at 15-20 cm (1500 kg DM/ha) to maintain quality throughout the rotation. Rotational grazing should always be used to protect basal buds to ensure persistence. By grazing the first paddock of the rotation at 1500 kg DM/ha, in a six paddock rotation the final paddock is 4000 kg DM/ha after 4-5 weeks. Higher than this quality begins to decline. Stocking rates should ensure vegetation is fully grazed within 7-10 days (Moot et al. 2003).

For conservation, the stands should be harvested at 40-50 cm to maximise quality, while minimising lodging risk (Moot et al. 2003). Lucerne should be cut above the basal buds, to stimulate bud expansion, by increase in the far red: red light ration at the plant base. High quality feed, such as lucerne, does come with animal health risks, commonly red gut. Fibre should be provided to stock to help reduce animal health risk – such as hay, however, palatable weeds, or the lignified proportions of the lucerne stems also help provide fibre (Moot et al. 2003).

From October through to February the aim remains to maximise the liveweight of priority stock. In the summer, without water stress, growth and development increases in response to increased temperature and photoperiod (Moot et al. 2003). Moisture availability strongly effects regrowth. Drought stress results in reduced DM production, and it increases crop canopy temperature due to reduced transpiration (Brown et al. 2003, Moot et al. 2003). Therefore, phenological development and senescence are increased which reduces quality. Under water stress, lucerne should be hard grazed and rested to prevent damage to basal buds, to allow rapid recovery following rainfall. Priority stock should graze solely on lucerne for 6-8 weeks to maximise liveweight gain with an allowance of 2.5-4.0 kg DM/hd/d (Moot et al., 2003). Stock will selectively graze high quality parts of the plant first. Residual can be grazed by low priority stock or mown. Optimal grazing management should allow a 35±4-day regrowth period (Moot *et al.,* 2003).

The focus of autumn management shifts from production to lucerne stand persistence. As a long-day plant, lucernes thermal time requirement to flower increases under a decreasing photoperiod. To replenish root reserves for overwintering and spring production, lucerne stands should be left to reach 50% flowering in late-February/March before grazing (Moot et al. 2003). Root reserves, come spring, support basal bud development and shoot growth through carbohydrate translocation. Therefore, the management of lucerne monocultures is well understood for productivity so will be applied to CA systems.

2.3.2 Cocksfoot/subterranean clover pastures

Subterranean clover (SC) is a winter annual, legume species, widely used in summer-dry, rainfed environments in Oceania and elsewhere (Guo et al. 2023). In dryland systems, spring is critical to maximise pasture production for high stock growth rates, before summer dry (Brown et al. 2006). Sub clover provides a high-protein and energy feed source - ME ~12 MJ ME/kg DM (Olykan et al. 2019, Guo et al. 2023) – grazed by ewes during early lactation, to increase milk production, and live weight (LW) gain of lambs. Particularly valuable to east coast dryland sheep and beef systems. Correct management of SC has resulted in increased liveweight (LW), as seen at Tempello, Marlborough (Grigg et al. 2008). Lamb LW gain increased from 258 g/head/day in 2001, to 350 g/head/day in 2007. Raising total production from 60 to 76 tonnes, despite decreased ewe numbers between 2001 and 2007.

Cocksfoot (CF) is a commonly sown pasture grass in New Zealand, recommended for areas with low to moderate soil fertility typically in summer-dry regions, due to its drought tolerance (Mills et al. 2006). A study at Lincoln University found cocksfoot under non-limiting conditions can yield 22 t DM/ha (Mills et al. 2006). But only 7.5 t DM/ha when N and water are limiting. Under dryland

conditions with N, a yield of 15 t DM/ha was achieved (Mills et al. 2006). When temperature was accounted for using thermal time, growth rate of non-limited CF was 7.0 kg DM/^{o}Cd, compared to 3.3 kg DM/^{o}Cd without N. Drought impacted growth consistently, with a reduction in yield of 1.42 %/mm of soil moisture deficit beyond the critical threshold, regardless of N application (Mills et al. 2006). While N was found to have the greatest impact on yield when water was not limited, growth cannot occur without adequate soil moisture. When sufficient water was present, growth was primarily determined by the availability of N in the system (Mills et al. 2006)

Sub clover and CF are commonly sown together as a high quality, drought resilient pasture. Where SC provides N to increase the yield and quality of cocksfoot, while cocksfoot's clumped growth habit prevents shading out of sub clover (Brown et al. 2006, Mills et al. 2006). In dryland conditions CF/SC pastures have been found to yield 12 t DM/ha/yr and produce 814 to 912 kg LW/ha/yr (Ates et al., 2010; Mills & Moot, 2010). These pastures also yielded 79-96 GJ ME/ha/yr, and yield of 269-316 kg N/ha (Mills & Moot, 2010). Managed CF/SC pastures maintain low weed contributions. By year seven, unsown component accounted for 28% of total yield, compared with 55% in RG/WC pastures (Mills et al. 2008). At Ashley Dene research farm, SC pastures grew at >60 kg DM/ha/day in spring – 40% faster than grass-dominate pastures under non-limited conditions (Ates et al. 2010). Mills & Moot, (2010) and Brown et al., (2006) concluded that lucerne and/or CF/SC pastures were persistent, high yielding pastures for dryland systems, which increased quality and quantity of feed during times of high demand. As a result, improved liveweight production and finished lambs earlier, compared with RG-based pastures.

As with lucerne, grazing management is important to the persistence of SC in pasture swards, particularly during vulnerable periods. Olykan et al. (2019) outlined a grazing management regime for a summer-dry Wairarapa hill-country farm. Sub clover germinates in autumn following rainfall >20 mm. Grows through the winter and early spring before flowering mid-spring, setting seed and dying prior to summer moisture deficit in December. The lifecycle of the plant allows persistence where white clover often fails. Key to SC's persistence is management of grass competition for light, and restriction of livestock grazing to protect flowers and ensure seed set (> 200 seeds/m^{2}) (Ates et al. 2008). Therefore, late summer/early autumn, pastures require hard grazing to 600 kg DM/ha allowing light to the base of the canopy (Olykan et al. 2019). After sufficient rainfall for germination, grazing should be restricted until the growing point has been pulled below the soil surface (typically four trifoliate leaves) (Thomas, 2003).

High priority stock (e.g. ewes with twin lambs) should graze from July through to flowering (Olykan et al. 2019). Through flowering, cattle at low stocking rate (1.5/ha) or weaned lambs can also graze during October to maintain grass growth at 1200 kg DM/ha. During seed set, grazing should be

avoided to allow runners to spread and set seed. Post-seed set, depending on the feed quality, graze priority stock, followed by low-priority stock to clean-up mature pasture. Then graze through summer as seasonal rainfall allows.

Ates et al. (2008) investigated the effect of stocking rate on SC and animal production under rainfed conditions at Ashley Dene, Canterbury in 2006 and 2007. They found under low (8.3 ewes +twins/ha) individual lamb growth was higher (327-385 g/hd/d), but total production was lower. Compared to high (13.9 ewes + twin lambs/ha) which had a spring growth rate of 253-285 g/hd/d, but due to more animals, produced more product per hectare. Final lamb weights were 29-32 kg under high, and 34-40.5 kg under low. This difference was due to greater pasture mass; 5450 (low) compared to 4860 (high) kg DM/ha, with a greater clover content; ~3000 (low) compared to ~2700 (high) kg DM/ha. As a result, low had a greater ME which fluctuated between 10.5 and 12.0 MJ ME/kg DM. Improved diet quality from clover lead to greater lamb LWG, particularly noticeable in the mid-November to early-December results. During this period, clover content declined by 10%, which resulted in declined growth rates 260 and 158 g/head/d at low and high stocking rate, respectively. This is because, crude protein is essential for accelerated growth of lambs due to high requirement from muscle growth (Brookes & Nicol 2017)**.**

Therefore, CF/SC pastures provide high-quality early spring pasture in summer-dry systems, allowing high growth rates >350 g/hd/d. The growth cycle of CF/SC pairs well with lucerne. As with lucerne, management of CF/SC pastures is well researched and will be followed in CA systems.

2.4 Comparison of grazing systems

Regenerative agriculture is a relatively new concept to New Zealand agriculture, the research focus has been around distinguishing RA from CA New Zealand systems. Due to this, there are few on-farm comparisons between the two management systems. However, Tozer et al., (2023) completed a farm management and pasture survey on 13 regenerative and 12 conventional sheep and beef farms in the North Island of New Zealand. Farms were paired based on geographical location and livestock type. Pasture samples were collected at 2-3 month intervals, 30 random samples were taken along a transect across each farm. Pasture samples were bulked, mixed and sub-sampled. Herbage nutrient content was taken from ground freeze-dried (-20^{o}C) sub-samples. The near infrared reflectance spectroscopy (NIRS) analysis of the herbage sample gave crude protein, digestibility and metabolisable energy. Botanical composition was sorted from the remainder of the sample, separated into perennial ryegrass, other grasses, legumes, broadleaf species and dead within 48 h of collection.

The survey found that there was no significant difference in the number of grass, legume and broadleaved species (Tozer et al. 2023). Regenerative pastures had a greater total number of plant species 9.4 compared with 7.7 species. However, regenerative managed pastures had 30% less perennial ryegrass, while the percentage of other grasses and broadleaf species was similar in both systems. Between the two systems there was no difference in before and after grazing herbage mass (Tozer et al. 2023).

Regenerative farms tended to focus heavily on cattle, with fewer livestock classes (two) compared to conventional farms (four). This could be attributed to the smaller size of RA farms (average 176 ha), compared to CA (average 335 ha) (Tozer et al. 2023). Interestingly, 5% of the farm area was re-grassed under regenerative management, compared with 3% under conventional management. Both management systems showed preference for direct drilling over full cultivation. RA farmers commonly used pasture seed mix which included 20 pasture species, whereas conventional farmers used between 2-6 species of a range of grasses, legumes and herbs. Tozer et al. (2023) discussed that while regenerative farmers aimed to achieve greater diversity in their pastures, this was not achieved in the measured pastures which had not been cropped in the prior five years. However, it was noted that repeated measurements would be required throughout the year. There was no difference in herbage quality (e.g. ME, CP and NDF) between systems. Therefore, animal performance per kilogram of DM eaten should be similar between systems.

The paper determined that the greatest difference between the management systems was the fertiliser policies. Regenerative farmers consistently thought synthetic fertilisers such as superphosphate, DAP and urea should not be used for regenerative farming. This was also found in the survey by Grelet et al. (2021). However, there was no consistent trend regarding herbicide and chemical usage (Tozer et al. 2023).

RA farmers were found to use a broader range of nutrients, such as lime, and mineral mixes containing trace elements and base cations (Tozer et al. 2023). As a result, soils had a higher pH, as well as greater exchangeable calcium, magnesium and sodium. Herbage contained greater amounts of calcium, boron and molybdenum, however, tended to have a lower Olsen P. The reduction in N and P inputs correlated to the reduction in perennial ryegrass and increased legume growth. However, it was noted that legume content may decline in the future, as P was not being applied. Olsen P levels were not reflected in the herbage analysis for both conventional and regenerative pastures, which indicated that P was non-limiting for plant growth. Despite fertiliser management differences, herbage mass between farm types were similar, while pasture growth was found to be

slow following summer drought. RA farmers aimed to maintain higher residuals, but it was highlighted that this was not always attainable in practice, particularly following drought.
Other similarities between the systems included minimal reliance on imported feed, with a focus on feed produced on farm from pasture and crops, and a reduction or elimination of tillage. These practices are considered characteristics of regenerative farming (Newton et al., 2020; Tozer et al., 2023). The paper questioned whether New Zealand conventional sheep and beef farms could be considered regenerative in many aspects as mentioned by (Grelet et al. 2021).

2.5 Methods of estimating intake to explain changes in liveweight

This section aims to explain methods of estimating intake and how they relate to animal performance. There are three main methods of estimating intake: the disappearance method, n-alkanes and theoretical ME requirements. The disappearance method and theoretical intake were used in the research and therefore will have a larger focus in this section.

2.5.1 Apparent intake – pre and post disappearance method

The disappearance method is a direct measurement of pasture mass before- and after- grazing, where the difference in mass represents the amount eaten (Akdağ & Ocak 2019). Results can be reliable if the grazing period is short under high stocking density. In this respect it would work well for measurement of intake under regenerative management. However, bias when sampling could become an issue. The main disadvantage is the re-growth of the pasture during the period of grazing, under low intensity and/or extensive grazing. This is a particular issue in periods of high growth (Sharrow & Motazedian 1983). This is because, growth during the period of grazing may result in a reduced estimated intake value. Therefore, estimation of intake becomes difficult to determine when measuring the difference between pre- and post-grazing masses under a longer grazing duration (Akdağ & Ocak 2019). This can be mitigated by taking extra samples between grazing to calculate the rate of pasture growth overtime. However, if the grazing period is one to three days, then it is accepted that grass re-growth is not significant (Burns et al. 1994). The method is generally used to estimate herd intake, rather than individual animal intake (Akdağ & Ocak 2019a). However, is low-cost, easy to implement and returned typically reliable results. The method involved the harvest of pasture from a known area, before and after grazing to estimate pasture mass per hectare. Samples are often dried to estimate dry matter (DM) content to calculate kg DM/ha, which can then be used to estimate DM intake (kg DM/ha), shown in Equation 2.1.

Equation 2.1: Calculation to estimate apparent intake through the disappearance method (Akdağ & Ocak 2019)

$$\frac{(DM\ in\ the\ cage\ or\ before\ grazing\ (kg/ha\ ) - DM\ out\ of\ the\ cage\ or\ post\ grazing\ (kg/ha\ ) x Area(ha)}{Number\ of\ grazing\ days}$$

Macoon et al. (2003) in a study on Holstein cows found that the disappearance method and animal performance method resulted in estimates of intake that were not different and therefore suitable for estimation of intake. Studies have found the disappearance method to overestimate intake Sharrow & Motazedian (1983) and Akdağ & Ocak (2019). Studies by Burns et al. (1994) and Macoon et al. (2003) found that the herbage disappearance method was closely approximated to the animal performance estimation when animal grazing was short (1-3 days grazing), rotational and if a cutting technique which accounted for trampled material was used (~3 cm).

2.5.2 Alkenes and Alkanes

Methods of estimating grazing animal intake are often labour intensive and expensive (Decruyenaere et al. 2009). They can also be unrepresentative of the true grazing conditions experienced by the animals, which leads to inaccuracy. Indirect measurement of intake included use of indigestible plant components (e.g. lignin, alkanes or insoluble ash excreted in the faeces) as faecal markers to estimate intake (Akdağ & Ocak 2019). For a compound to be successfully used as a marker it needs to be unabsorbable and should be unaffected by the microbial population of the rumen.

The n-alkane method is commonly used to estimate animal intake first introduced by Mayes et al. (1986) as an alternative to the chromium oxide marker method**.** The n-alkane markers naturally exist in the epicuticular waxes of plants along with alkenes, long-chain alcohols, sterols, aldehydes, long-chain fatty acids and flavonoids (Pepeta et al. 2022). These compounds can be used as biomarkers and are unique to different forages and plant parts. Therefore, oesophageal extrusa, stomach contents or faeces can be used to estimate botanical composition of the animal's overall diet (Akdağ & Ocak 2019, Pepeta et al. 2022). Compounds such as alkenes can be used to determine diet composition. Odd-chain lengths n-alkanes (C_{29}, C_{31} and C_{33}) naturally exist in higher proportion than even-chain lengths (C_{30}, C_{32}, C_{34}, C_{36}) (Lippke 2002, Akdağ & Ocak 2019). Rate of recovery from faecal samples approach 100% from C_{31} (Lippke 2002). Commonly, alkanes are administered by a commercial capsule which secretes a known dosage of the n-alkane typically C_{32} (Smit et al. 2005). The n-alkane method uses the ratio of odd- to even-chain length alkanes in the dung to determine herbage intake by the animal. The method allows accurate individual determination of feed intake without information on total dung or digestibility of the feed (Mayes et al. 1986). However, administration of capsules is highly labour intensive and comes into contention with animal welfare, and therefore was not used on the regenerative agriculture dryland experiment.

2.5.3 Theoretical intake

Feed value is based on the nutritive value and intake (Waghorn et al. 2017). Pastures range from poor quality (high fibre, low digestibility and low intake) to highly digestible (high protein, low fibre

and high (≥11) ME) in a range of mixtures and monocultures. For ruminants grazing temperate forages, energy is usually the most limiting factor for productivity. Intake of a forage can be limited by bulk (high water content) and fibre. These are the primary cause for decreased production in grazing high-quality pasture in comparison with total mixed ration diets (Waghorn et al. 2017). Fibre provides a significant source of energy but needs to be chewed (ruminated) to reduce its size to move it out of the rumen, limiting daily intake (Waghorn et al. 2017). Forage consumed by ruminants is distinguished by the difference between what is on offer and what is eaten. Selection of what is eaten is driven by pasture species and the age of the animal. Selection can also be affected by palatability, aversion and nutrient requirements, but most significantly by availability (Cosgrove & Edwards 2017, Waghorn et al. 2017). Under intensively managed grazing systems with consistent pasture residual, opportunity for selection is decreased. However, this intensity maintains higher quality pastures compared with extensively managed systems where selection is high, but quality is sacrificed (Waghorn et al. 2017). Based on this, CA systems are likely to maintain quality for longer, in comparison to RA systems which allow high selectivity.

Young stock tends to select a higher protein, low fibre diet compared with mature animals (Hughes et al. 1984). This is because protein requirements in younger stock are higher and reduce with age, due to requirements for muscle growth and development (Brookes & Nicol 2017, Lee et al. 2020). To increase lamb growth rate, high protein forages such as lucerne are commonly grazed in New Zealand dryland systems. Sheep and cattle selectively graze both grass and legumes when given the opportunity (Hughes et al. 1984, Waghorn et al. 2017). Ruminants also tend to select leaf over stem and avoid dead material - low energy and protein content (Waghorn et al. 2017).

Animal production is a function of feed intake, which is a function of feed availability, nutrient demand, appetite and composition of the diet (Waghorn et al. 2017). In most grazing systems stock are required to meet the dual purpose of animal production and sward maintenance. Therefore, young stock are usually allowed *ad libitum* access to feed, followed by lower priority stock (e.g. weaned lambs followed by ewes). Highest intakes are achieved with high quality forages, as rumination and eating time are reduced, therefore, the animal can eat more. For example, if the feed is high in fibre, residues may remain in the rumen until fermentation is almost complete – limiting feed intake. In contrast, intake can also be limited by high quality legume feed which is rapidly digested and results in the production of ammonia and volatile fatty acids. Consequently, results in decreased intake where adequate fibre is not provided (Waghorn et al. 2017).

The weight of green pasture eaten to meet requirements of lambs can exceed 4% of liveweight. Therefore, for a 35 kg lamb, DM requirement is therefore 1.4 kg DM/hd/d (NRC 2007). However, as

sheep get larger the proportion of LW the animal can intake decreases where a 60 kg ewe can only ingest between 2-4% of its LW. Therefore, intake can be estimated based on the quality of the feed eaten (ME, digestibility/palatability, DM%, and pasture availability - grazing pasture mass), and liveweight of the animal. A high-quality pasture will have an ME ~13 MJ ME/kg DM, where a medium pasture will have an ME ~11 MJME/kg DM and a crude protein percentage of ~25 and ~15% respectively. Dry matter proportion differs among pasture species, and seasonally. For example, C3 grasses (temperate grass; perennial ryegrass, cocksfoot etc) typically have a DM% of 20%, made up of 20% crude protein (CP), 22% non-fibre carbohydrate (NFC) and 43% neutral detergent fibre (NDF) (Waghorn et al. 2017). Whereas for legumes (white and red clover, lucerne), these were 18, 28, 27 and 30% for DM, CP, NFC and NDF respectively.

Intake is strongly influenced by feed availability (Cosgrove & Edwards 2017). There is a curvilinear relationship between increased pre-grazing pasture mass and pasture intake. Therefore, at higher pre-grazing masses there is increased pasture intake and increased per head performance. However, the proportion of pasture utilised will be low due to high post-grazing residuals/high selectivity. Whereas, under lower pre-grazing pasture mass there is decreased intake and performance, but greater utilisation. Selectively, from within a pasture has a large impact on intake (Cosgrove & Edwards 2017). For both sheep and cattle, time of rumination is decreased when fed a clover diet in comparison with grass. With results of 5.4 and 7.9 (sheep) and 2.8 and 4.6 (cattle) seconds/g DM ingested, for clover and grass respectively. This also allows greater intake as rumination time decreases. Thus, more feed can be ingested per day. Therefore, as explained by Waghorn et al. (2017) high protein, low fibre diets - increase the intake of animals and consequently result in increased performance, particularly for young growing stock such as lambs and hoggets. Therefore, it likely that animals dominantly grazing lucerne will have a higher intake than animals grazing a mixed sward, or grass dominated sward due to increased fibre content increasing rumination time. Waghorn et al. (2017) described the protein and energy requirements of sheep and cattle for maintenance and production. With increased production, energy for maintenance increases with increased digestion and metabolism of a higher nutrient intake. This requires a larger liver, and increased heart effort. The proportion of energy for maintenance declines as more is used for synthesis of product (e.g. muscle, wool or milk).

Maintenance requirements for animals are affected by (Nicol & Brookes 2017): Species: larger animals require more energy. Liveweight: higher for larger/heavier animals. Age: higher requirement for younger animals than older animals on a per kg live weight basis. Sex: higher for males than females. Grazing environment: increased pasture mass, decreased grazing cost – reduced energy expenditure grazing. Topographical environment: increased requirement on hill country – increased

expenditure walking. Climate: increased requirements below critical temperature – because of wind, temperature or rain – higher expenditure maintaining warmth. Feed quality: lower maintenance requirements with high ME feed.

Additional ME requirements are required for liveweight change (rate and composition of the animal), pregnancy (litter size, birth weight, stage of gestation), and lactation (milk yield, milk composition, and weaning weight). Failure to meet the energy requirements results in decreases in liveweight where the pasture either is of insufficient quantity and/or quality. Calculations based on a range of assumptions and measurements have some error associated with them. However, estimates of nutrient requirements are generally accepted to be within ±10%. Therefore, rounded to the nearest 0.5 MJ below 10 MJ ME/kg DM, and 1.0 MJ above 10 MJ ME/kg DM (Nicol & Brookes 2017). Actual requirements between animals will also differ due to inherent between-animal variation. Therefore, when defining requirements for a flock/herd inclusion of a safety margin is important to prevent underfeeding some individual animals.

