Final report

Response of Rangeland goats to supplements and development of a least-cost supplement calculator

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Abstract

The objective of this project was to determine the nutritional requirements of Rangeland goats and to provide industry with a tool to assist with supplementation decisions. A comprehensive review of the literature on nutritional requirements of Rangeland goats was completed. A series of supplement dose response (Experiments 1, 2, 3a) and protein inclusion (Experiment 3b) experiments determined the liveweight gain response of young entire male Rangeland goats to a range of diets. The highest liveweight gains were achieved when goats were fed starch-based supplements (80 to 165 g/day above unsupplemented goats) and with a higher crude protein content (170 g/day). Higher liveweight gain (up to 200 g/day) was achieved when goats had *ad libitum* access to commercial pellets in outdoor group pens. Equations describing the response of liveweight gain to supplement intake were used to generate a relative-cost of supplement calculator in EXCEL for use by industry that allows a comparison of the relative-cost of different supplements to achieve a target liveweight gain (g/day) or a target liveweight (kg) based on local supplement costs. The data contributes to existing information on the nutrient requirements of young entire male Rangeland goats with area's for future nutrition research to increase productivity of Rangeland goats proposed.

Executive summary

Background

Traditionally Rangeland goats have been raised on native vegetation with little or no access to improved forages or supplements. This typically results in slow and inconsistent growth rates of young goats targeted for slaughter. However, with goat meat prices at near historical highs, investment in alternative management practices including the provision of supplements to increase liveweight gain of goats managed behind exclusion fences may be a viable option for Rangeland goat producers. The decision on which supplement to use will depend on the local and seasonal availability of the supplement, cost of supplement (including freight), growth rate in response to supplement type and level of intake and the quality and quantity of the existing basal diet (i.e. the deficiency which the supplement will address) which will determine the likely productivity response to a supplement. This project collated published and unpublished information on nutritional requirements of goats for use by research, development and adoption workers, and developed a simple-to-use relative-cost of supplement calculator to assist producers make more informed decisions on the relative production and economic response of different supplementation strategies of young entire male Rangeland goats.

Objectives

The objectives of this project were to:

- review of unpublished and published data on the nutritional requirements of goats, with emphasis on goats managed under Rangeland/semi-arid environments for meat production used to guide formulation of nutritional treatments to be used in supplement dose response experiments,
- collate intake and growth responses (and equations) of Rangeland goats of different stages of maturity to a range of supplements (protein, energy) when fed different basal diets used to generate a relative-cost of supplement calculator,
- deliver an easy-to-use excel-based relative-cost of supplement calculator available for download by goat producers to assist them make decisions regarding supplementation,
- recommend pathways to adoption, new extension materials and publications, and assistance in the development of on-farm validation methods/projects, and
- submit a final report outlining the learnings from the project and recommended next steps.

Methodology

The methods involved in the current project were:

- review the existing literature to consolidate all available and relevant information regarding the nutritional requirements of Rangeland goats. The review accessed information from published and unpublished data, industry extension materials and tools, and Australian and international theoretical feeding standards,

- conduct a series of supplement dose response feeding trials with young entire male Rangeland goats to develop relationships between supplement intake, basal diet intake and liveweight gain with associated measurements of rumen function and metabolism,

- utilise the dose-response equations to generate a relative-cost of supplement calculator to assist goat producers to make more informed decisions on the relative benefits of feeding different types and amounts of supplements to goats to achieve a target liveweight or a target liveweight gain, and

- disseminate project activities through a series of articles in 'Goats on the Move' and presentations at various research and industry forums.

Results/key findings

At low supplement allowances liveweight gain of young entire male Rangeland goats is more responsive to a protein meal, however at higher supplement allowances this class of goat is more responsive to a starch-based supplement. High rates of liveweight gain (150 to 200 g/day; 1 to 1.4 kg/week) are achievable for young entire male Rangeland goats with *ad libitum* access to a high ME and high CP concentrate ration, and a source of roughage and water. The relative-cost of supplement calculator demonstrates that the least-cost supplement may not always be the most beneficial in terms of number of days and total feed costs to achieve a target liveweight. These decisions will be based on local availability and prices of feeds, and the calculator provides producers with a tool that will assist them to make more informed decisions on the relative benefits of various supplements.

Benefits to industry

This project has integrated theoretical concepts, historical literature and current feeding experiments to collate a large body of information on the nutritional management of Rangeland goats that will be of value to research, extension and adoption staff working with goat producers. The project also provides some ground-truthing of likely liveweight gain of goats fed various supplements and rations. The project has produced a simple-to-use relative-cost of supplement calculator that that will assist producers with decisions related to supplementation of Rangeland goats, by estimating the number of days and the feed cost ($/goat) to reach a target liveweight.

Future research and recommendations

It is recommended that,

- pilot testing of the relative-cost of supplement calculator is completed and any final changes, validation and interface upgrades be completed,
- dissemination of the availability of the calculator occurs via 'Goats on the Move' and other industry forums,
- on-farm validation of the supplementation calculator be conducted via one or more producer demonstration sites, and
- researchable issues identified within the current project, and included within the current report, be presented to GIRDAC and at other industry forums and included as options in any future research prioritisation activities to be undertaken by industry.

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1 Background

Traditionally Rangeland goats have been raised on native vegetation