The total energy requirement of an animal is the sum of their metabolisable energy (ME) requirements for maintenance, liveweight change, pregnancy, and lactation (Nicol & Brookes 2017). Metabolisable energy is that energy which is available to the animal or readily digestible. Maintenance requirements are defined as the amount of ME required to keep an animal at a constant body weight, or constant energy content – in the absence of pregnancy, milk production or liveweight change. Costs of grazing should also be accounted for in maintenance (Nicol & Brookes 2017). While few animals solely require maintenance energy, it provides a basis to which other production energy requirements are added to. Theoretical methods can be used to back calculate the amount of energy that would have been required to achieve the change in average liveweight. Therefore, can infer the amount of energy that the animal consumed or relative intake if average pasture ME is known. Equations for ME maintenance and change shown in Table 2.4

Protein requirement for maintenance of whole-body protein synthesis (synthesis and degradation of proteins occur simultaneously) is 10-20 g/day/kg $BW^{0.75}$ in sheep (Waghorn et al. 2017). Metabolisable protein (MP) is calculated by a factorial approach which sums the MP needed to replace degraded tissue as MP retained in products of growth such as wool, pregnancy and milk (Brookes & Nicol 2017). Protein requirements were not calculated for this study.

Table 2.4: Metabolisable Energy (ME) requirements for grazing sheep (adapted from Nicol & Brookes (2017).

ME calculations (Nicol & Brookes 2017)
ME for basal metabolic rate is calculated from: **ME_b = species*sex*0.28*EXP(-0.03*age in years)*(LWT^0.75)/k_m** Where: Species = 1.0, 1.3, 1.5 and 1.4 for sheep, beef cattle, dairy cattle, and deer respectively Sex = 1.0 for females and castrates, and 1.15 for entire males and cryptorchids k_m = M/D*0.02+0.5, where M/D = ME concentration of the feed DM (MJ ME/kg DM)
Grazing activity includes energy to chew, and walking activity: **ME graze = LWT*[(species*DM intake*(0.09-Dig)]/k_m** Where: Species = 0.02 for sheep & deer < 100 kg and 0.0025 MJ/kg LWT for cattle & deer > 100 kg. Dig = DM digestibility, calculated as (M/D)/15.088
ME move = [0.0026*LWT*S*(TRS/SD)/(0.57*PM+0.16)]/k_m Where: S= Slope (1.0, 1.5, 2.0 for flat, easy and hard hill respectively) TSR/SD = relative stocking rate which takes default value of 1.0 for sheep, beef cattle and deer, and 0.07 for dairy cattle. PM = pasture mass in tonnes DM/ha
Finally, other activity costs associated with grazing: **MEactivity = LWT*[(0.0026*Hkm)+(0.028*Vkm)]/km** Where: Hkm = horizontal km walked Vkm = vertical km climbed
Metabolisable energy requirements for liveweight gain are calculated as: **ME_g=1.1*LWT*NE_g/k_g** Where: LWG = liveweight gain (kg/day) NE_g = (0.92*LWG)*((6.7+(((920*LWG)/4 *(SRW^0.75)))-1))+(20.3-(((920*LWG)/(4*(SRW^0.75)))-1))/(1+EXP(-6*((LWT/SRW)-0.4)))) SRW= standard reference weight or mature body size (kg) k_g (dry) = (M/D*0.042)+0.006

2.6 Effect of Olsen P on pasture production

Low soil phosphorous is common in New Zealand dryland systems (Maxwell et al. 2013). Consequently, legume persistence is often restricted. Legumes in these systems are an important source of nitrogen and feed value. Phosphorus is important for persistence of legumes in a pasture sward. In general, increased soil P allows a higher proportion of legume to persist. At lower Olsen P, legumes are often outcompeted by grasses. This is because grass demand for P needs to be fulfilled before the legume (Scott 1973). A study by Maxwell et al. (2013) found that 95% of maximum yield in sub clover was 6.3 g DM/pot at a rate of 500 mg P kg^{-1}, this was also where white clover reached 95% maximum yield (Moir et al. 2016). Sub clover also had the greatest yield response to P - after arrow leaf clover - at low phosphorus input 100 mg P kg^{-1} (Moir et al. 2016). Differences in P use efficiency among legume species can be attributed to genetic adaptation to low fertility environments (Maxwell et al. 2013).

Lucerne has been found to grow in low P environments with little effect on yield. A glasshouse experiment by Berenji et al. (2017) found a three-way interaction between lime, P and nitrogen. The experiment had nitrogen treatments: N1 – control (0); N2 – 50 kg N/ha; N3 – rhizobia inoculation. Phosphorous treatments: P1- control (0); P2 – 250 mg P/kg soil. Lime treatments: 0, 0.5, 1, 2 and 4 t lime/ha. They found that with increased lime number of plants and root DM (g DM/m^2) increased.

Plant survival was also increased with increased N, which highlighted the importance of rhizobia for lucerne survival and persistence, where in the control tubes on average only six of 20 plants survived 228 days. Whereas 50 kg N/ha or rhizobia inoculate increased plant survival to 13. The paper did not look at shoot biomass, however, root biomass at 2t lime/ha, with rhizobia inoculant and no P, resulted in 880 g/m^2. This was an increase from 260 g/m^2 with 1 t lime/ha in the same treatment. This result suggests that pH and nitrogen availability are more important for lucerne growth than P – however further research is required.

Olsen P is the commonly used method of measuring plant available P in New Zealand. It was first developed in 1954 by Olsen et al., (1954) to predict crop growth response to P fertiliser inputs in calcareous soils. These are soils with a high carbonate content (>2% calcium carbonate), and was primarily used through North, central and western United States (Sims 2000).
Edmeades et al. (2006) using a dataset of 2244 pasture P, K and S field trials in New Zealand, found where data were sufficient, that pasture yield based on Olsen P had a strong relationship, and could be estimated based on Olsen P.

Roach et al., (1995) investigated the effect of years of nil or maintenance application of P fertiliser (250 kg/ha/yr superphosphate) on pasture production and botanical composition. The experiment was measured on a hill country farmlet near Te Kuiti at AgResearch's Kuiti Research Area long term grazing trial, established in 1983. The soil type was sedimentary, with a small variable component of volcanic ash in the topsoil. Nil P resulted in a 29-35% decrease in annual pasture production, as well as 54-72% reduction in legume production (white clover). Plots were located on easy (10-20^o) or steep (25-35^o) slopes in four paddocks with either north or south facing aspects. An application of 23 kg P/ha to nil P treatments, resulted in a 180-330% increase in legume content, which was twice as high on steep slopes as easy slopes. Withholding P for 10 years resulted in total pasture production reduction of one-third, as well as decreased legume component by two-thirds. Application of P, even at rate of 23 kg/ha increased legume content significantly, which increase N fixation, and therefore significantly increased feed quality, important for livestock production.

Therefore, Olsen P is closely correlated with legume content and pasture production as the grass requirement must be met before the legume has access to P. In theory by maintaining an Olsen P around 20, in comparison to 10, pasture mass should be increased along with legume content, providing increased quantity and quality pasture for grazing livestock. However, where grass is not present, increased Olsen P may not affect legume production.

2.7 Conclusions

Regenerative agriculture has been proposed as a farm system which aims to holistically manage soils, plants and animals, to improve their production as well as social/cultural factors. The idea has stemmed out of the US, dominated by monocultural systems, which have historically led to soil degradation.

- Conventional systems within New Zealand, display many characteristics generally agreed to be regenerative. The main difference is the use of synthetic fertilisers/chemicals.
- Regenerative farmers aim to have greater diversity in their pastures - graze intensely for shorter periods, maintain higher residuals.
- Diverse pastures under conventional management have been found to increase yield in summer-dry areas, compared to RG/WC pastures. Animal production on diverse pasture or under regenerative management has not been researched.
- Lucerne monoculture and CF/SC pasture have proven to be high quality, drought tolerant forages, which produce high growth rates (>300 g LW/head/d).
- The disappearance method and theoretical intake are accurate measurements of animal intake, which can be associated to liveweight gain.
- Olsen P is considered important for maintaining persistence of legumes in pasture swards. Under low P conditions, legumes are often outcompeted by grass species, reducing nitrogen fixation and pasture quality.
- Research suggests that Olsen P may not affect the performance of lucerne monocultures, therefore Olsen P may not affect yield or pasture quality. However, will likely affect multispecies mixes due to greater proportion of grasses. RA pastures with high Olsen P are more likely to have higher legume production than low Olsen P.

Chapter 3

Materials and Methods

3.1 Site description

Data on Coopworth ewe hogget and lamb live weight and forage variables were collected over 11 months (September 11, 2022 – August 3, 2023) from the long-term, farmlet-scale Regenerative Agriculture Dryland Experiment (RADE) at Lincoln University's Field Research Centre (43°38'54.20"S, 172°27'34.30''E, 9 m above sea level). The experiment is made up of five Latin squares (LS), in paddocks H11, H12, H13, H14, H17 and H19 of the Lincoln University horticultural area, located on Templeton silt loam and Wakanui silt loam soils (Manaaki Whenua 2024). Templeton soils found at the site are defined using USDA classification as Typic Immature Pallic Soils (Manaaki Whenua 2024), characterised as moderately well drained with high water holding capacity (148-165 mm/m). The Wakanui silt loam is classified as a Mottled Immature Pallic Soil (Manaaki Whenua 2024), characterised as imperfectly drained with a high soil water holding capacity 166 mm/m. Both soil types have no significant rooting barrier. Across the experimental site, an average AWC of 157 mm/m was used. The perimeter of the experimental area is surrounded by hedged poplar and willow trees, with heights between 8 and 20 metres, which is one of the reasons a LS design was chosen (Watson et al. 2024).

The long term average (2002-2022) annual rainfall of the site is approximately 590±26.5 mm/yr (Figure 3.1) with a potential evapotranspiration of ~1000 mm (Figure 3.3) (NIWA 2024). However, in the period the Coopworth's grazed the RADE experiment rainfall was 690 mm (1 September 2022 to 31 August 2023) (Figure 3.1). February, March and July received a higher amount of rainfall than typically expected, with 40-60 mm more than the long-term mean. Temperature ranges and monthly PET are shown in Figures 3.2 and 3.3, respectively. Figure 3.4 is the potential soil moisture deficit against actual soil moisture deficit, using 157 mm per one metre of soil as the available water capacity (Manaaki Whenua 2024).

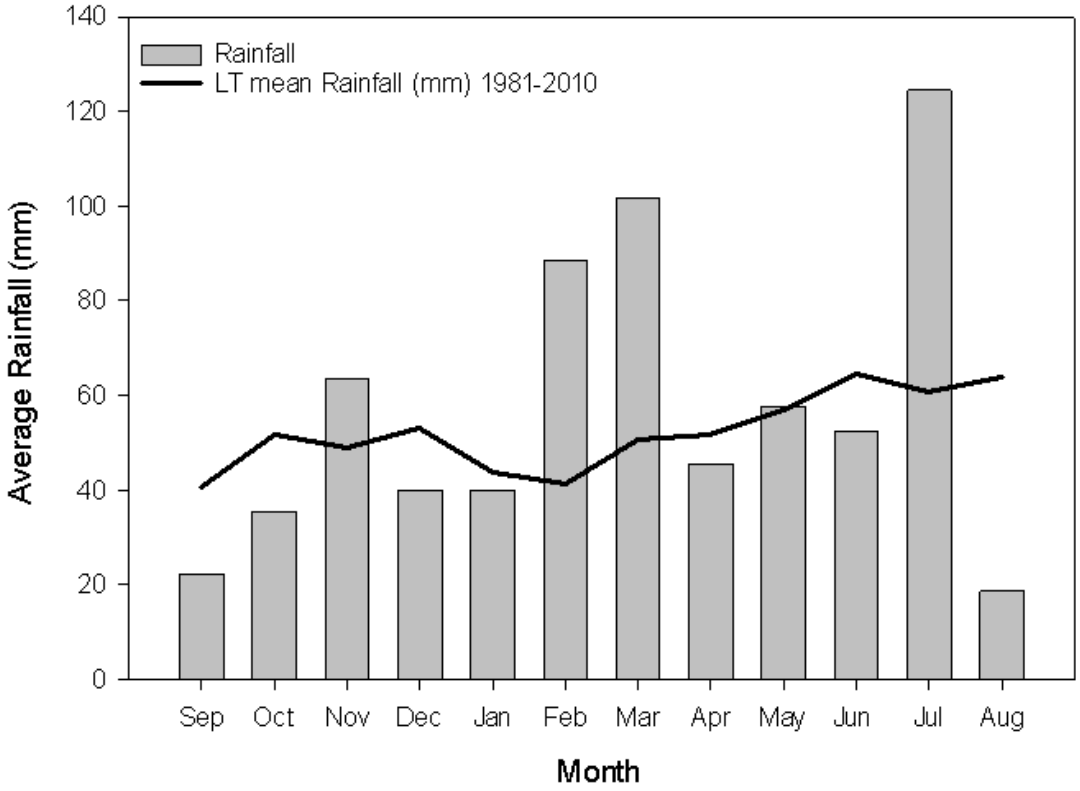

Figure 3.1: Accumulated monthly rainfall between September 2022 and August 2023, against the long term mean rainfall (1981-2010). Daa from Broadfields weather station, Lincoln (NIWA 2024).

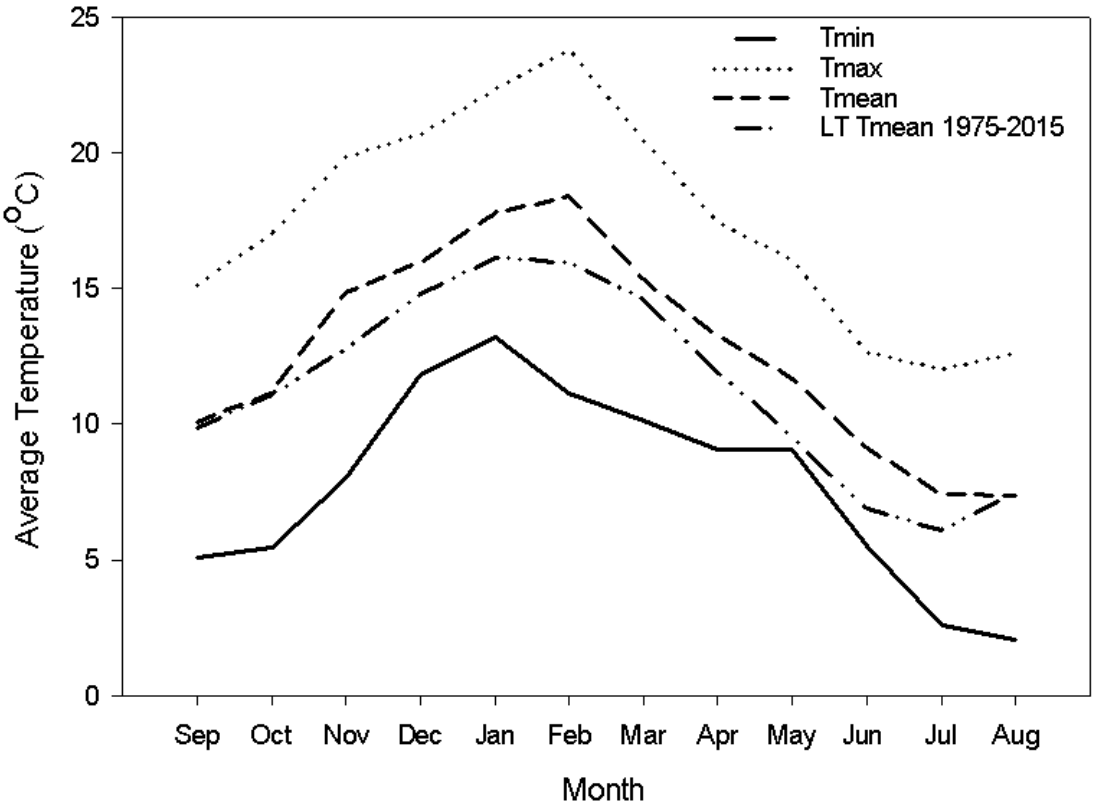

Figure 3.2: Average monthly minimum, mean and maximum temperatures against the long term (LT) mean monthly temperature (1975-2015) from the Broadfields weather station, Lincoln (NIWA 2024).

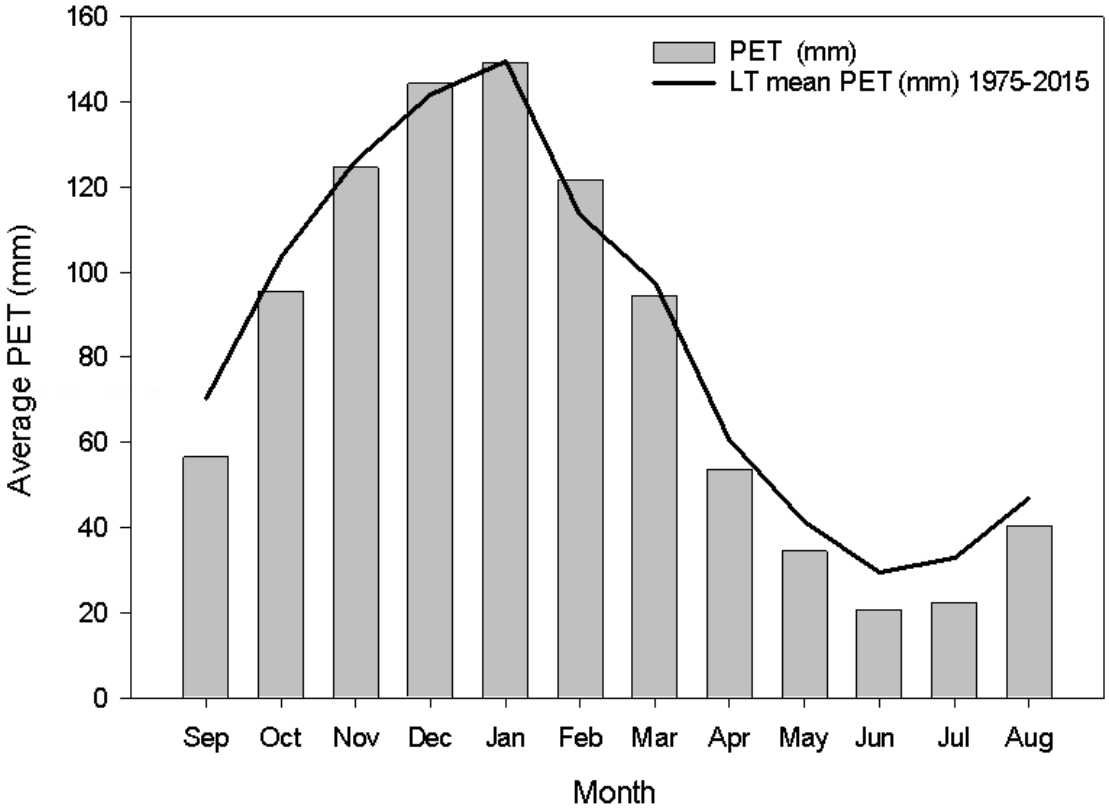

Figure 3.3: Accumulated monthly potential evapotranspiration (PET) against long term (LT) average monthly PET (1975-2015) from Broadfields weather station (NIWA 2024).

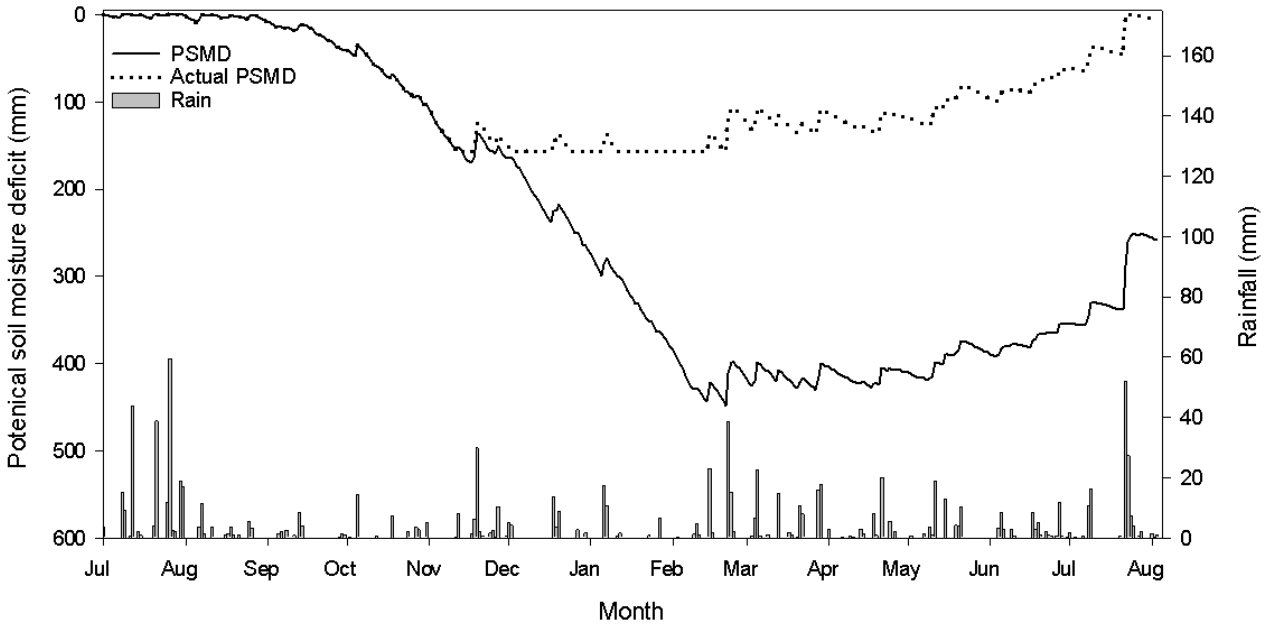

Figure 3.4: Potential and actual soil moisture deficit and rainfall between 1 July 2022 and 3 August 2023. Data from Broadfields weather station (NIWA 2024).

3.2 Latin square history and establishment

Throughout the research period, all five of the Latin squares were established and used for the grazing of the Coopworth hoggets and lambs. Prior to the establishment of the RADE, LS1 (located in H17) was sown in lucerne from 28 November 2017, which was cultivated and fallowed from 26 August 2020. Subsequently, it was sown into greenfeed oats (*Avena sativa* L.) from 6 May 2021 and

cultivated and fallowed again from 18 October 2021. In LS2 (located in H19), the west half was an Italian ryegrass (*Lolium multiflorum* L.) pasture, while the east half was a perennial ryegrass/white clover pasture from 1 April 2019. LS2 was cultivated and fallowed from 2 September 2021. Both LS were soil tested shown in Table 3.1. Soil samples were collected across each plot and bulked by Olsen P treatment and LS on 9-10 November 2021.

Table 3.1: Mean soil test results for the five Latin squares in the RADE under high and low P on 18 November 2021, 20 July 2021 and 25 August 2023 at Lincoln University.

Sample date	Latin square	Core length	pH	Olsen P (µg/mL)	Sulphate S (µg/mL)
18 Nov 2021	LS1 high	7.5	5.4	15	9
	LS1 low	7.5	5.4	8	4
	LS2 high	7.5	5.5	10	11
	LS2 low	7.5	5.6	8	4
20 July 2021	H11 (LS4/5)	7.5	6.2	18	-
	H14 (LS3)	7.5	6.0	13	-
25 Aug 2023	LS1 high	7.5	7.04	12.1	5.61
	LS1 low	7.5	7.06	8.36	3.22
	LS2 high	7.5	6.54	11.1	4.24
	LS2 low	7.5	6.58	10.2	4.24
	LS3 high	7.5	6.13	20.0	2.72
	LS3 low	7.5	6.15	18.1	1.30
	LS4 high	7.5	6.14	14.7	4.77
	LS4 low	7.5	6.11	17.2	4.81
	LS5 high	7.5	6.05	15.1	9.65
	LS5 low	7.5	6.06	11.1	2.90

Superphosphate (9% P, 11% S) was applied at 200 kg/ha to high Olsen P treatment plots in LS1 on 16 April 2021, and Columns 3 and 4 of LS2 on 30 July 2021, Columns 1 and 2 on 10 August 2021. Superphosphate was applied again to both LS on 14 October 2021 (total 36 kg P/ha). Lime was applied at rates of 6 and 2 t/ha on 8 November to LS1 and LS2 respectively based on previous soil pH levels.

LS1 and 2 were irrigated at 50 mm on 15-25 November, then sprayed with glyphosate (570 g/L at 2L/ha in 200L/ha water) on 26 November 2021. Sulphur Super 20 (8% P and 20.6% S) was then applied at 350 and 50 kg/ha (28 and 4 kg P/ha) to high and low plots respectively on 30 November – 1 December 2021. Soil was cultivated to a seedbed on 3-9 December 2021, prior to sowing (Flexiseeder plot drill) and seedbed reconsolidation (Cambridge roller) in LS2 (10 December 2021) and LS1 (13 December 2021) (see Appendices 1 and 2 for species and sowing rates for LS1 and LS2 respectively). First grazing occurred on 15 February 2022 in LS2 and 7 March 2022 in LS1.
In LS3 (located in H13 and H14), the northern end was in a 2-year-old cocksfoot multispecies pasture, while the south end was under lucerne monoculture for nine years, before being fallowed for six months prior to RADE establishment. There was no Olsen P treatment on this area prior to the RADE, therefore, the establishment period (Coopworth grazing) was used to adjust Olsen P. Soil test results

can be found in Table 3.1. Baleage was made twice off the LS, on the 15 November 2021 and 24 January 2022. The site was irrigated with 100mm water between 16-19 November, before sprayed out with glyphosate (2 L/ha) on 8 February 2022. The square was cultivated to 10 cm using a Dutch harrow-Cambridge roller combination on 1 March. High fertility plots received 400 kg/ha Superphosphate before final cultivation on 8 March, prior to sowing (flexiseeder drill; 10-20 mm sowing depth) on 9 March 2022 (see Appendices 3 for species and sowing rates respectively). Reconsolidation post-sowing using Cambridge roller. The first winter forage plots (Plots: 41-48) began grazing 8 June 2022.

LS4 and LS5 were across two paddocks (H11 and H12), with LS4 on the northern end, and LS5 on the south. The west half of each LS was previously a four-year-old cocksfoot based multispecies pasture, and the eastern-half was a two-year-old diploid Italian ryegrass pasture. Similarly to LS3, the Olsen P treatments were established during the Coopworth period of the RADE trial. LS4 began development on 2 June 2022, it was grazed 13 June until 9 July 2022 once all plot areas were grazed, then sprayed (2L/ha glyphosate) on 24 August 2022. The LS was then cultivated using Dutch harrow-Cambridge roller combination prior to drilling on 18 October 2022 (see Appendices 2 for species and sowing rates). First grazing begun on 11 December 2022. LS5 was grazed with resident pastures until 21 February 2023, when it was sprayed (2 L/ha glyphosate) prior to cultivation again using the Dutch harrow-Cambridge roller combination prior to drilling on 16 March 2023 (see Appendices 4 for species and sowing rates). First grazing post drilling occurred 10 July 2023.

Soil testing and sulphur superphosphate were applied as required to all five Latin squares to meet desired Olsen P levels of 10 mg/kg (low) or 20 mg/kg (high) between November 2021 and spring 2023.

3.3 Treatment and Experimental design

The experimental design was fully described by Watson et al. (2024). It utilises a 2x2 factorial design comparing two dryland sheep production systems—regenerative agriculture (RA) and conventional agriculture (CA)—at the two targeted Olsen P fertility levels. The experimental layout is a Latin square design with five 4x4 Latin squares (80 plots in total) to account for paddock, soil, and hedge effects (see Figure 3.5). The experiment is ongoing, so details presented here focus on the initial grazing period before all plots were fully established.

The RA pasture mixes were developed in consultation with a Technical Advisory Group (TAG) composed of five experienced RA practitioners from Canterbury and Otago sheep and beef farms. These RA pastures were multispecies mixes, with perennial pastures including 12 species (grasses,

legumes, and herbs) and annual forages containing eight species (brassicas, legumes, grasses, and herbs). The RA system was based on the TAGs interpretation of RA principles. These include minimal tillage (limited to 5-10% of the farm area annually for winter forage crops and pasture renewal), soil protection, live roots maintenance, enhanced biodiversity, and integrated livestock. No chemical pesticides were permitted following the initial pasture removal for the experiment. The CA system, utilised monoculture lucerne pastures, cocksfoot subterranean clover mixes, and annual ryegrass (*L. multiflorium*) and rape (*Brassica napus*) as winter forages. Both RA and CA systems were evaluated across the two Olsen P fertility levels, allowing an analysis of resource efficiency and adaptability to different fertility environments.

The four treatments are: High Conventional (HC), Low Conventional (LC), High Regenerative (HR), and Low Regenerative (LR) were randomly assigned with the restriction of one treatment per each row and each column. The experimental plots are located within paddocks H11, H12, H13, H14, H17, and H19 at the Lincoln University Horticulture Research Area. Latin square and therefore individual plot areas differ based on the original paddock sizes. Areas are: 0.087 ha in Latin Squares 1 and 2 (30 x 29 m), 0.132 ha in Latin Square 3 (28.7 x 46 m), and 0.089 ha in Latin Squares 4 and 5 (38.5 x 23 m). Each plot is enclosed with electric fence netting and equipped with a water trough, with laneways between Columns 1 and 2, and 3 and 4 to facilitate stock access. Total area for each treatment group (20 plots) is 1.936 ha, of which 1.847 ha was actively used throughout the experimental period reported in this research.

Figure 3.5: Layout of the 2x2 factorial experiment with two dryland sheep production - regenerative agriculture (R) and conventional agriculture (C) under two Olsen P levels; low (L) and high (H) in a 4x4 Latin square design. Latin square 1 (plots 1-16), 2 (plots 17-32), 3 (plots 33-48), 4 (plots 49-64) and 5 (plots 65-80). Location of plot 1 was 43°38'54.28" S, 172°27'34.28" E, 9 m above sea level.

The experiment was established over a 16-month period. Consequently, between 11 September 2022 and 2 August 2023, not all Latin squares (LS) were fully established or active, therefore the dataset was incomplete in certain periods. This restricted some data analysis options because they did not include all five squares. Furthermore, accumulated LW production per hectare is a single value for each treatment because sheep grazed across all five LS. Therefore, there is no replication of flock data but individual liveweights were measured to give total accumulated liveweight production. Therefore, these data are shown without standard errors.

LS1, (Plots; 1-16), included 16 plots with four replicates of each treatment level. This square compared regenerative 12-species lucerne-based pastures with conventional monoculture lucerne under high and low Olsen P levels (Appendices 1). LS2, (Plots; 17-32), had the same layout but used a different lucerne cultivar ('Kaituna' in LS1 vs. 'Takahe' in LS2) (Appendices 2). LS4, (Plots 49-64), used the same pastures as LS2.

LS3 (Plots: 33-48), compares conventional cocksfoot/subterranean clover pastures with regenerative 12-species grass-based pastures. Rows 3 and 4 of LS3, located in Paddock H14, were set up for winter forage with four regenerative multispecies ryegrass plots and conventional monocultures, comprising two annual ryegrass plots and two rape plots, each replicated at two fertility levels (Appendices 3). LS5 (Plots: 65-80) had four of its plots excluded from the RADE experiment due to its involvement in an ongoing LegacyNet experiment (Plots 73, 74, 77, 78). The remainder of LS5 was developed into conventional cocksfoot/subterranean clover and regenerative grass-based multispecies pasture (Appendices 4). However, during the experimental period, LS5 plots were either in grass-clover pastures or under development as described above, with first grazing of sown species in Rotation 8.

LS1, LS2, and LS3 were established and actively used by the 2022 hogget flock, with LS4 added during this grazing period. LS5 (plots 65-72, 75,76, 79, and 80) was used as resident pastures (including cocksfoot/subterranean clover mixes and annual ryegrass with volunteer white clover) until development. An example of lucerne based pastures is shown in Figure 3.6.

Figure 3.6: Lucerne monoculture (taken 21/11/2022, LS2, left), and 12 species lucerne-based mix (taken 23/11/2022, LS2, right). Photos by B. Holt.

3.4 Grazing management

The experimental period analysed in this research runs between September 2022 and August 2023 which was the period two groups of Coopworth hoggets and lambs grazed; 2022 flock (hoggets) - 22 September 2022 to 3 March 2023; flock 2023 (lambs) - 3 March 2023 to 3 August 2023. Average weights at the beginning and end of each grazing period are shown in Table 3.2. Experimental period used in this study started from the 31 August 2022 for pasture data and 22 September 2022 for animal measurement. For liveweight gain (LWG) against intake in the 2022 flock this started from the 19 September at 0 kg DM/ha.

Prior to the experimental period analysed in this study, LS1 and LS2 were grazed in rows of four plots, to create an eight-row full grazing rotation, grazed by 100 non-measured mature Coopworth ewes. Their first grazing rotation began on 15 February 2022 and finished on 18 March 2022. Ewe lambs (7-12 months old) entered the first row of LS2 on 18 March, rotated roughly every seven days depending on pasture mass. On 22 August 2022 the 80 ewe lambs were then considered ewe hoggets (12-19 months old), and they continued to graze until 3 March 2023. These were replaced with another 80 ewe lambs that grazed until 3 August 2023. Grazing rotation per treatment group and grazing period of each flock can be seen in Appendix 5. Sheep were randomly assigned to treatment groups on 15 February 2022, 18 March 2022, and 3 March 2023. Consistent pasture and animal measurements began mid-August 2022 once plots were separated and grazed individually by their respective treatment groups of 20 Coopworth hoggets. Therefore the 2022 Coopworth lamb period was not analysed.

Table 3.2: Liveweights at the beginning and end of grazing periods for 2022 and 2023 Coopworth flocks grazing the four treatments: high conventional (HC), low conventional (LC), high regenerative (HR) and low regenerative (LR) on the RADE at Lincoln University.

Flock	Weigh date	Treatment	Average Weight (kg)
2022 Hogget Flock	22/09/2022	HC	54.2
		LC	51.3
		HR	51.6
		LR	50.8
	3/03/2023	HC	85.2
		LC	81.1
		HR	76.4
		LR	77.2
2023 Lamb flock	3/03/2023	HC	36.6
		LC	36.6
		HR	36.1
		LR	36.0
	03/08/2023	HC	53.7
		LC	53.0
		HR	51.5
		LR	50.2

During the study period, the stocking rate was 20 sheep/1.847 ha per treatment (80 sheep total; 10.8 sheep/ha). Rotational grazing was used across all four farmlets. During the period of Coopworth hogget grazing, LS4 (plots 49-64) was established in spring 2022, and grazed from January 2023. Plots 41-48 were grazed until autumn sown in 2023, and LS5 plots 65-73, 75, 76, 79 and 80 were grazed as resident pastures before sowing on 16 March 2023 and were not grazed again until after the Coopworth period (spring 2023). During the study period the average growth duration (i.e. from a plot either grazed, cut or sown) was shorter for RA than CA (42 compared to 48 days). Duration of the grazing phase was also shorter for RA than CA (3 compared with 7 days, respectively). Average stock density (number of sheep/ha grazing in a plot on a given day) was higher in RA than CA (205 and 104 sheep/ha, respectively). This was because for the majority of time there were 20 sheep/plot in RA, and 10 sheep/plot in CA. This resulted from two groups of 10 sheep being used in each CA treatment, and therefore a lower stocking density, but same stocking rate across all four treatments.

3.5 Sheep measurements

Hoggets/lambs in both 2023 and 2022 were randomly allocated to a treatment group upon arrival from Ashley Dene, Research farm. The starting month of September 2022 was chosen as data became more consistent from mid-August 2022. However, the closest weigh date was 22 September, with the previous weigh date being 30 June 2022. The plot for each treatment at weight began to be grazed between 11 and 19 September 2022 (shown in Appendices 5). The weight data from the 30 June, allowed average liveweight per treatment to be estimated back to 11 September 2022 from 22 September. Calculation shown in Equation 3.1 for growth rate. This was calculated by estimated daily growth rates from the difference in weight between 30 June and 22 September, divided by the number of days (85 days). Growth rates between the measured average values were used to estimate live-weight on a given day in each treatment. This was then applied to each plot movement. From this liveweight gain (LWG) per hectare was calculated per movement to match the interpolated full design herbage intake and yield measurements that were used to show intake and yield accumulation over time. LWG calculations are shown in Equation 3.1.

Equation 3.1: Method used to estimate daily growth rate, and LWG (kg)/ha, and accumulate over time for 2022 and 2023 flocks on the RADE at Lincoln University.

$$LWG\ between\ measurements\ =\ difference\ between\ measured\ values.$$

$$Growth\ rate = \frac{Change\ in\ LW\ between\ measured\ dates}{days\ between\ measurements}$$

$$LWG/ha/d\ =\ growth\ rate * 10.8\ sheep/ha$$

$$LWG/ha/month\ =\ LWG/ha/d\ x\ number\ of\ days\ between\ measured\ values$$

$$Accumulated\ LWG/ha\ =\ sum\ of\ LWG\ per\ ha\ over\ time.$$

The liveweight of the Coopworth hoggets was measured at approximately monthly intervals. Sheep were generally weighed full, brought in the morning of weighing, weighed and returned to their treatment. All 20 sheep in all four treatments were weighed on the same day. Body condition score was not taken for the Coopworth sheep. An example of sheep weighing is shown in Figure 3.7. Liveweight (LW) gain (LWG/ha) was analysed per treatment. Individual animal LW was checked for outliers by running a grouped line graph of each sheep's live weight within a group overtime to make sure there were no extreme high or low values within each treatment. Average LW per head was calculated monthly by averaging individual treatment weights of all 20 sheep. Average LW gain per head per day was calculated by dividing the difference between the two weights (average LW gain/head/month) by the number of days. Accumulated LWG per ha was calculated by multiplying average LW gain/head/month by 10.8 sheep/ha. Feed conversion efficiency was calculated though split line and linear regression analyses of accumulated treatment LWG/ha against accumulated treatment intake (kg DM/ha).

Figure 3.7: Example of sheep weighing, photo taken 28 March 2024, weighing Bohepe ewes grazing RADE post Coopworth period on the RADE at Lincoln University. Photo by B.Holt.

3.6 Herbage analysis

Pasture measurements were taken, pre- and post-grazing or other herbage removal event (e.g. topping, hay making etc). The herbage measurements used to explain liveweight gain of the

Coopworth hoggets was from quadrat herbage cuts (three 0.5 m^2 quadrat cuts to ~2 cm height along the longest axis of the plot) to estimate herbage mass pre-grazing, and the amount removed post-grazing. Samples were collected, weighed as whole sample, then a subsample of ~200 g and 100 g, pre and post grazing respectfully was dried (65 ^{o}C for 48h) to estimate dry matter proportion to calculate mass (kg DM/ha). A separate subsample of ~400 pieces was sorted and dried to determine botanical composition. Each sown species (e.g. tall fescue and meadow fescue were pooled together within the botanical composition as a mix of two species as 'Fescue'), weed and dead was separated and dried as individual components to determine the proportion of DM/ha.

From the pre- and post-grazing quadrat cuts a subsample was taken for grinding using an herbage sample grinder to form a fine powder. Herbage nutritional value was measured from the ground, dried sample. Ground samples were tested for pasture quality by a near infrared spectroscopy (NIRS) machine. The NIRS is calibrated with wet chemistry to measure feed values including metabolisable energy (MJ ME/kg DM), crude protein (%), and neutral detergent fibre (%). Each pre- and post-grazing bulk sample was analysed for feed quality values to help estimate feed quality values of ingested feed over time.

Forage samples were used to estimate fresh and dry matter production per hectare. Pre- and post-graze masses were used to estimate intake per hectare using the apparent intake method (disappearance method) (Section 2.5.1). Pasture measurements also included botanical composition for both pre- and post-grazing to estimate selectivity of sheep grazing. Summed treatment yields for the legume, herb and grass proportions were used within the study to examine the amount on offer and any animal selectivity by showing proportion of eaten components against what was on offer, therefore can see if animals chose to eat a greater proportion for example of the legume component.

3.7 Statistical analysis

Data were prepared and collected in a Microsoft excel software. Data were checked for missing values and outliers. The presented analysis covers measurements between 31 August 2022 and 3 August 2023. During this time the pastures were grazed by Coopworth hoggets which were then subsequently replaced with Coopworth lambs. These periods were analysed separately. All analyses were conducted in Genstat 23rd edition software.

For accumulated yield over time for each of the four treatments and Coopworth flock was analysed from the "sum yield" variable. In Year 1, s-shaped logistic curves were fitted. Dates were converted to number of days where Day 0 was 31/08/2022 and Day 168 was 15/02/2023. Form of the fitted curve was: y = A + (C/(1 + EXP(-B(x - M))) where A is the y-intercept, B is the rate of steepness of the

curve, C is the asymptote (maximum value), and M is the value of the midpoint. For the second flock (Day 0 = 18/02/2023 and Day 196 = 30/08/2023) grouped polynomial regression was performed based of the shape of the response during the observation period. The form of the regression was y = A + B*x* + C*x*2, where A is the y-intercept and B, and C are constants. Improvements to the model logistic and polynomial models were evaluated by improvements in the R^2 and whether the change in model complexity was significant ($p < 0.05$). Yield was calculated to start at 0 kg DM/ha for each flock. Linear regression was then performed between accumulated DM yield and thermal time. The slope of thermal time standardised growth rate (kg DM/ha/^{o}Cd) was calculated across each grazing period for the Coopworth hoggets and then lambs. The base temperature for thermal time accumulation was based on air temperatures, set at 3 ^{o}C (Mills et al. 2006).

For botanical composition, the sum of pasture components (grass, legume and herb) yields was accumulated from the beginning of the experiment. These data provided the average yield across all plots in the treatment on the 3 August 2023. Data were weighted to account for differences in plot size across the five Latin squares. To achieve this, the yield of individual plots was multiplied by the reciprocal of plot area to calculate the weighted yield. Forage intake (average summed kg DM/ha per treatment) was calculated from a starting point of 0 for each flock between 31 August 2022 and 3 August 2023 and then analysed.

Accumulated yield and intake periods ran from 31 August 2022 to 15 February 2023 for the 2022 Coopworth ewe hoggets (5 ½ months) and from 16 February to 27 July 2023 for the 2023 Coopworth ewe lambs (4 ½ months) based on a calculated linear interpolation between measured values. Changes in these masses from one day to another within each growth period were calculated as daily yields, and cumulative yields were totalled across growth periods. Herbage DM yield was analysed using split linear regression for the 2022 flock, and multiple split line and linear regression for the 2023 flock against thermal time (^{o}Cd) to determine temperature adjusted standardised growth rates for each treatment between grazing periods. The sum of intake (kg DM/ha) was linearly interpolated as the difference between pre and post grazing masses as an average across plots within a treatment. This was analysed against yield to determine pasture utilisation for each treatment, and against liveweight gain (LWG/ha) to determine feed conversion efficiency.

Liveweight gain per hectare was calculated as the difference in liveweight between plot movements. Average liveweight per move was calculated based on daily growth rate. The difference in weight was then multiplied by 10.8 sheep/ha to get LWG/ha between flock movements. These values were then accumulated to get accumulated LWG/ha throughout the grazing period.

Herbage quality factors were analysed using a general analysis of variation (ANOVA) with a treatment structure of "Treatment/System*Fertility" *(*main effects and their interaction) and a block structure of "Latin Square/(Row*Column)". They were separated by season, Spring (1 September to 30 November), summer (1 December to 28 February), autumn (1 March to 31 May), and winter (1 June to 31 August).

In addition to yield, intake, botanical composition and quality measures, different methods of estimating intake were also investigated. This is because intake is important to understand LWG and potential animal growth. From the RADE experiment the disappearance method and theoretical methods (energy requirements and based on LW) could be used to estimate intake. The disappearance method was calculated using Equation 3.2.

Equation 3.2: Disappearance method equation (Akdağ & Ocak 2019).

$$\frac{(DM\ in\ the\ cage\ or\ before\ grazing\ (kg/ha\ ) - DM\ out\ of\ the\ cage\ or\ post\ grazing\ (kg/ha\ )xArea(ha)}{Number\ of\ grazing\ days}$$

Metabolisable energy requirements were calculated using equations from Nicol & Brookes (2017), based on sampled energy and LW data (Table 2.4, Section 2.5.3). Mature LW for the Coopworth's ewes were estimated at 60 kg. Methods of estimating intake were analysed as an individual method against treatment to see if there were differences among treatments for each method. Then each method was compared within the treatment using the function of "treatment*method*, with a block structure of "rotation". A rotation was defined as a grazing sequence with no repeated plots. Once a plot within a treatment was repeated a new rotation began even if not all plots within a treatment had been grazed.

In addition to estimation of intake a comparison was made between measured ME of bulk feed on offer and the ME of the feed selected by the animals. When analysing the data, some measurements had missing ME values which were estimated by averaging ME before and after missing value or estimated based on same treatment and plot species within the same period (number of estimated values: pre; 23, post; 35 out of 431 data points in each pre- and post- grazing measurements). Where an average could not be used, missing values were estimated to the nearest 0.5. Metabolisable energy concentration of the feed was calculated from Equation 3.3.

Equation 3.3: Metabolisable energy concentration equation

$$(ME\ pre\ x\ pre\ mass) - (ME\ post\ x\ post\ mass) = (ME\ intake/ha)/DM\ intake\ (pre\ mass - post\ mass)$$
$$= Concentration\ of\ ME\ in\ the\ DM\ eaten.$$

Metabolisable energy values which were greater than 20 or less than 0 were removed, negative values or extremely high values resulted from either pre or post mass or ME, input or measurement error. Of 431 observations, 54 were removed from the ME concentration analysis.

Specific periods of differences in LWG were analysed through an unbalanced one-way ANOVA, without blocking to assess the pre-grazing ME, CP, NDF and pasture mass of plots grazed.

Chapter 4

Results

4.1 Liveweight gain

Figure 4.1 shows the accumulated total liveweight gain (LWG/ha) of the 2022 and 2023 Coopworth flocks, respectively. In the 2022 flock, LWG of all four increased until 21 February 2023. At this time LWG of the high conventional (HC), high regenerative (HR) and low regenerative (LR) declined (21 February – 3 March 2023). In contrast, LWG of the low conventional (LC) continued to increase. The LWG of the regenerative and conventional treatments began to deviate between 26 October and 13 December 2022, when LWG of RA flocks accumulated at a slower rate particularly for the LR sheep. Conventional treatments from the 2022 flock on 3 March 2023 had accumulated 336 (HC) and 323 (LC) kg LWG/ha, whilst regenerative treatments accumulated 269 (HR) and 286 (LR) kg LWG/ha. Figure 4.1 also shows LWG was accumulated at the same rate for the four new flocks from March until July 2023. On average the monthly LWG was 43 (HR) and 41 (LR) kg /ha between 3 April and 5 July. The LC continued to gain an average of 43 kg LWG/ha/month between 3 April and 5 July, and 6.8 kg/ha between 5 July and 3 August. The HC flock averaged 40 and 24 kg LWG/ha for the same periods. The LWG in the HC continued to increase through July and August but it declined in the other three treatments. This resulted in 186 kg LWG/ha in HC, compared with 178, 167 and 154 kg LWG/ha for LC, HR and LR, respectively. Between July and August, regenerative treatment flocks lost 6.6 (HR) and 8.4 (LR) kg/ha.

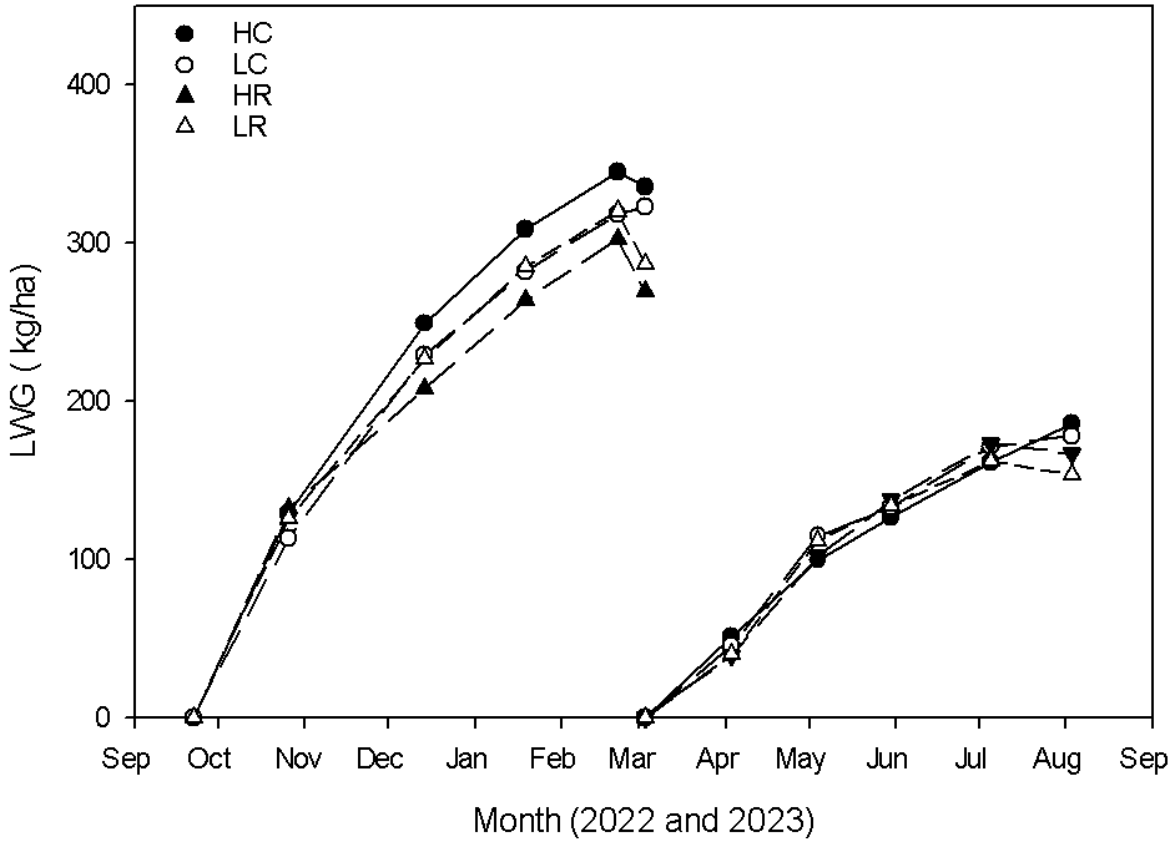

Figure 4.1: Accumulated liveweight gain of 2022 flock between 22 September 2022 and 3 March 2023 and the 2023 flock from 3 March to 3 August 2023 for Coopworth hoggets and lambs respectively, grazing either high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University.

4.2 Yield

Figures 4.2a and b. show the accumulated dry matter yields associated with the liveweight gain of the two flocks. Yield data related to the first flock are from 31 August 2022 to15 February 2023 (a) and for the second flock from 16 February to 3 August 2023 (b). Figure 4.2a analysis showed logistic curves (R^2=0.99) with a final accumulated yield of 5000±544 kg DM/ha on 15 February 2023. The curves rate of steepness was 0.03±0.02 (B value), with a midpoint value (M value) of 55.5±2.15 days (equivalent to 25 October 2022) were common for all four treatments. Implementing this change increased (P=0.018) the R^2 of the relationship from 0.98 when a single curve was fitted to all four treatments. Treatments had different A (y-intercepts) and C (asymptote) values. Forms of the curves were; HC yield = -746.9+(5767/(1+EXP(-0.003*(*x*-55.5))), LC yield = -760.1 + (5557/(1 + EXP(-0.003*(*x* – 55.5))), HR yield = -919.1 + (6423/(1 + EXP(-0.003(*x* – 55.5))) and LR yield = -935.4 + (6280/(1 + EXP(-0.003(*x* – 55.5))).

Accumulated yield over time for the second flock was analysed by fitting a single polynomial curve to data from all four treatments resulted in an R^2 of 0.94. This was improved (p<0.001) by fitting a grouped polynomial regression (Figure 4.2b) with parallel lines (R^2=0.97), where the linear (26.22±1.89) and quadratic (-0.06±0.01) constants were common to all four pasture treatments but y-intercepts differed. Specifically, y-intercepts were 155.7 (HC), 294.2 (LC), -112.7 (HR) and -170.8

(LR). Final DM yields for each treatment were 2897 (HC), 2903 (LC), 2662 (HR), and 2369 (LR) kg DM/ha on 3 August 2023.

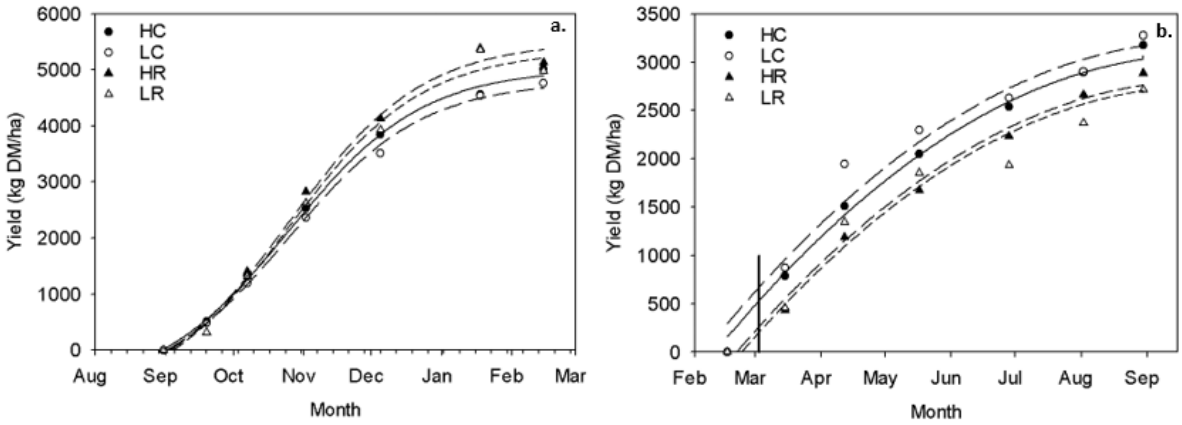

Figure 4.2: Accumulated dry matter (DM) yield between 31 August 2022 and 15 February 2023 (a) and 16 February and 3 August 2023 (b) for Coopworth hoggets and lambs respectively, grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. Forms of the curves for Figure 4.2a were; HC yield = -746.9+(5767/(1+EXP(-0.003*(x-55.5))), LC yield = -760.1 + (5557/(1 + EXP(-0.003*(x – 55.5))), HR yield = -919.1 + (6423/(1 + EXP(-0.003(x – 55.5))) and LR yield = -935.4 + (6280/(1 + EXP(-0.003(x – 55.5))). Figure 4.2b polynomial regressions fitted were: HC yield = 155.7 + 26.22x -0.06x^2, LC yield = 294.2 + 26.22x -0.06x^2, HR yield = -112.7 + 26.22x -0.06x^2, LR yield = -170.8 + 26.22x -0.06x^2. Vertical line on Figure 4.2b indicates the 3rd March 2023 when the 2023 flock commenced grazing.

Accumulated DM yield against thermal time was explained (R^2 = 0.98) by a split line regression (Figure 4.3). The break point was found at 4955±143 kg DM/ha after 1080±35.8 ^oCd (16 December 2022). Slope 1 (the initial linear increase portion) accumulated at a rate of 4.56±0.2 kg DM/ha/^oCd between 31 August and 21 December 2022. In contrast, after the breakpoint Slope 2 was 0.020± 0.42 kg DM/ha/^oCd from 22 December 2022 to15 February 2023.

Figure 4.4 shows a linear yield increase for HC and HR at 1.89 ± 0.072 kg DM/ha/^oCd between 15 March and 3 August 2023. However, they had different intercepts with HC at 98.8±60.6 kg DM/ha ($p<0.001$), compared with -166±60.6 kg DM/ha for HR. For LC and LR a two-stage piecewise model was fitted. In the first phase LC and LR pastures grew at a rate of 2.76±0.24 and 1.90±0.44 kg DM/ha/^oCd for LC and LR, respectively. The second phase began after 696±1.9 and 933±463^oCd for LC and LR, when growth slowed to 1.30±0.20 and 1.06±0.69 kg DM/ha/^oCd, respectively. This was 31-44% slower ($p <0.001$) than high fertility treatments after the break point.

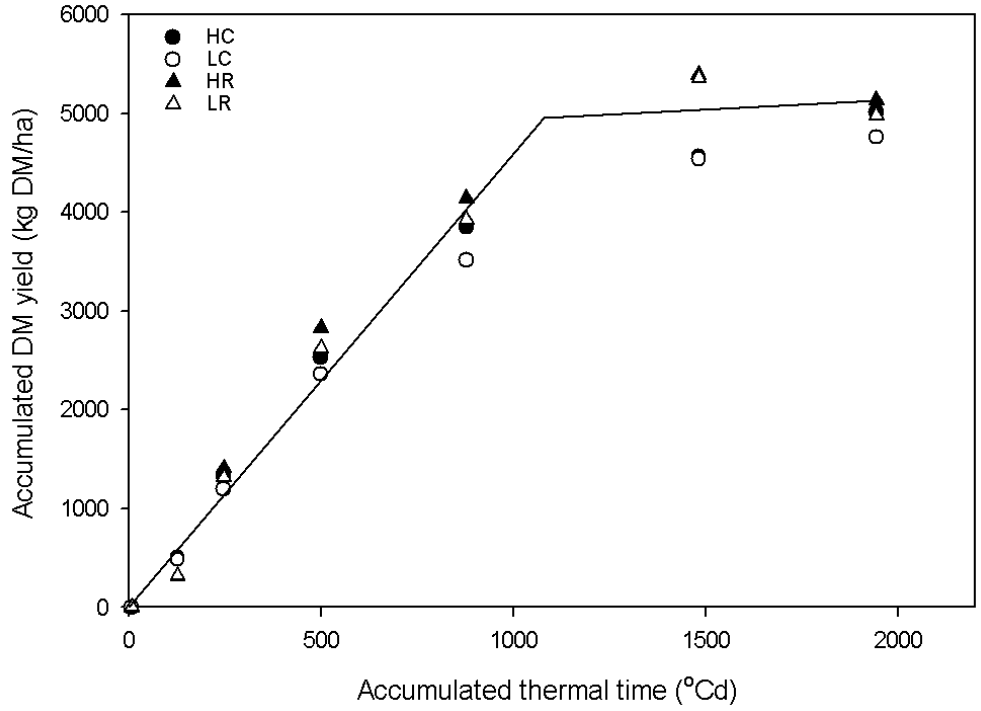

Figure 4.3: Accumulated dry matter (DM) yield of all grazed plots averaged across five Latin squares against accumulated thermal time (Tb=3 °C) between 31 August 2022 and 15 February 2023 for Coopworth hoggets grazing high conventional and low Olsen P (HC and LC respectfully) and high regenerative and low Olsen P (HR and LR, respectfully) pastures grown at Lincoln University. Slope 1 = 4.56±0.2 kg DM/ha/°Cd, Slope 2 =0.020±0.42 kg DM/ha/°Cd (R^2=0.98), 4955±143 kg DM/ha after 1080±35.8 °Cd.

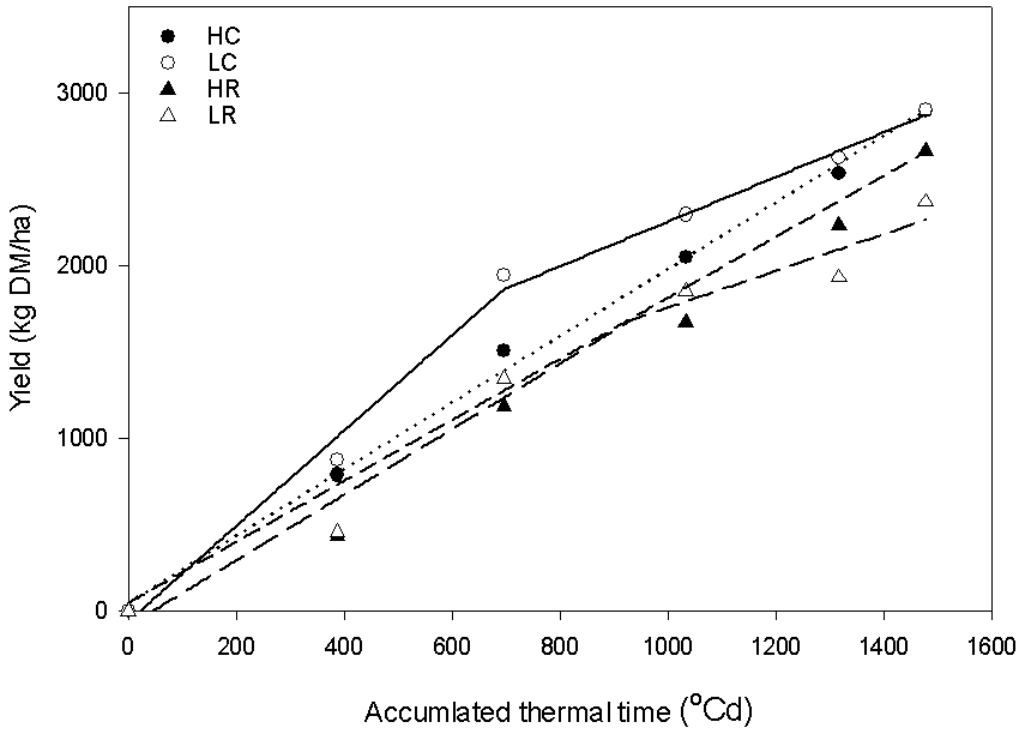

Figure 4.4: Accumulated dry matter (DM) yield against thermal time (Tb=3°C) for Coopworth lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) and low regenerative (LR) pastures grown at Lincoln University. Slope of HC and HR (1.86± 0.055 kg DM/ha/°Cd) (R2=0.95). Slope 1 of LC (2.76±0.24 kg DM/ha/°Cd, breakpoint mean of 1860 kg DM/ha and 696±1.91°Cd), Slope 2 (1.30±0.20 kg DM/ha/°Cd) (R^2= 0.99). Slope 1 of LR (y = 1.90 ± 0.44 kg DM/ha/°Cd, break point mean = 1685±703 kg DM/ha and 745±234 °Cd), slope 2 of LR (y= 1.06 ± 0.69 kg DM/ha/°Cd) (R^2 = 0.94).

4.3 Intake

Figure 4.5 shows the accumulated intake over time for both Coopworth flocks. Figure 4.5a. shows that there was no difference (P =0.879) in intake between the four treatment groups with a total accumulated intake of ~4000±208 kg DM/ha. The 2022 flock intake was represented by a split line regression for all four treatments (R^2= 0.98), where Slope 1 increased at a rate of 14.0±3.32 kg DM/ha/d. The intake of Slope 2 was 38.1±2.03 kg DM/ha/d. The break point occurred at 846±246 kg DM/ha. The 2023 flock (Figure 4.5b) regenerative treatments had a lower (p<0.001) intake than conventional treatments. HC and LC had an accumulated intake of ~2800±123 kg DM/ha. Within regenerative treatments LR had a lower (p= 0.006, R^2=0.98) intake than HR. Accumulated intake was 2200 (HR), and 1868 (LR) ±123 kg DM/ha. The grouped linear regression found HC had an intake of 15.6±0.65 kg DM/ha/d. LC, HR and LR had intakes of 16.5 (p=0.315), 13.8 (p=0.075) and 11.6 (p < 0.001) ±0.91 kg DM/ha/d. Therefore in the 2023 flock, LR had the lowest intake per day, where the 2022 treatments had no difference in intake.

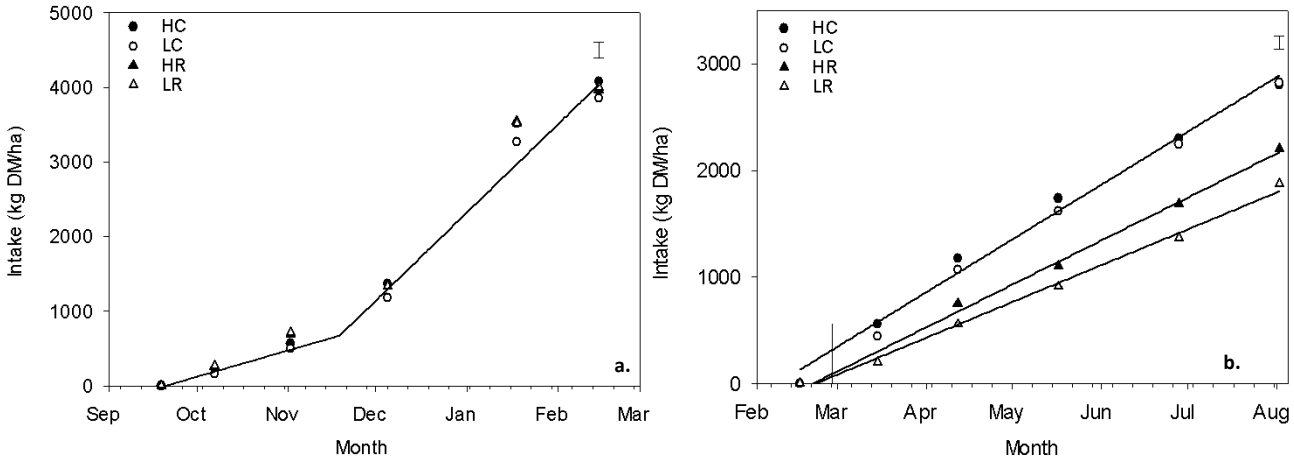

Figure 4.5: Accumulated intake over time for the 2022 flock (a. 19 September 2022 – 15 February 2023) and the 2023 flock (b. 16 February 2023 – 3 August 2023) for Coopworth hoggets and lambs respectively, grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. Line on Figure4.5b. shows when the second flock was introduced in 2023. S.e. of average intake over time; was 204 for a, and 123 for b. Figure 4.5a Slope 1 =14.0±3.32 kg DM/ha/d, Slope 2 =38.1±2.03 kg DM/ha/d, breakpoint = 846±246 kg DM/ha on ~18 Novemeber, 2022. Figure 4.5b; HC=15.6±0.645 kg DM/ha/d, LC=16.5±0.91 kg DM/ha/d, HR=13.8±0.91 kg DM/ha/d and LR=11.6±0.91 kg DM/ha/d.

Intake in response to yield for the two flocks are shown in Figures 4.6 and 4.7. Figure 4.6 shows a split line regression (R^2=0.93, s.e.= 413) with an x-axis break point at 3362±284 kg DM/ha, and y-axis break point at 832±345 kg DM/ha. Slope 1 increased at 0.28±0.13 kg DM intake/kg DM produced. However, Slope 2 was 1.74 ±0.20 kg DM intake/kg DM produced.

Figure 4.7 shows the relationship between intake and yield for the 2023 flock. This was also explained by a split line regression (R^2=0.96, s.e. of 169). The x-axis breakpoint was 1851±3.16 kg DM/ha, and y-axis breakpoint of 1118±70.7 kg DM/ha. Slope 1 increased at 0.63±0.09 kg DM intake/kg DM produced, followed by 1.54±0.12kg DM intake/kg DM produced.

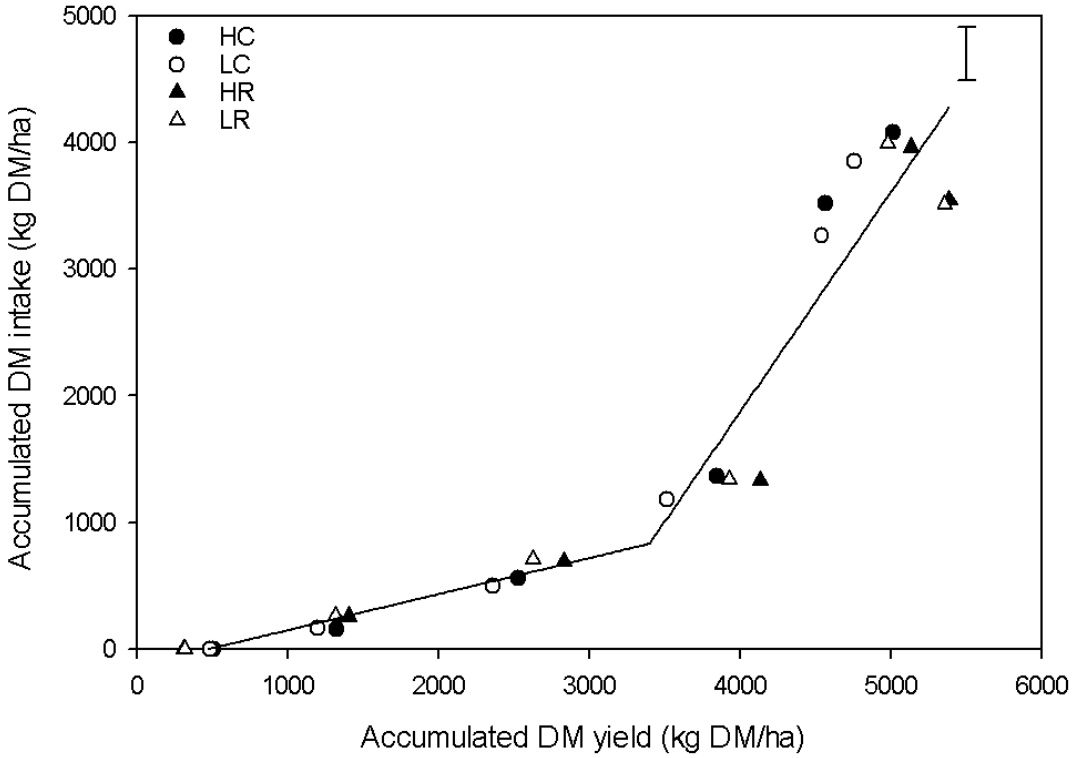

Figure 4.6: Accumulated dry matter (DM) intake (kg/ha) against accumulated yield (kg DM/ha) for Coopworth hoggets grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. X-axis breakpoint of 3362±284 kg DM/ha, y-axis breakpoint of 832 ±345 kg DM/ha, Slope 1 = 0.28±0.13 kg DM intake/kg DM produced. Slope 2 = 1.74±0.20 kg DM intake/kg DM produced. S.e = 413, for average intake and yield over time.

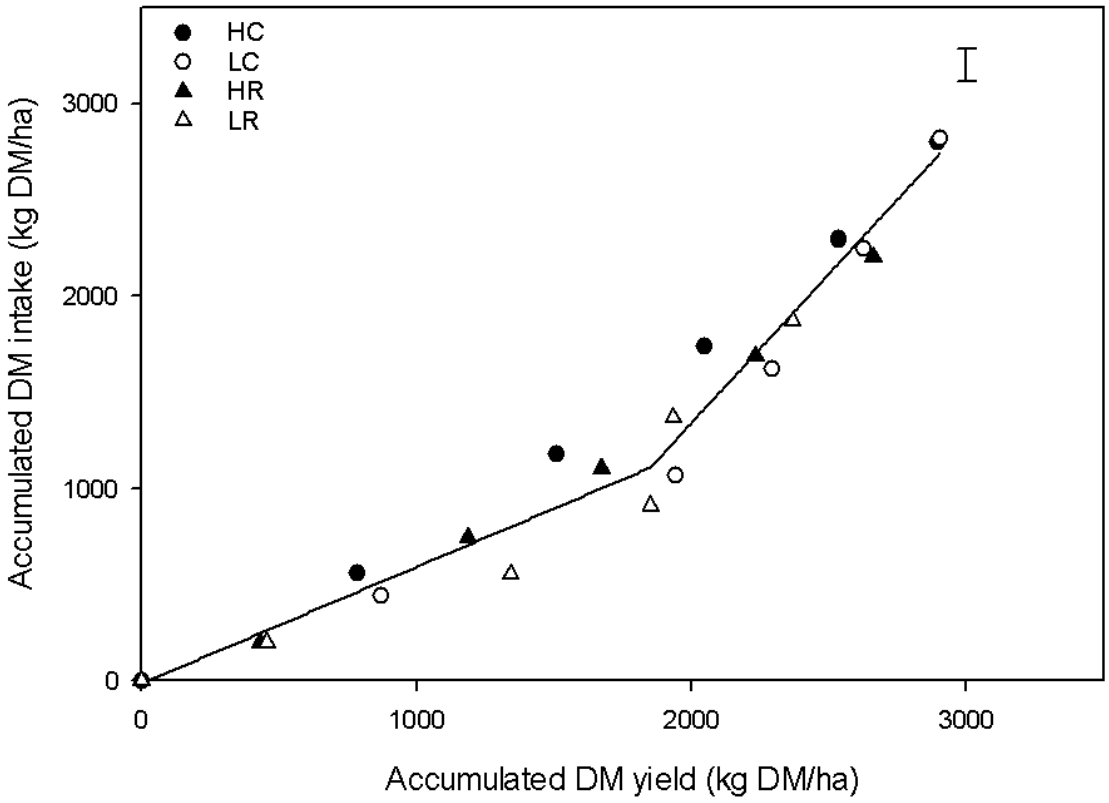

Figure 4.7: Accumulated intake (kg DM/ha) against accumulated yield (kg DM/ha) for Coopworth lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. Split line regression (R2=0.96), x-axis break point at 1851±3.16 kg DM/ha, y-axis break point at 1118.1±3.16 kg DM/ha. Slope one = 0.63±0.09 kg DM intake/ kg DM produced, slope two = 1.54±0.12 kg DM intake/kg DM produced. S.e = 169, for average intake and yield over time.

4.4 Feed conversion efficiency

Feed conversion efficiency is shown in Figures 4.8 and 4.9. The 2022 flock was explained by a split line regression (R^2=0.93, s.e. 31 LWG/ha), with a break point at 948±165 kg DM/ha and 215±21.1 kg LWG/ha. Until the break point LWG/ha accumulated at a rate of 219±34 g LWG/kg DM eaten. This means for each kg of liveweight gain, 4.02 kg DM intake was required. However, after the break point the hoggets grew at rate of 33±7.72 g LW/kg DM, equivalent to 30.3 kg DM/kg LWG.
In contrast, the 2023 flock (Figure 4.9) showed a linear relationship between intake (kg DM/ha) and LWG (kg/ha) with no breakpoint. Feed conversion efficiency was 85±5.97 g LW/kg DM which equates to 11.8 kg DM for each kg LW gain.

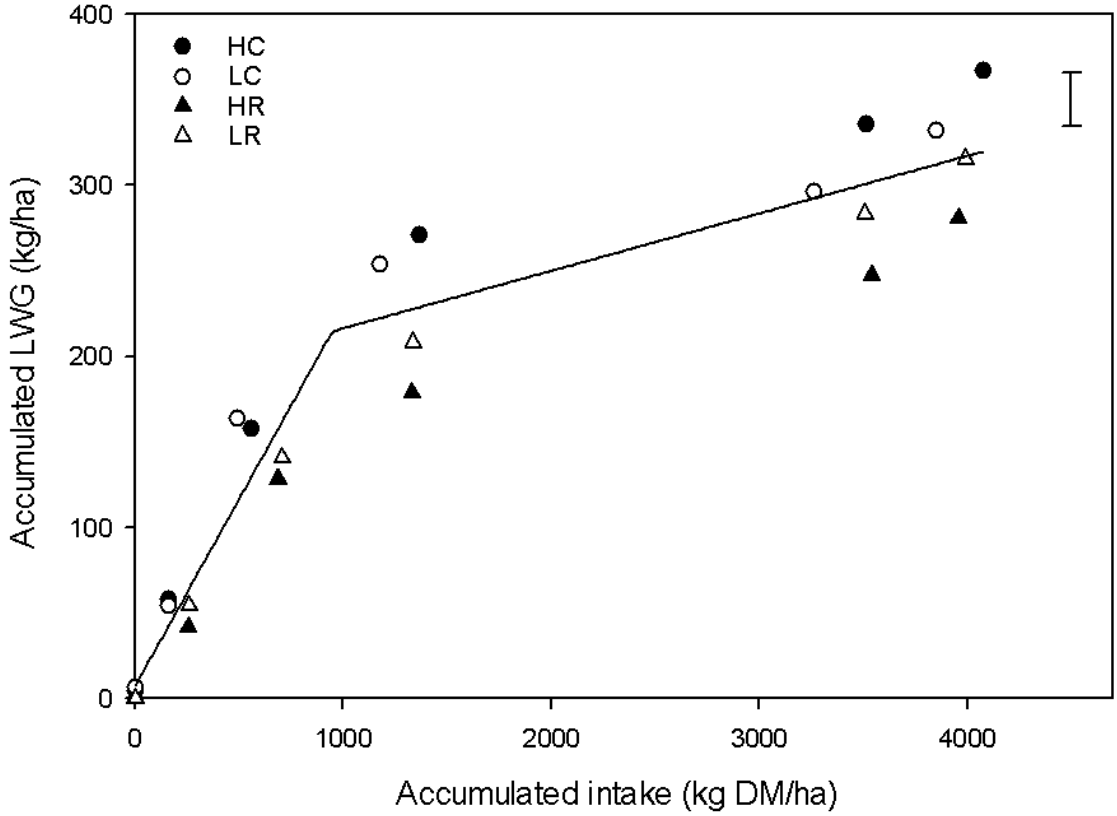

Figure 4.8: Accumulated liveweight gain (LWG) against accumulated intake (kg DM/ha) for Coopworth hoggets grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. X-axis breakpoint of 949±165 kg DM/ha, y-axis of 215±21.1 kg LWG/ha. Slope 1 rate of 219±34 g LW/kg DM eaten. Slope 2 rate of 33±7.72 g LW/kg DM.

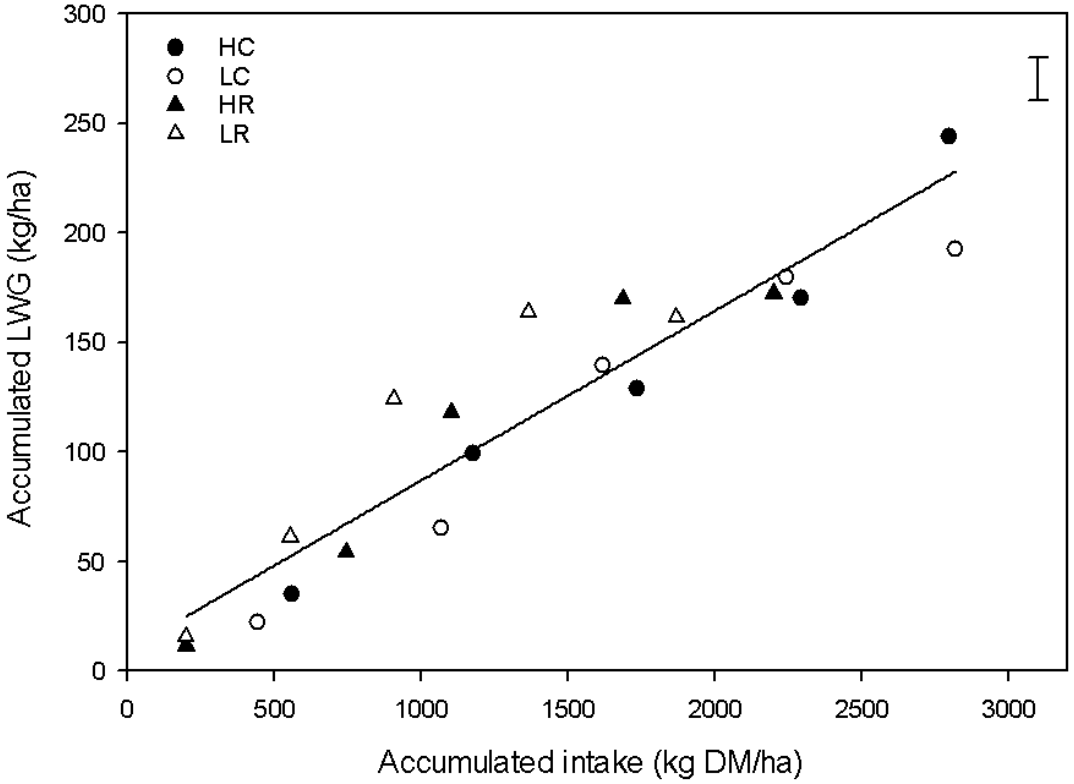

Figure 4.9: Accumulated liveweight gain (LWG) against accumulated dry matter intake (kg DM/ha) for Coopworth lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University in 2023. Feed conversion efficiency slope was 85±5.97 g LW/kg DM.

4.5 Herbage quality

Figures 4.10, 4.11 and 4.12 show the average seasonal metabolisable energy (ME), crude protein (CP) and neutral detergent fibre (NDF) from bulk herbage samples from all grazed plots in each treatment between 1 September 2022 and 27 July 2023.

ME was not different ($p = 0.46$) amongst pasture systems. All four treatments had an average ME of 10.2±0.18 MJ ME/kg DM. Seasonally, there was no difference ($P=0.17$) in average ME among treatments for the grazing period. However, between seasons pasture quality was affected ($p<0.001$) with an average ME of 10.8 ±0.15 (spring), 9.8±0.11 (summer), 10.2±0.13 (autumn), and 10.4±0.13 (winter) MJ ME/kg DM.

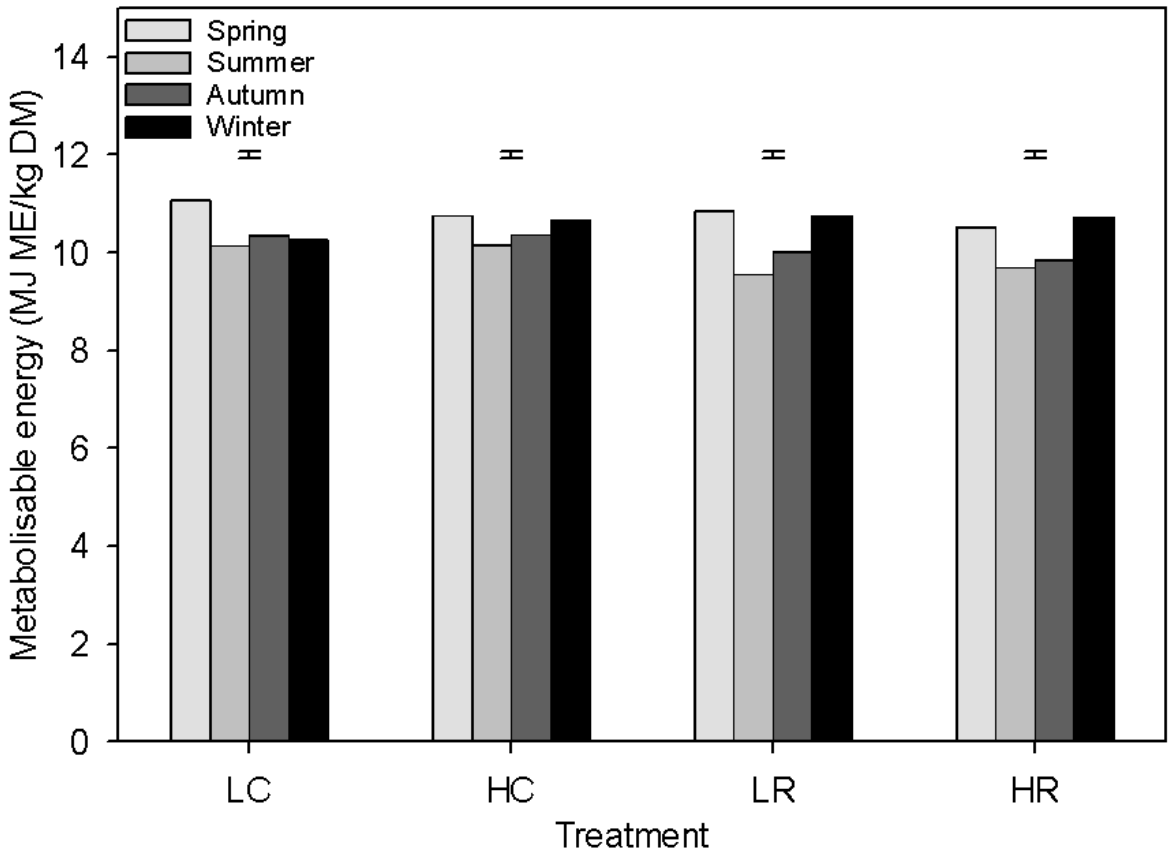

Figure 4.10: Mean metabolisable energy (MJ ME/kg DM) per treatment between 1 September 2022 and 27 July 2023 for Coopworth hoggets and lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. Treatment average s.e. of 0.17.

Crude protein differed between farm systems (conventional and regenerative) but not Olsen P (high and low) difference (Figure 4.11). This was confirmed by a post-hoc Tukey's test where RA treatments were lower ($p < 0.001$) in crude protein than CA treatments. Regenerative systems had an average CP of 15.1±0.94 % while conventional systems had an average of 19.9±0.94 %. Seasonally, CP differed ($p < 0.001$) among treatments with a reduction during summer across all four treatments, and highest CP in the autumn and spring. Conventional treatments on average had a greater CP% DM than regenerative treatments - 21.1±0.53 (HC and LC), 15.1±0.51 CP% (HR and LR). Seasonally, average CP% (Figure 4.5.2) was found to be 19.3±0.62, 14.3±0.50, 21.1±0.50, and 18.58±0.53 for spring, summer, autumn and winter respectively.

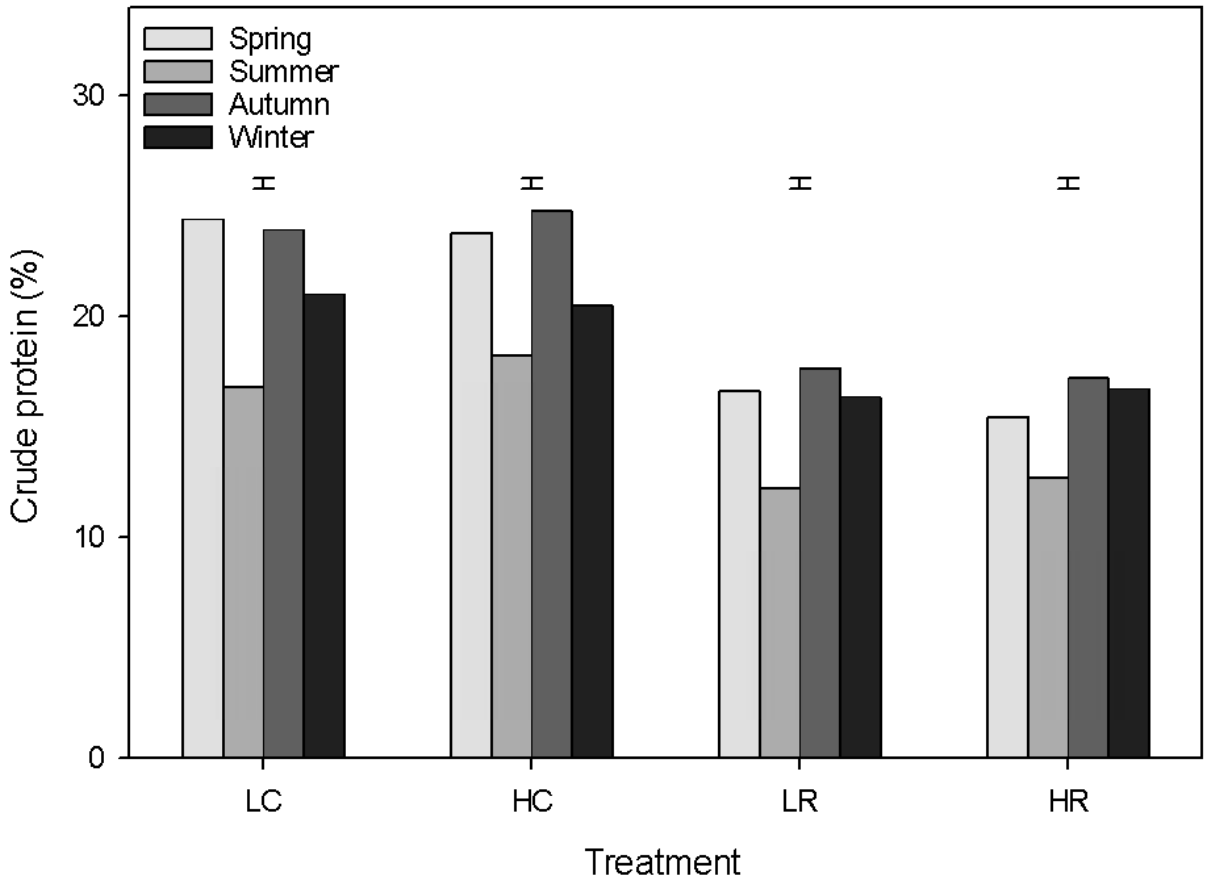

Figure 4.11: Seasonal crude protein (%) average per treatment between 1 September 2022 and 27 July 2023 for Coopworth hoggets and lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. Treatment average s.e. of 0.53, 0.52, and 0.51 for HC, LC and HR and LR respectively.

Neutral detergent fibre (NDF) differed between systems. Regenerative treatments had 14% greater ($P<0.001$) NDF% than conventional treatments (Figure 4.12). NDF was found on average to be 40.3 and 46.9±1.11 NDF% for conventional and regenerative, respectively. Within treatments, season had affected ($p < 0.001$) NDF. Across all four treatments, spring and winter had the lowest NDF content (39.0±1.25 and 38.3±1.10 NDF%, respectively), while summer had the greatest NDF (48.6±0.91 NDF%). Autumn had an average of 42.7±1.02 NDF%. Between treatments, conventional treatments had the lowest mean NDF in all four seasons – 34.8±1.25, 44.1±0.91, 37.91±1.02 and 34.84±1.07 NDF%, in spring, summer, autumn and winter, respectively. This compares with regenerative treatments which averaged 41.9±1.25, 50.9±0.91, 48.4±1.02 and 40.7±1.07 NDF%, in spring, summer, autumn and winter, respectively.

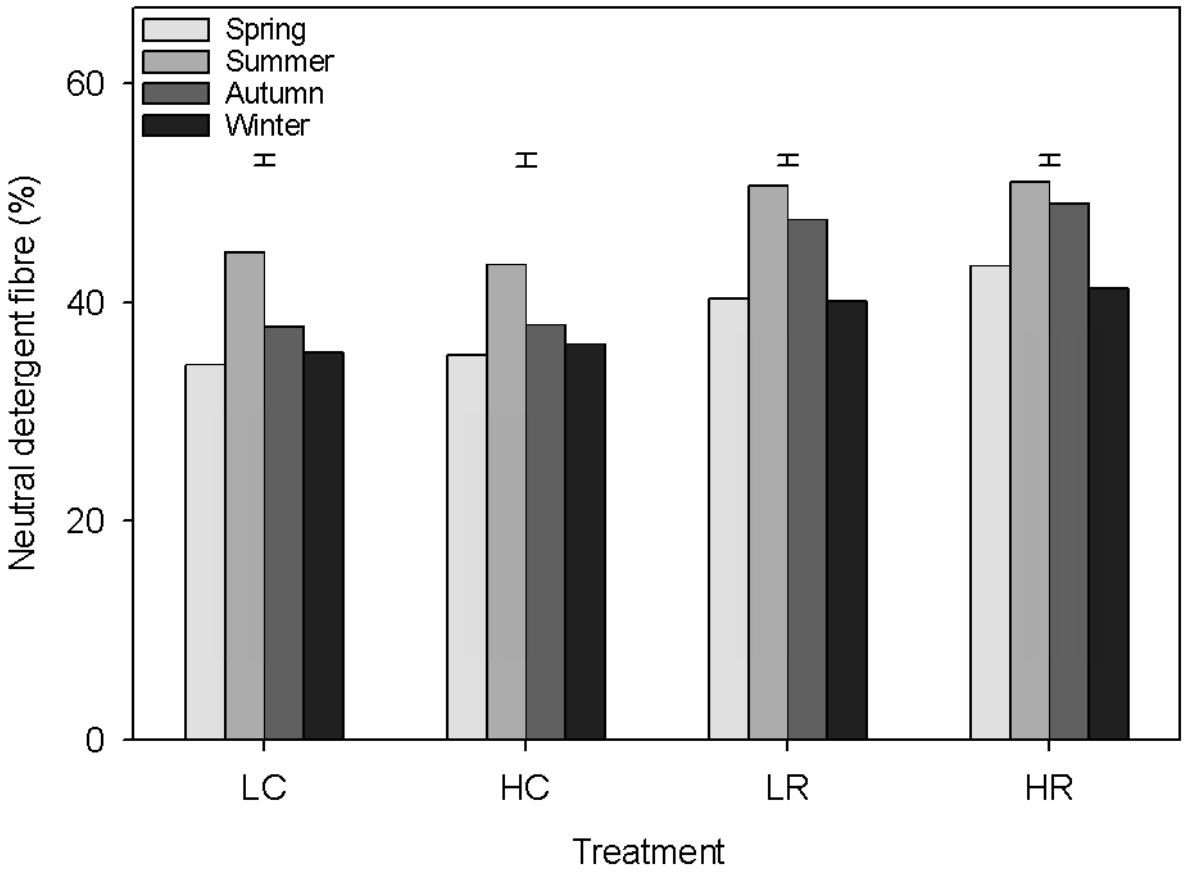

Figure 4.12: Mean seasonal neutral detergent fibre (NDF%) between 1 September 2022 and 27 July 2023 for Coopworth hoggets and lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. Mean s.e. of 1.11.

4.6 Botanical composition

Botanical composition of the pasture yields is shown in Figure 4.13. Pasture treatment affected the amount of grass ($p=0.013$), legume ($p <0.001$) and herb ($p<0.001$) grown. For conventional treatments the grass yield was: 2005 and 2267±412 kg DM/ha, legume 6263 and 5960±457 kg DM/ha, and herb 375 and 471± 306 kg DM/ha for LC and HC, respectively. Regenerative treatments had a higher ($p <0.001$) amount of both herb and lower legume. The grass yield: 2870 and 3969±411 kg DM/ha, legume yield was 3557 and 3319±457 kg DM/ha, and herb yield; 3121 and 2973±306 kg DM/ha, for LR and HR, respectively. The post-hoc Tukey's test found that HR had the highest grass yield. LC and HC had the lowest grass yield, and LR was not different from the conventional treatments or HR. Herb yield was highest under regenerative management. Whereas legume yield was found to be highest under conventional management.

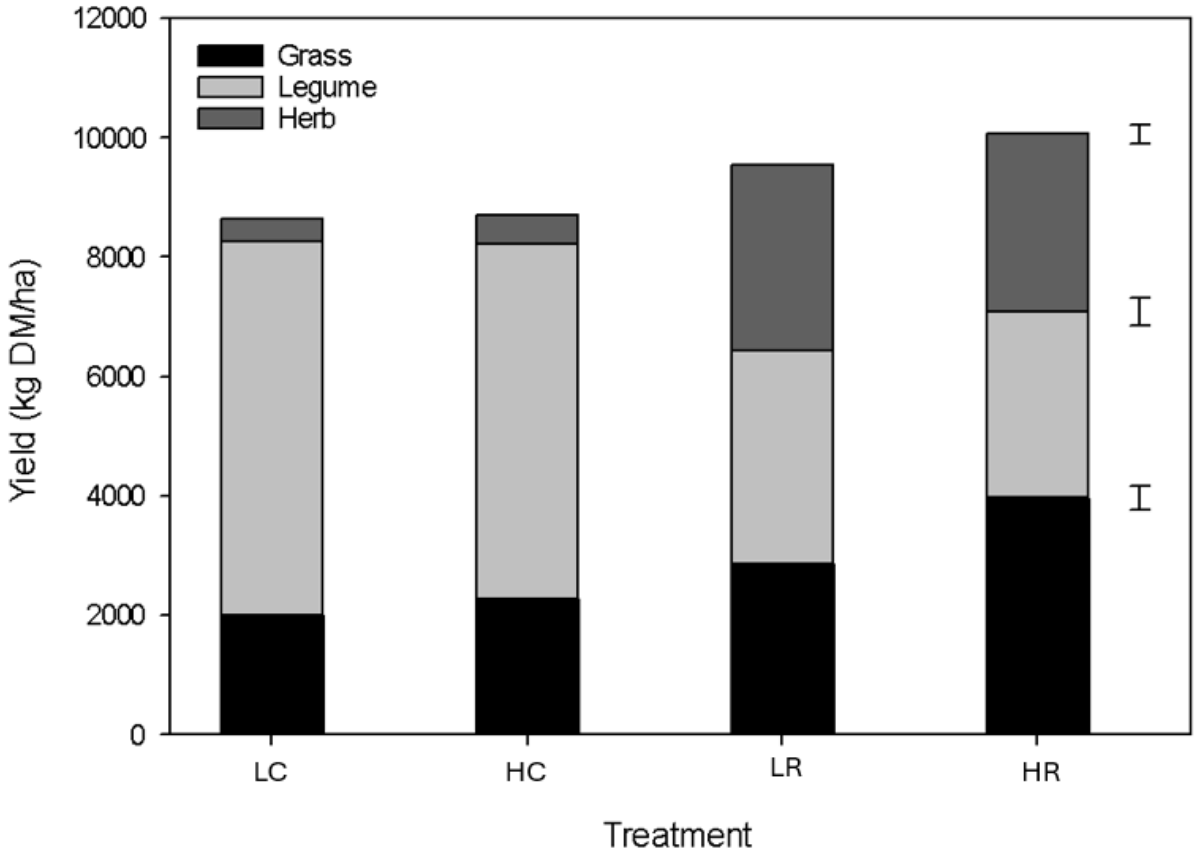

Figure 4.13: Mean accumulated dry matter (DM) yield contribution from grass, legume and herb for high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures grown at Lincoln University. S.e. of 412 (grass), 457 (legume) and 306 (herb).

Figure 4.14 shows the accumulated intake of grass ($p=0.146$), legume ($p < 0.001$) and herb ($p <0.001$) within each treatment. Grass intake was not different among treatments with a mean intake of 1594±318 kg DM/ha confirmed by a Tukey post-hoc test. Individual treatments had an intake of 1454 (HC), 1385 (LC), 2241 (HR) and 1294 (LR) ±318 kg DM/ha. Legume intake differed between systems ($p <0.001$) as confirmed by a Tukey post-hoc test. Conventional management had a greater ($P<0.001$) intake of legume; 5369 (HC) and 5732 (LC) ±426 kg DM/ha, compared with 2936 (HR) and 3359 (LR) ±426 kg DM/ha. Herb intake also differed ($p <0.001$) between systems. Herb intake was greater ($p<0.001$) under regenerative management; 2784 (HR) and 2961 (LR) ±289 kg DM/ha, compared with conventional management; 264 (HC) and 218 (LC) ±289 kg DM/ha.

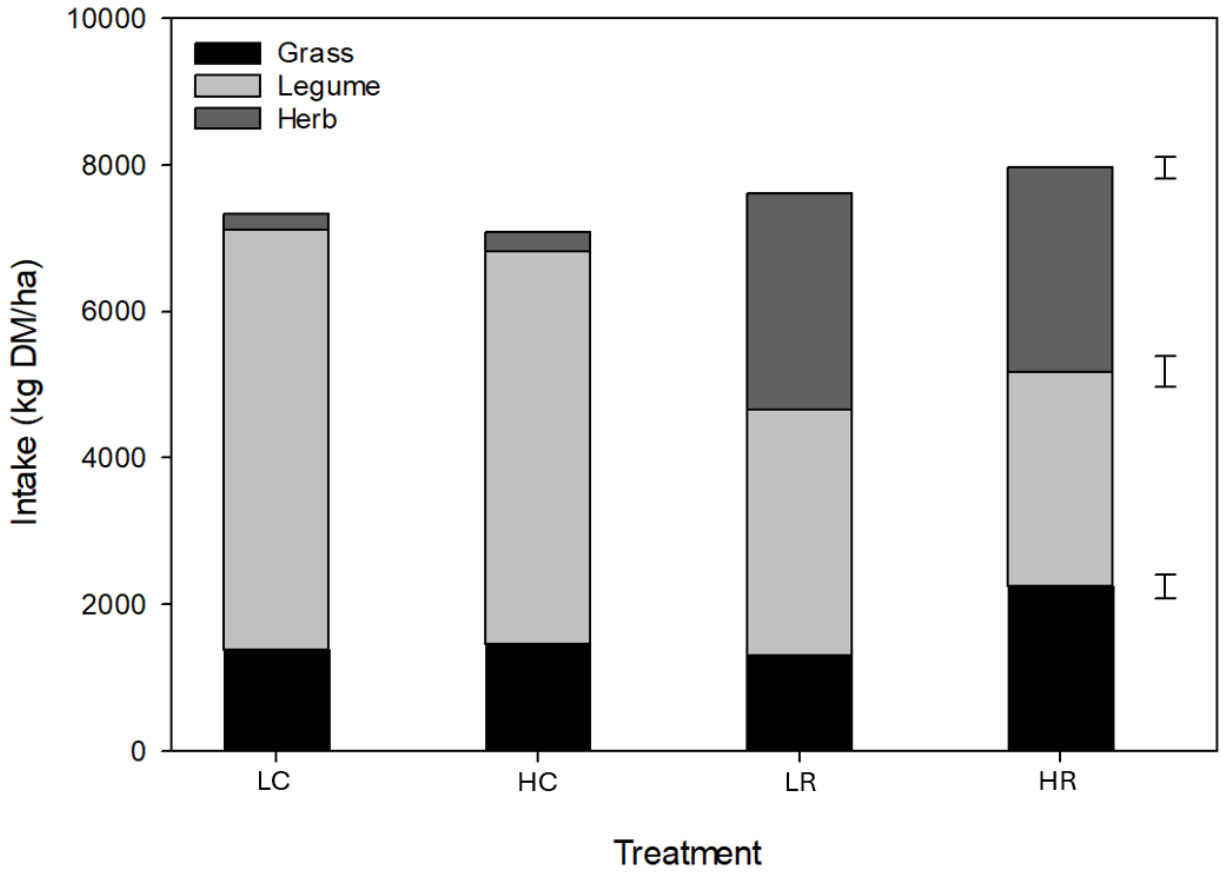

Figure 4.14: Average accumulated dry matter (DM) intake (kg/ha) contribution from grass, legume and herb for high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. S.e. of 318 (grass), 426 (legume) and 289 (herb).

4.7 Pasture mass

Figure 4.15 shows the average pasture mass (kg DM/ha) pre-grazing for each grazing rotation between 11 September 2022 and 3 August 2023. Flock change from 2022 to 2023 occurred during rotation five, rotations and flock grazing periods are shown in Appendix 5. The differences in start and end dates are due to regenerative systems having a shorter grazing duration, and therefore faster rotations compared with conventional flocks. Average pasture cover differed (P = 0.002) among rotations and treatments. Mean pasture covers per treatment were 3077^{a}, 2928^{ab}, 2580^{bc} and 2406^{c}±119 for HR, LR, HC and LC, respectively. Thus, on average HR had the greatest pasture cover, while LC had the lowest average pasture cover. Figure 4.15 shows that pasture mass declined in conventional pasture from Rotation 4 to ~2000±119 kg DM/ha. In contrast, regenerative pastures declined in pasture mass for Rotation 5 (~1900±119 kg DM/ha), which then increases (~2700±119 kg DM/ha) until Rotation 7 when it began to decline again in Rotation 8 (2100 and 2400±119 kg DM/ha, LR and HR, respectively).

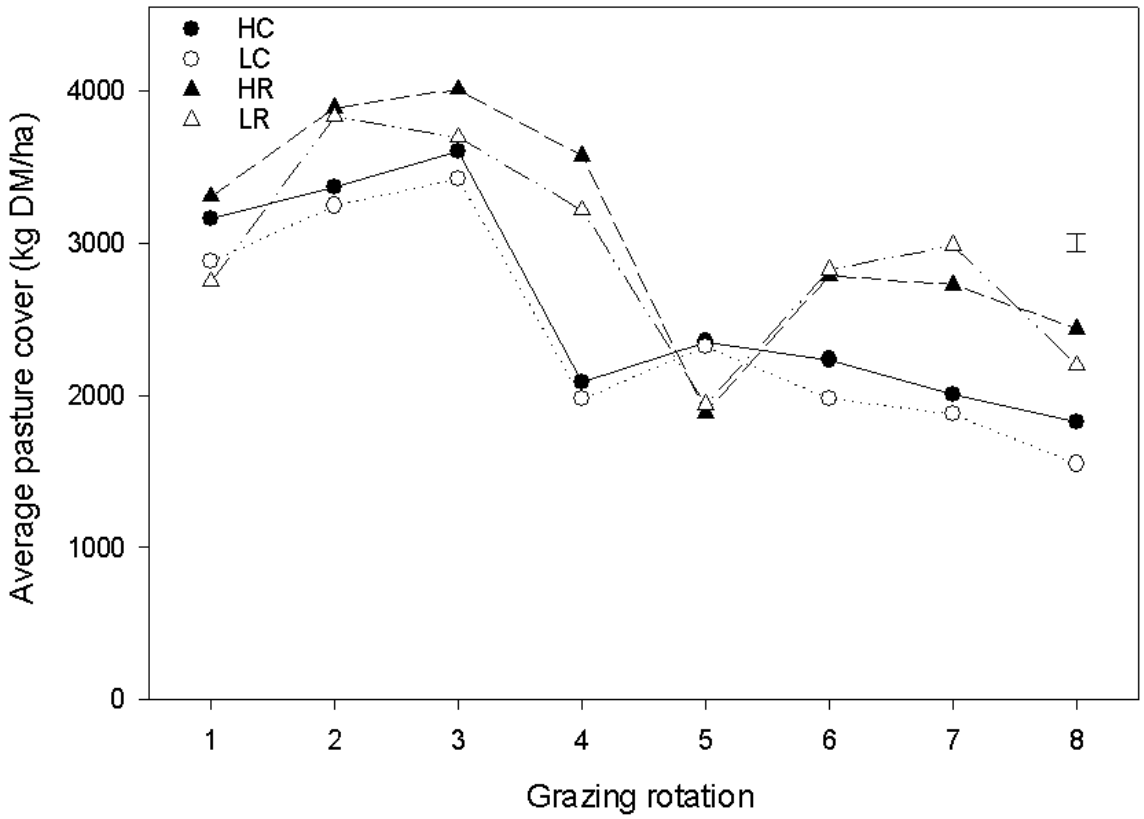

Figure 4.15: Average pasture mass (kg DM/ha) per grazing rotation for Coopworth hoggets and lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures between 11 September 2022 and 3 August 2023 at Lincoln University. Average pasture cover s.e. of 119.2 kg DM/ha. Flock change occurred between Rotation 4 and 5.

4.8 Methods of estimating intake

Four methods of estimating intake were analysed as shown in Figure 4.16. The method of estimation was significant ($p < 0.001$). Theoretical intake based on ME requirements for maintenance and liveweight change averaged 1.09±0.19 kg DM/head/d. In contrast, estimation of intake based on 4% of liveweight averaged 2.35±0.07 kg DM/hd/d, which was 126% greater than theoretical ME intake. The disappearance method was not different among treatments ($P = 0.087$), with an average intake of 1.84±0.18 kg DM/head/d. This was close related to the value estimated from 3% LW which was not different ($P<0.736$) among treatments with an average intake of 1.76±0.05 kg DM/hd/d.

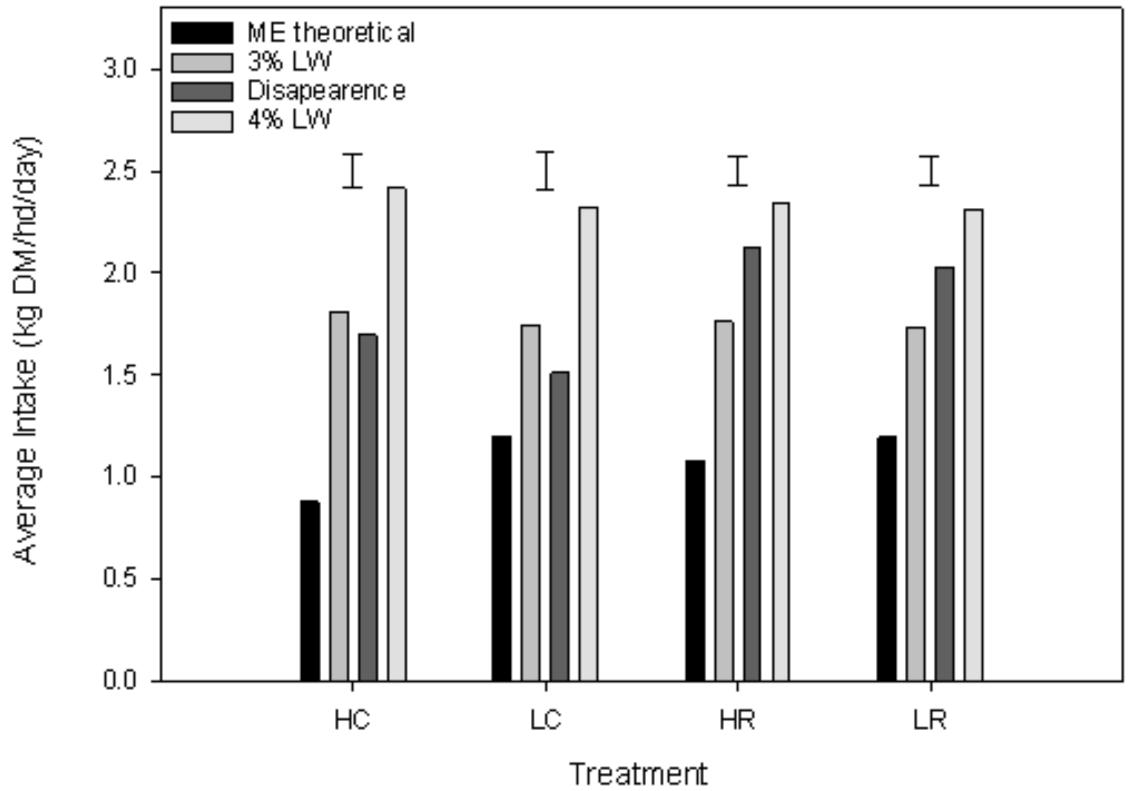

Figure 4.16: Average intake based on four methods of estimating animal intake (ME energy requirements, 3% liveweight (LW), the disappearance method and 4% LW), for Coopworth hoggets and lambs grazing high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University. S.e. of methods within treatments of 0.16 (HC), 0.18(LC), 0.14 (HR) and 0.14 (LR) kg DM/hd/d.

4.9 Specific periods of LWG differences

Table 4.1 shows the pre-grazing mass, ME, CP and NDF for specific periods where differences in accumulated LWG against the research period average. Between the 26 October and 13 December, there was no difference ($p < 0.92$) in pasture mass or ME ($p < 0.557$), however CP was higher ($p < 0.001$) in CA treatments, and NDF was lower ($p < 0.001$). Between 21 February and 2 March 2023, pre-grazing pasture mass ($p < 0.086$), ME ($p < 0.740$), CP ($p < 0.614$) and NDF ($p < 0.314$) were not different between treatments. Mean pasture mass was 1149±422 kg DM/ha, CP; 17.4±4.66 %/kg DM, ME; 9.3 MJ ME/kg DM and NDF was 44.7±7.39 %/kg DM. Between 30 June and 3 August CP was the only factor which was different ($p < 0.001$), where LR had the lowest CP (15.9±0.89%/kg DM), while HC had the highest CP content (21.1±0.89 %/kg DM).

Table 4.1: Analysis of pre-grazing pasture mass (kg DM/ha), metabolisable energy (ME), crude protein (CP) and neutral detergent fibre (NDF) of specific periods where LWG accumulation rate changed, compared with the pasture and quality averages of the research period (bolded) for Coopworth hoggets and lambs grazing; high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures on the RADE at Lincoln University.

	Dates	LC	HC	LR	HR	P value	Max s.e.d
Pre Mass (kg DM/ha)	26/10/2022-13/12/2023	3424	3695	3702	3646	0.918	468
	21/02/2023-2/03/2023	1298	1801	573	924	0.086	422
	30/06/2023-3/08/2023	1517	1692	1990	2081	0.151	178
	11/09/2022-3/08/2023	**2423^{a}**	**2574^{ab}**	**2927^{bc}**	**3095^{c}**	**<0.001**	183.3
ME (MJ ME/kg DM)	26/10/2022-13/12/2023	9.8	9.7	9.9	9.4	0.557	0.6
	21/02/2023-2/03/2023	9.4	10.1	9.0	8.8	0.740	1.2
	30/06/2023-3/08/2023	9.9	10.0	10.7	10.7	0.653	0.52
	11/09/2022-3/08/2023	**10.4**	**10.4**	**10.1**	**10.1**	**0.46**	**0.09**
CP (%/kg DM)	26/10/2022-13/12/2023	24.4^{a}	23.0^{a}	17.7^{b}	17.5^{b}	<0.001	4.37
	21/02/2023-2/03/2023	18.7	20.2	16.4	14.4	0.614	4.66
	30/06/2023-3/08/2023	20.4^{ab}	21.1^{a}	15.9^{c}	17.1^{bc}	<0.001	0.86
	11/09/2022-3/08/2023	**21.2^{b}**	**21.7^{b}**	**15.5^{a}**	**15.3^{a}**	**<0.001**	**0.47**
NDF (%/kg DM)	26/10/2022-13/12/2023	37.9^{a}	36.7^{a}	50.2^{b}	50.2^{b}	<0.001	1.79
	21/02/2023-2/03/2023	41.3	37.8	50.4	49.1	0.314	7.39
	30/06/2023-3/08/2023	34.4	36.8	40.0	39.0	0.619	3.05
	11/09/2022-3/08/2023	**38.9^{a}**	**39.1^{a}**	**46.4^{b}**	**47.6^{b}**	**<0.001**	**0.55**

4.10 Metabolisable energy concentration

Figure 4.17 shows the relationship between ME of the bulk pasture sample against the calculated estimated ME of the selected diet. Overall, all four treatments are shown to select a diet which is of a higher ME (MJ/kg DM) than the ME of the bulk sample taken. In theory animals would be meeting energy requirements with a lower intake than calculated based on bulk ME values. Therefore, the relationship shows there is some issue with intake methodology as where selectivity is possible animals will select a diet with a greater ME than measured.

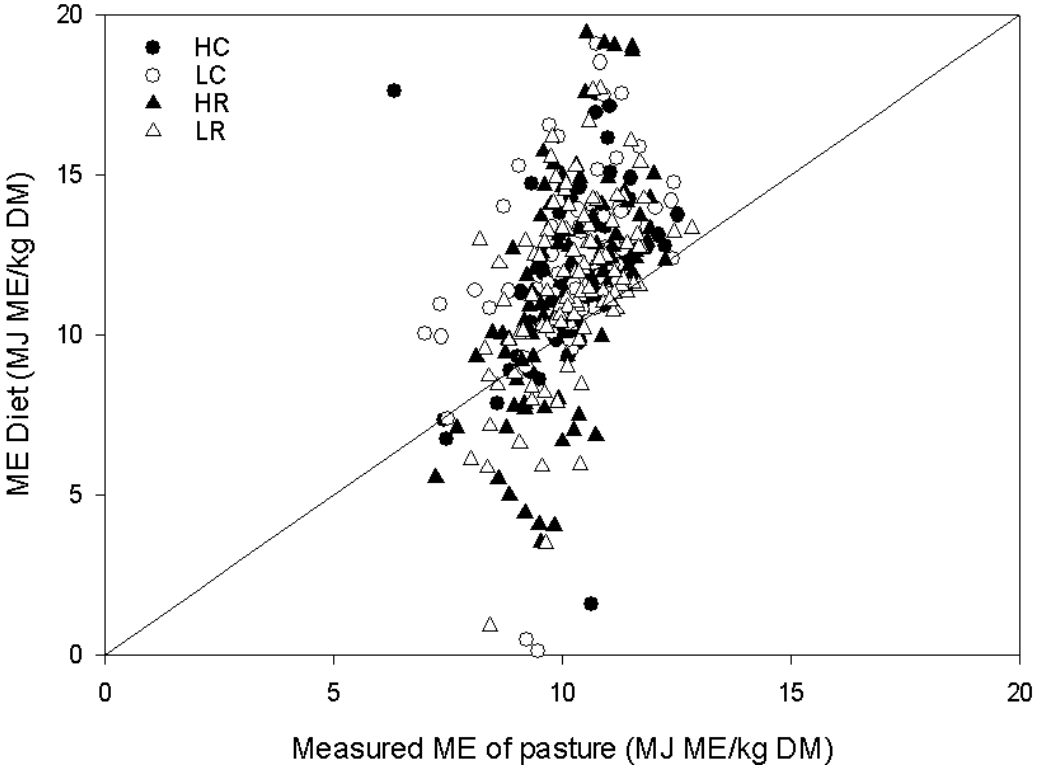

Figure 4.17: Metabolisable energy (ME) concentration of the feed selected in contrast to ME offered, with a 1:1 line to show diet selectivity for Coopworth hoggets and lambs grazing between 11 September 2022 and 3 August 2023 at Lincoln University on either high conventional (HC), low conventional (LC), high regenerative (HR) or low regenerative (LR) pastures at Lincoln University.

Chapter 5

Discussion

The aim of this research was to quantify the liveweight gain of Coopworth hoggets and lambs which grazed conventional and regenerative pastures under high or low Olsen P levels, between September 2022 and August 2023. This was achieved by quantifying liveweight gain over time, as well as related yield, intake and quality parameters to explain differences in growth between and within treatment groups for each of the four treatment flocks within the Coopworth hoggets and lambs, separate grazing periods. In this chapter the changes in liveweight between the flocks in each year will be described followed by a discussion of the variables that explain the observed differences in LWG/ha. To do this, results are presented as relating to the 2022 hogget flock followed by the 2023 lamb flock. Results are considered on a flock grazing period basis before specific periods are investigated that coincided with the periods of different LWG.

5.1 Liveweight gain

There were differences in liveweight gain amongst the treatment groups. These can be explained by pasture availability and quality which impacted intake and therefore the ability of animals to optimise energy and protein acquisition. In turn pasture growth and quality were affected by soil moisture availability. Figure 4.1 shows that the Coopworth hoggets and lambs grazing conventional treatments on the 3 March had a greater LWG/ha than those on regenerative treatments. Specifically, for hoggets grazing between 26 October and 13 December 2022 there was a trend for lower live weight growth particularly for the HR flock. This trend continued until the 21 February 2023 by which time the HC flock had the highest liveweight gain. After this measurement date, HC, HR and LR flocks lost weight, shown as a decline in LWG/ha, but the LC flock accumulated an additional 4.6 kg/ha. On average, regenerative treatments lost 33.4 kg LWG/ha, where HC lost 8.9 kg LWG/ha. But at the end of the measurement period the LWG from HC was still the heaviest (336 kg LWG/ha), followed by LC (323 kg LWG/ha) which were on average 42 and 60 kg greater than LR and HR respectively.

The replacement lambs entered the farmlets on 3rd March 2023. Their LWG/ha was not different amongst flocks until 5 July 2023. However, between 5 July and 3 August the flocks on regenerative pastures lost on average 7.5 kg LWG/ha. Those on conventional pastures continued to increase their LWG so on average there was 15 (HR) and 28 (LR) kg/ha difference when they were removed and replaced by Bohepe ewes for the next grazing period. To explain these changes in LWG/ha herbage yield, and quality measurements are discussed as explanatory variables, because LWG is a direct

response to the amount of feed and the quality of feed an animal can consume (Waghorn et al. 2017).

5.2 Yield

2022:
One of the main factors affecting animal intake and therefore LWG is pasture availability. Accumulated yield gives an indication of pasture availability overtime and was related to thermal time to give a standardised growth rate, accounting for temperature (Valentine & Kemp 2017). Accumulated yield in the first year was ~5000 kg DM/ha per treatment (Figure 4.2a). The growth response curve was defined by a logistic curve which accounted for the lag, exponential and ceiling phases of growth which is consistent with the literature (Brougham 1955, Valentine & Kemp 2017). Yield accumulation achieves a maximum rate of growth, and then declines due to increased rate of senescence, attributable to tissue turnover and increased maintenance respiration (Valentine & Kemp 2017). All four treatment showed a period of around three weeks of a lag phase where rate of yield accumulation was slow, followed by an exponential phase between October and December, before yield accumulation plateaued (ceiling phase).

Further analysis of the accumulated yield data against thermal time shown in Figure 4.3 describes the relationship as a split line regression where Slope 2 was 99.6% slower than Slope 1. The break point between Slope 1 and Slope 2 coincides with the onset of water stress shown in Figure 3.4. The break point occurs on 16 December, but its accuracy is limited by the low number of points available. The point at which pasture growth is expected to cease at an actual soil moisture deficit (ASMD) of 157 mm was reached on the 13 November 2022. Because temperature is accounted for through thermal time, the only other two factors which could be affecting yield were nitrogen and water availability (Mills et al. 2006). Between November and March, the ASMD remained at 157 mm with no indication of soil water recharge. Therefore, only rainfall events greater than the soil evaporation loss are available to be used by the plant and hence the pasture growth rate was minimal as shown by the lack of accumulation after the break point.

Coming out of summer, N should not be a limiting factor due to the accumulated organic matter over the spring/summer available for mineralisation through the autumn. An estimate of N fixation was calculated based on the legume yield of each treatment (Figure 4.13) and estimated N fixation of 25-30 kg N/t legume (Lucas et al. 2010). Under the regenerative treatments between, 88 and 105 (LR) kg N/ha/yr and 83 and 99 (HR) kg N/ha/yr could have been fixed from 3.60 and 3.32 t legume, LR and HR respectively. The LC was estimated to fix between 158 and 189 kg N/ha/yr (6.3 t legume/ha), and HC between 148 and 177 kg N/ha /yr (6.0 t legume/ha).

During summer there is typically higher mineralisation due to increased soil temperature provided moisture is not limiting. Optimal temperature for mineralisation is 25 ^{o}C, with soil moisture between 80 and 100% of field capacity (Guntiñas et al. 2012). Therefore, mineralisation of N probably decreased through the summer. However, with rainfall events the rate of mineralisation is likely to have increased through March - with rainfall - to meet plant demand (Bilotto et al. 2021). Plants continue to use water until they run out of water in the root zone. Once there is no water available, then no growth will occur (Mills et al. 2006). The N response to fertiliser application in the autumn is usually lower due to limited soil moisture, and high levels of mineralised N from legume N fixation and organic matter (Sun et al. 2008). Therefore, it is likely pasture growth was impaired by water limitation more so than a N limitation.

2023:

Accumulated yield for the period of grazing of the second flock yielded 2900 kg DM/ha for CA treatments and 2662 and 2369 kg DM/ha for HR and LR respectively (Figure 4.2b). Figure 4.4 shows the low P treatments initially responded more rapidly to rainfall through March, where 0 corresponds to 16 February 2023, and at ~700 ^{o}Cd is approximately 14 April 2023. Interestingly, high P treatments did not exhibit a split regression model but grew linearly between 16 February and 3 August 2023. From mid-April, until 1 July a total of 151 mm of rainfall was received. Whereas in the month of March 102 mm of rain was received. Figure 3.3 shows the PET of February, March and April was ~120, 100 and 60 mm, respectively. Therefore, the PET during March was equal to rainfall which explains why the ASMD did not get lower than 100 mm in the top metre of soil. As a result, only rainfall events larger than the requirement of soil evaporation would have allowed plant uptake and growth (Mills et al. 2008). Smaller events can be expected to have evaporated before the water was used by plants. The lack of soil moisture is reflected in the low rate of growth shown in Figure 4.4. The high P treatments only grew at 1.86 kg DM/ha/^{o}Cd, or 44% slower than a N deficit pasture (Mills et al. 2006).

Water use efficiency:

Water use efficiency (WUE) for Year 1 yield, was calculated based on yield produced and rainfall received during the period. Between 31 August 2022 and 15 February 2023 there was 230 mm rainfall recorded. This assumes the soil profile had met field capacity through the winter, as shown in Figure 3.4. Therefore, to produce an average of 5000 kg DM/ha the average water use efficiency of the treatments was 21.8 kg DM/mm in Year 1. Between 16 February and 3 August 2023, a total of 442 mm was received in rainfall. Therefore, to achieve yields of 2897, 2903, 2662 and 2369 kg DM/ha was produced (HC, LC, HR and LR respectfully) the water use efficiency was approximately 6.60, 6.60, 6.02 and 5.40 kg DM/mm respectively for Year 2. The water use efficiency of a ryegrass/white clover pasture has been found to be 20kg DM/mm and around 24 kg DM/mm for lucerne (Moot et al.

2008). Therefore, the water use efficiency found for the accumulated yield of the first Coopworth flock (Year 1) is what would be expected. However, the WUE for the second flock (Year 2) was ~14 kg DM/mm lower than expected, which indicates that ~70% of received rainfall was lost to soil evaporation during this period, or remained in the soil, recharging the profile to be used for growth the subsequent spring. During the autumn plants, for example lucerne, begin partitioning a greater proportion of photo assimilates to the roots to replenish reserves for the winter and subsequent spring growth. As a result, shoot yield is reduced, which decreases WUE (Moot et al. 2003).

From the 13 November 2022, the actual soil moisture deficit had reached the available water capacity of the soil 157 mm/m. Rainfall between 13 November 2022 and 15 February 2023 was 164 mm, therefore at 20 kg DM/mm rainfall (Moot et al. 2008) the expected yield between 13 November and 15 February was 3300 kg DM/ha. However, because only ~1700 kg DM/ha was produced it can be estimated that 48% of the rainfall was lost as soil evaporation.

5.3 Intake

Intake is directly linked to the growth of an animal and indicates what is happening within the system. It is the function of feed availability, composition, appetite and nutrient demand (Waghorn et al. 2017). Within grazing systems intake is often less than *ad libitum* because grazing livestock are used for pasture management and production (Section 2.5.3). In conventional systems, this means that grazing rotation and duration are altered to maintain pasture quality, often at the expense of animal performance. However, within regenerative systems the high density, short duration in theory allows a greater level of selectivity by animals.

Figure 4.5a and b show the accumulated intake of the two Coopworth flocks. The 2022 flock (Figure 4.5a) was found to have no difference among treatments. In mid-November, rate of intake increased from 14 kg DM/ha/d to 38 kg DM/ha/day. This is likely to be slightly high, as equates to 3.5 kg DM/head/d from 1.3 kg DM/head/day in the previous slope. Although, as pastures were accumulating, pre- and post-grazing residuals increased. Therefore, the potential for bias when selecting representative pre-and post-grazing samples increased (Section 2.5.1). However, when related to accumulated yield, this slope was explained by the animals eating into accumulated biomass (Figure 4.6).

Figure 4.5b (2023 flock) however, shows that the two CA flocks had the same rate of intake at 16 kg DM/ha/d which equates to 1.50 kg DM/hd/d. In contrast, intake of HR was 13.8 kg DM/ha/d (1.27 kg DM/hd/d), and LR had the lowest intake of 11.6 kg DM/hd/d (1.10 kg DM/hd/d). Therefore, CA treatments had the greatest intake, while LR had the lowest intake.

Figures 4.6 and 4.7 show the accumulated DM intake (kg/ha) in relation to accumulated dry matter yield (kg DM/ha). The first slope of Figure 4.6 indicated that biomass was accumulating in the treatments. For example, when ~4 t DM/ha of yield had accumulated only ~1.5 t DM/ha had been eaten. However, after this, the accumulated biomass was being eaten at a faster rate than production. Therefore, by the time 5 t DM/ha was produced ~4 t DM/ha had been consumed (~80% utilisation). The increased rate of intake corresponds with the decreased yield accumulation due to water stress. This indicates that through the spring herbage accumulated, building canopy cover - often referred to as a pasture surplus (Webby & Bywater 2017). During this period the growth of the pasture was greater than the demand by the animals, which is expected during the exponential phase of the sigmoid pasture accumulation curve (Figure 4.2a) (Valentine & Kemp 2017, Webby & Bywater 2017). However, with the onset of moisture stress, pasture growth was reduced, shown as stable in Figure 4.3, but there are still animal requirements to be met. Therefore, accumulated pasture cover is eaten into, showing increased rate of intake relative to accumulated yield. Figure 4.6 begins at between 300 and 500 kg DM/ha yield due to the accumulation of yield starting on the 31 August 2022, whereas intake begins from 11 September, when the Coopworth hogget grazing period commenced. By early March, most of the pasture cover would have been eaten into through the summer dry. However, recorded rainfall through March (102 mm), increased pasture growth (Figure 4.4). This meant that between March and April, pasture growth rate increased, and intake was 0.63 kg DM eaten/kg DM produced (Figure 4.7). This increased to 1.54 kg DM eaten/kg DM produced between April and August as temperatures declined into winter temperatures which would have restricted growth, with mean temperatures dropping below 10 ^{o}C from May 2023 (Figure 3.2). Therefore, total thermal time accumulation is reduced and as a result rate of pasture growth is decreased (Figure 4.4) (Moot et al. 2017).

5.3.1 Feed conversion efficiency

Feed conversion efficiency (FCE) is the rate in which eaten dry matter is converted into LWG (Figure 4.8 and 4.9.). Initially, all four treatment groups from the 2022 flock were growing at a rate of 219 g LWG/kg DM eaten or 4 kg DM/kg LWG. Therefore, at an intake of 1.5 kg DM/hd/d, the daily growth would have been ~329 g/hd/d. Rate of LWG accumulation was high considering the grazing animals were also between 12 and 16 months old, and nearly at mature body weight (60 kg) on the 22 September 2022. This result is consistent with lamb growth rates found on lucerne monoculture and CF/SC pastures (>300 g/hd/d) (Avery et al. 2008, Grigg et al. 2008). However, at ~1000 kg DM intake (beginning of December 2022, Figure 4.8) the rate decreased to 33 g LWG/kg DM eaten (50 g/hd/d, at intake of 1.5 kg DM), or 30 kg DM/kg LWG, corresponding to the period of water stress, and decreased ($p<0.001$) pasture quality (average summer ME; 9.8 MJ ME/kg DM, CP; 14.3 %/kg DM, NDF; 48.6 %/kg DM). Similar results were found by Mills et al. (2015), where summer growth rates

were significantly lower ($p<0.05$) than spring growth rates due to increased quality of spring feed compared to summer (Mills et al. 2015). Mills et al. (2015) compared a range of dryland pastures including lucerne and CF/SC at Lincoln University. Spring FCE in ewe hoggets and lambs was found to be approximately 73 g LWG/kg DM eaten, or 206 g/hd/d grazing lucerne (Mills et al. 2015). While in summer, maximum daily growth rate was 194 g/hd/d on lucerne, and 105 g/hd/d on grass based pastures (Mills et al. 2015).

The second group of Coopworth's had a linear FCE, of 85 g LWG/kg DM (127 g/hd/d at 1.5 kg DM intake), or 11.8 kg DM/kg LWG. This group were lambs of between 7 and 12 months old. This result is comparatively low compared with results found by Ryan-Salter (2019) who achieved an annual average of 131 g LWG/kg DM eaten for CF/lupin and lucerne pastures in the Mackenzie Basin, New Zealand. However, is similar to results found by Mills et al. (2015), who found autumn growth rates of between 83 and 134 g/hd/d on grass-based and lucerne pastures respectively. The average LWG/kg DM eaten between the two Coopworth flocks was 149 g LWG/kg DM (~224 g/hd/d, at intake of 1.5 kg DM), comparable to the annual result Ryan-Salter (2019) found, and spring growth results found by Mills et al. (2015).

Feed conversion efficiency is a function of feed quality (nutrient density and energy), animal genetics and digestibility, composition of weight gain, and nutrient utilisation (Gaillard et al. 2020). Therefore, differences in rate of conversion are a result of differences within these factors. Because all four treatments had the same FCE, these factors are not expected to be different. Therefore, differences in accumulated LWG had to be a result of the amount an animal could eat per day.

5.4 Quality

Intake is affected by the quality of the feed, which is affected by botanical composition (Section 2.5.3). Theoretical intake, pre- and post-grazing mass and grazing duration also affect intake as these factors affect selectivity. If feed available is reduced, or grazing duration is extended animals are forced to eat a less palatable, lower quality diet, which can compromise intake and production (Waghorn et al. 2017). Therefore, to address quality effect on intake, the seasonal ME, CP and NDF as well as the overall yield and intake of grass, legume and herb were analysed.

5.4.1 Metabolisable energy, crude protein and neutral detergent fibre

Metabolisable energy in pastures was not different ($p < 0.46$) across treatments per season with an annual average of 10.2 MJ ME/kg DM. Summer, as expected (Valentine & Kemp 2017), had the lowest ME of 9.8 MJ ME/kg DM ($p<0.001$), while spring had the highest; 10.8 MJ ME/kg DM (Figure 4.10). Lower summer energy contents are the result of increased maintenance respiration and

therefore the ratio of water soluble to structural carbohydrates is decreased (Moot et al. 2017). There is also increased NDF, as a result of increased dead material as mature pastures have greater proportions of older leaves, and reproductive stems. When water stress is added it increases canopy temperature so the rate of senescence and phenological development increases, which results in the increase in dead material, and this produces a pasture of lower quality (Moot et al. 2017, Valentine & Kemp 2017). However, this occurred in all four treatment groups, where the summer period resulted in lower ME. Therefore, differences in LWG were not explained by differences in energy content of the feed. This was further confirmed by the selected ME of the diet against the measured ME from the pasture samples (Figure 4.17). This showed that the selected diet generally was of a higher value than the measured bulk sample. The method has known limitations with some high values (above ~13 MJ ME/kg DM) beyond realistic expectation caused by issues with assessing pre- and post-grazing mass. However, the overall data mass shows that, when given the opportunity, animals will select a diet of higher quality than the measured sample (Cosgrove & Edwards 2017). Shown by majority of the values being above the 1:1 ratio line.

Crude protein was found to be affected by season and by system type ($p< 0.001$) (regenerative and conventional) but was unaffected by Olsen P level (Figure 4.11). On average, conventional treatments had a 5% greater CP concentration. From crude protein, N% of the aboveground biomass can be calculated. On average regenerative pastures had a N% of 2.42%, whereas conventional treatments had an average N% of 3.20%. Therefore, because of the legume dominance of the conventional pastures (Figure 4.13), they were non-limited by N and were able to maintain a high N%. Mills & Moot (2010) reported a lucerne yield of >500 kg N/ha/yr, with an average leaf N concentration of ~3-4%, whereas CF/SC pastures yielded ~300 kg N/ha/yr, at a N% of 3.5%. N concentration of grasses was found to range between 1.9 and 4.6% (Mills & Moot 2010). Therefore, regenerative pastures, due to the lower legume content (Figure 4.13) resulted in a reduced N concentration. It is likely that these pastures were N deficient, as typically CP is around 20% (Waghorn et al. 2017). Figure 4.11 shows that CP was reduced ($P <0.001$) in summer and therefore brought the average down. Conventional treatments in spring, autumn and winter had a CP between 21-25%, while regenerative treatments CP was between ~17 and 20%. Whereas in summer this dropped to an average across RA treatments of 14% and ~18% in CA treatments.

Neutral detergent fibre (NDF) is the proportion of fibre in the feed including cellulose, hemicellulose and lignin. NDF content was found to be highest ($p<0.001$) in regenerative pastures, on average 47%, compared with 40% in conventional pastures. However, as with ME and CP, was affected by season with highest ($p<0.001$) NDF values across all treatments in the summer. This is because, plants go into reproductive development, which increases structural carbohydrates due to stem elongation

(Valentine & Kemp 2017). This was higher in the regenerative pastures due to the greater grass proportion (Figure 4.13). This is because of the growth habit of perennial grasses. Through the early spring, grasses will grow vegetatively, until their vernalisation requirement is met. This enables the plant to sense photoperiod and switch from vegetative to reproductive development (Moot et al. 2017, Valentine & Kemp 2017). Once a species specific photoperiod and/or thermal time requirement is met this will result in stem extension, increasing structural carbohydrates, and decreasing pasture quality. Stem extension and seeding increase leaf and tiller death and fibre content, which lower digestibility and thus quality (Moot et al. 2017). This growth habit means that no part of a plant in a perennial pasture can be older than 18 months (Valentine & Kemp 2017). Legumes produce less structural carbohydrates and maintain quality in the leaf material. Therefore, the NDF proportion doesn't increase as much during the summer when the pasture is dominated by legumes - such as the CA treatments.

Quality was different between systems for CP and NDF. The decreased NDF of the CA pastures would have allowed animals to eat more per day due to decreased rumination time (Cosgrove & Edwards 2017), as seen by the increased intake of the 2023 flock shown in Figure 4.5b. In addition, the higher protein content may have increased growth of the animals, through supporting greater muscle development (Brookes & Nicol 2017, Lee et al. 2020).

5.4.2 Botanical composition – yield and intake

Botanical yield (Figure 4.13) and intake (Figure 4.14) were analysed as an accumulated yield of grass, legume and herb for each treatment. The botanical composition of CA pastures had a greater proportion of legume at between 40-47% more than RA pastures ($p<0.001$). This was due to the lucerne monoculture base of three Latin squares (LS1, LS2 and LS4). HR was found to have the highest grass yield ($p=0.013$), HC and LC had the lowest. However, LR grass yield was not different from the CA treatments or HR. Herb was lowest in CA pastures, however, this is because no herb was sown in the CA pastures. The herbs that were present would have accumulated from resident pastures in LS5 or volunteer plantain/chicory.

An interesting finding from this data is that the LR grass yield was not different from CA or HR treatments. It had the same legume content as HR which suggests that the lower Olsen P did not reduce the legume content as much as previous research discussed (Section 2.6). The lower grass component would have allowed the legumes to persist in the sward (Section 2.2.2), as they would have been able to compete for water, light and nutrients (Black et al. 2021). Interestingly, across all four treatment groups, grass intake was the same at ~1600 kg DM/ha. This means that despite grass yield being higher in HR, the animals selected against the grass component in favour of legume and

herb components. This with time, may result in an increased grass proportion, as animals are selecting against it, making it more competitive for light, water and nutrients as it is not having to re-establish as much of a canopy post-grazing. Therefore, further research into botanical changes over time may show that the grass component increases (McNally et al. 2015, Rutledge et al. 2017), while legume and herb content decreases within the RA treatment (Section 2.2.2). Conventional systems had a greater legume intake (>2000 kg DM/ha more than regenerative treatments). Whereas RA treatments had a greater herb intake (>2000 kg DM/ha).

5.5 Pasture mass

Another method of understanding pasture availability to help explain yield and intake is through average pasture mass (kg DM/ha) per grazing rotation (Figure 4.15). The decline in pasture mass corresponds with water stress and the decline of LWG of the 2022 Coopworth hogget flock shown in Figure 4.1. Rotations 4 and 5 (Appendix 5), correspond to December to March, depending on treatment group. Rotation 4, for conventional groups (January/February) had an average pre-grazing pasture mass of ~2000 kg DM/ha, compared with 3500 kg DM/ha the rotation prior. This pasture mass slightly increased in Rotation 5 (~2300 kg DM/ha), before steadily declining through Rotation 6 to 8, corresponding to autumn root replenishment as the lucerne flowered and went into dormancy (Section 2.3.1)(Moot et al. 2003). Lucerne dominated three of the conventional Latin squares (LS1, LS2 and LS4). During this time, establishment of subterranean clover, and associated grazing management was used to reduce cocksfoot competition and allow sub clover seedlings to establish through the autumn (Section 2.3.2).

Through the first four rotations, regenerative pastures maintained a pre-grazing mass of between ~3000-4000 kg DM/ha, peaking in Rotation 3. Average pasture cover began to decline in Rotation 4 but reached a low of ~1900 kg DM/ha in Rotation 5. Pasture cover increased to ~2700-3000 kg DM/ha for Rotations 6 and 7, then again reduced to ~2500 kg DM/ha in Rotation 8, approximately 500 kg DM/ha greater than conventional treatments. This is likely because the proportion of lucerne within the diverse pastures was lower, and therefore, while lucerne went dormant, other species within the sward continued to grow, resulting in a reduced negative response. This also shows that while RA management aims to maintain a greater pasture residual, it is not always possible in practice, particularly when faced with a moisture deficit (Tozer et al. 2023).

As indicated by Waghorn et al. (2017), and Cosgrove & Edwards (2017) availability of pasture directly impacts on intake. Therefore, in both groups during these periods of decreased pasture cover, the ability of selection by the animal is reduced. The pastures during Rotations 4 and 5 were also water stressed, so the quality of the pasture would have reduced as a result of increased rate of

development, increasing fibre content (Valentine & Kemp 2017, Moot et al. 2021). As a results, grazing animals would have had to eat more to reach daily requirements but may have been restricted by pasture availability or fibre content.

Table 4.1 shows the average pre-grazing pasture mass and quality factors at periods when the accumulation of LWG deviated, compared with the average throughout the experimental period. There were three periods were LWG deviated, between the 26 October and 13 December 2022, 21 February and 2 March 2023, and 30 June and 3 August 2023. In the first period, CA pastures had a greater CP and lower NDF content, and consequently animals were able to eat more, allowing a greater rate of growth over time.

The second period was in the final 11 days that the first Coopworth flock grazed, when animals in HR, LR and HC flocks lost weight. Interestingly, the pre-grazing mass, ME, CP and NDF were not different among treatments. However, the pre-grazing masses were between 1000-2000kg DM/ha lower than the research period average, indicating that there was low available feed (mean pasture cover of 1149 kg DM/ha), of a lower quality indicated by the NDF content which averaged 44.7 % and ME of 9.3 MJ ME/kg DM. Consequently, as a result of the summer dry, HC, and in particular RA treatments were unable to meet daily energy requirements, and therefore animals lost weight as expressed by the decrease in LWG/ha.

Between the 30 June and 3 August, CP content was the only different factor, which was found to be highest in HC (21.1 %/kg DM), compared with 15.9 % in LR. Average pasture mass was 1820 kg DM/ha. This may have restricted intake as many of the treatment groups were being break-fed during this period. The decreased CP of RA treatments can be expected to have increased the amount of feed required for Coopworth hoggets to meet their protein requirement. However, further research into the theoretical intake of CP to meet maintenance and growth of each group is required to gain greater insight to difference between groups. Other factors including weather conditions could have contributed to the LWG losses during this period (Rotation 8) as 127 mm of rainfall was experienced during this period, which resulted in ponding on some plots in LS3 and LS5 (Plots: 79 and 80).

5.6 Methods of estimating intake:

Four methods of estimating intake were compared using forage mass, quality measurements, and animal liveweight. Methods of estimating intake included theoretical energy requirements (Nicol & Brookes 2017), the disappearance method, and 3 or 4% of LW. Based on the results found, it is likely the average intake was between 1.6 – 1.8 kg DM/hd/d, or around the average of 3-3.5% of average

LW within the period. However, the proportion of bodyweight an animal can eat, decreases with age, therefore, 1.6-1.8 kg DM/hd/d is more realistic (Waghorn et al. 2017).

The disappearance method was found to be similar to 3% LW in both CA treatments, however, was more closely related to 4% LW within RA treatments. It is likely that this was a result of error during measurement of collected samples, due to of the high pre-and post-grazing residuals. This resulted in the disappearance method potentially overestimating intake. Intake for RA treatments was likely similar to CA treatments, as high level of selectivity allowed animals to select a diet dominated by herb and legume (Figure 4.14). The theoretical calculations for energy requirements averaged around 1 kg DM/hd/d, which may be an underestimate of actual average intake, however, there were likely periods when intake due to low pasture mass was closer to the theoretical intake.

5.7 General discussion – opportunities and implications for dryland farming

Differences in LWG were explained by the difference in intake, botanical composition and quality of eaten pasture. CA treatments were able to produce a greater LWG/ha due to increased intake, of higher CP and lower NDF. NDF limits the intake of an animal, as it increases rumination time. Whereas low fibre forages such as legumes and herbs reduce rumination time and thus allow the animal to eat more per day (Daly et al. 1996, Nobilly et al. 2013, Cosgrove & Edwards 2017). Therefore, CA and RA treatments likely were able to eat a similar amount as a result of selectivity in RA treatments, however, the greater legume content of the CA lucerne-based diet allowed greater LWG (Ates et al. 2008, Mills et al. 2015).

The ability of CA treatments to eat more legume, meant that animals rate of growth increased over time, even with the same feed conversion efficiency and intake of RA. The botanical composition of intake (Figure 4.14) suggested that RA treatments selectively grazed legume and herb over grass components. As a result, the NDF of the selected diet may have been similar, but the lower legume component would have likely meant that the CA treatment ate more CP per day than RA treatment, facilitating greater growth. Similar to the concentration of ME (Figure 4.17), concentration of NDF and CP in the selected diet compared with the content on offer could have helped confirm this.

Water stress was a main factor influencing the accumulation of yield and quality of the pastures. Water stress prevents photosynthesis, increases canopy temperature and therefore, respiration and plant development specifically the time to flowering and leaf senescence rate increase (Moot et al. 2003, 2017, Valentine & Kemp 2017). Consequently, increasing fibre content with an increased proportion of structural carbohydrates, and decreasing protein and energy content - observed in the herbage quality through the summer period (December to February). Water stress is a common

factor facing summer-dry sheep and beef New Zealand farmers. Therefore, having a pasture which is resilient to drought stress, and fast to recover is important for the sustainability of the farm system. It is important to consider that most of the pastures analysed were no more than 18 months old. Therefore, further research into pasture and animal performance on these pastoral systems would be required to make informed management decisions.

The disappearance method was found to be more accurate for CA pastures than RA pastures due to the high grazing-residual of RA, increasing room for error in pre- and post-grazing measurements. Use of 4% of LW overestimated intake in both treatments, but 3% was found to be more accurate, and in CA treatments was similar to disappearance method. Using a percentage of LW does have limitations, because as animals increase in size, the proportion they can eat decreases (Section 2.5.3). Therefore, based on the average intakes of 3% and disappearance method, average intake was between 1.6 and 1.8 kg DM/hd/d. Theoretical ME requirements were found to underestimate intake – however, provide a based line for the minimum about of feed an animal requires for maintenance and growth (Section 2.5.3) (Nicol & Brookes 2017). Practical implications of this can be for feed planning purposes and can also be used to estimate the growth of an animal without taking pasture measurements.

This research found that CA pastures, regardless of Olsen P were able to produce greater LWG/ha. Across all researched factors, Olsen P did not have a consistent enough effect on animal or pasture production. Based on these results, maintaining an Olsen P of 20 did not increase legume content, pasture yield or quality factors, further research would be required to confirm these results. The greatest differences were at a system level, where CA pastures were able to support greater LWG/ha due to a higher legume content, which reduced NDF, and increased CP content.

5.8 Conclusion

The main objective of this research was to quantify the liveweight gain of Coopworth hoggets and lambs grazing conventional and regenerative dryland pastures under high and low Olsen P. This was explained by pasture yield, intake and quality factors. The main conclusions were:

- Conventional treatments had greater accumulated liveweight - 42 (LR) to 60 (HR) kg LWG/ha (hoggets), and 15 (HR) to 28 (LR) kg LWG/ha (lambs) more than regenerative treatments.
- Conventional treatments, had greater average crude protein - 20%, compared with 15% RA - and a lower mean neutral detergent fibre - 40%, compared with 46% RA. Which was a result of greater legume proportion in the lucerne-based conventional diet. Animals met daily intake requirements sooner, and rumination time was decreased, which allowed greater intake.

- Water stress was a main contributing factor to pasture availability, growth and quality. Pastures were water stressed (ASMD =157 mm) from 13 November 2022 until March 2023. Soil water had not recharged until July; therefore 2023 autumn and winter pasture growth was based on rainfall.
- Disappearance method was found to be more accurate for CA treatments than RA treatments. Intake was estimated to be between 1.6-1.8 kg DM/hd/d.
- There was no effect on legume content or pasture quality as a result of Olsen P during the experimental period – however, further research is required to confirm these results.

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Appendices

Appendix 1: Latin Square one species and sowing rates for regenerative and conventional systems for the RADE at Lincoln University.

System	Species	Cultivar	Rate (kg/ha)
Regenerative	Tall fescue (Fescua arundinacea)	Hummer	4
	Meadow Fescue (Fescua pratensis)	Oakdon	4
	Timothy (Phleum pratense)	WGB23587	2
	Prairie Grass (Bromus catharticus)	Jeronimo	5
	Cocksfoot (Dactylis glomerata)	Safin	0.5
	Phalaris (Phalaris arundinacea)	Mate	0.3
	Lucerne (Medicago sativa)	Kaituna	6
	Red clover (Trifolium pratense)	Amigain	1
	White clover (Trifolium repens)	Legacy	0.3
	Subterranean clover (Trifolium subterraneum)	Woogenellup	1
	Chicory (Cichorium intybus)	Choice	1
	Plantain (Plantago)	Captain	0.5
Conventional	Lucerne	Kaituna	15

Appendix 2: Latin Square two and four species and sowing rates for regenerative and conventional systems for the RADE at Lincoln University.

System	Species	Cultivar	Rate
Regenerative	Tall fescue	Hummer	4
	Meadow Fescue	Oakdon	4
	Timothy	WGB23587	2
	Prairie Grass	Jeronimo	5
	Cocksfoot	Safin	0.5
	Phalaris	Mate	0.3
	Lucerne	Takahe	6
	Red clover	Amigain	1
	White clover	Legacy	0.3
	Subterranean clover	Woogenellup	1
	Chicory	Choice	1
	Plantain	Captain	0.5
Conventional	Lucerne	Takahe	15

Appendix 3: Latin Square three species and sowing rates for regenerative and conventional systems for the RADE at Lincoln University.

Plot no.	System	Species	Cultivar	Rate (kg/ha)
33-40	Regenerative	Tall fescue	Hummer	5
		Meadow fescue	Oakdon	3
		Timothy	WGB23587	2
		Prairie grass	Jeronimo	5
		Cocksfoot	Safin	0.5
		Phalaris	Mate	0.3
		Balansa clover	Taipan	1
		Red clover	Amigain	2
		White clover	Legacy	0.5
		Sub clover	Woogenellup	1
		Chicory	Choice	1
		Plantain	Captain	0.5
	Conventional	Cocksfoot	Greenly II	4
		Subterranean clover	Denmark	10
		Subterranean clover	Narrikup	16
41-48	Regenerative – Winter forage	Rape (Brassica napus)	Titan	0.75
		Turnip (Brassica rapa subsp. rapa)	York globe	0.5
		Leafy turnip (Brassica rapa var. oleifera)	Pasja	1
		Annual ryegrass (Lolium multiflorium)	Devour	5
		Phacelia (Phacelia tanacetifolia)	Unnamed cultivar	1
		Plantain	Captain	1
		Balansa clover (Trifolium michelianum)	Taipan	1.25
		Persian clover (Trifolium resupinatum)	Laser	1.25
	Conventional – Winter forage	Annual ryegrass	Devour	25
41-48	Regenerative – perennial pasture sown autumn 2023.	Tall fescue	Hummer	5
		Meadow fescue	Oakdon	3
		Timothy	WGB23587	2
		Prairie grass	Jeronimo	5
		Cocksfoot	Safin	0.5
		Phalaris	Mate	0.3
		Balansa clover	Taipan	1
		Red clover	Amigain	2
		White clover	Legacy	0.5
		Sub clover	Woogenellup	1
		Chicory	Choice	1
		Plantain	Captain	0.5
	Conventional – perennial pasture sown autumn 2023.	Cocksfoot	Greenly II	4
		Subterranean clover	Denmark	10
		Subterranean clover	Narrikup	16

Appendix 4: Latin Square five species and sowing rates for regenerative and conventional systems for the RADE at Lincoln University**.**

System	Species	Cultivar	Rate (kg/ha)
Regenerative	Tall fescue	Hummer	5
	Meadow fescue	Oakdon	3
	Timothy	WGB23587	2
	Prairie grass	Jeronimo	5
	Cocksfoot	Safin	0.5
	Phalaris	Mate	0.3
	Balansa clover	Taipan	1
	Red clover	Amigain	2
	White clover	Legacy	0.5
	Sub clover	Woogenellup	1
	Chicory	Choice	1
	Plantain	Captain	0.5
Conventional	Cocksfoot	Greenly II	4
	Subterranean clover	Denmark	10
	Subterranean clover	Narrikup	16

Appendix 5: Grazing periods and plots for each treatment and flock for the RADE at Lincoln University.

Rotation	1	2	3	4	5	6	7	8
HC	11/09-28/10. Plots: 18,44,24,34,66,72,39,75,3,27,5,29,12	31/10-24/11. Plots: 18,14,24,3,27,5,29,12	29/11-6/01. Plots:14,18,34,24,56,39,59,49,3,62,2,7,5,29,12	11/01-24/02. Plots:34,14,39,44,18,45,24,66,72,27,75,29,49,3,5,56,12,59	25/02-5/04. Plots:14,18,62,24,49,3,34,5,39,56,12,59	7/04-16/05. Plots:14,62,18,34,24,39,27,29,49,3,5,6,5	17/05-4/07. Plots: 59,62,12,34,14,18,39,24,45,44,49,56	7/07-27/07. Plots: 59,62,66,72,27,75,34,29
LC	11/09-28/10. Plots: 17,43,23,36,68,37,70,1,79,28,7,30,10	31/10-24/11. Plots: 17,16,23,1,28,7,30,10	29/11-6/01. Plots: 16,17,36,23,55,37,60,50,1,61,28,7,30,10	11/01-24/02. Plots: 36,16,37,43,17,46,23,68,70,28,79,30,50,1,7,55,10,60	1/03-10/04. Plots: 16,61,17,50,23,36,1,37,7,55,10,60,16	11/04-19/05. Plots: 61,17,36,23,37,28,50,30,1,55,60,7	22/05-4/07. Plots: 61,10,36,16,37,17,23,43,46,50,55,60	7/07-28/07. Plots:61,8,70,73,79,28,36,30
HR	17/09-26/10. Plots:42,65,71,76,33,40,4,6,9,15,20,22,25,31	28/10-28/11. Plots: 33,40,65,71,76,4,6,9,15,20,22,25,31	30/11-28/12. Plots: 33,40,65,71,76,4,6,9,15,20,22,25,31	30/12-10/0.2 Plots: 33,40,51,64,54,57,65,71,76,42,47,4,6,9,15,20,22,25,31	13/02-13/03. Plots: 33,40,51,54,57,64,42,47,4,6,9,15	15/03-12/04. Plots: 42,47,20,22,33,40,51,54,57,64,4,6,9,15	14/04-18/05. Plots: 20,22,25,31,33,40,51,54,57,42,64,4,6,9	20/05-29/07. Plots:15,20,22,25,31,33,40,42,47,51,54,57,64,4,78,65,71,76,6
LR	15/09-21/10. Plots:41,67,69,80,35,38,2,8,11,13,19,21,2,6,32	24/10-23/11. Plots: 35,38,67,69,80,2,8,11,13,19,21,26,32	25/11-23/12. Plots: 35,38,67,69,80,2,8,11,13,19,21,26,32	26/12-6/02. Plots: 35,38,52,63,53,58,67,69,80,41,48,2,8,11,13,19,21,26,32	8/02-17/03. Plots: 35,38,52,53,58,63,41,48,2,8,11,13,19	20/03-19/04. Plots: 41,48,21,35,38,52,53,58,63,2,8,11,13,19	21/04-26/05. Plots: 21,26,32,35,38,52,53,58,63,41,2,8,11,13,19	29/05-28/07. Plots: 21,26,32,35,38,41,48,52,53,58,63,2,74,67,8,69,80
2022 flock (Coopworth ewe hoggets)	11 September 2022 - 3 March 2023							
2023 flock (Coopworth ewe lambs)					3 March 2023 - 3 August 2023			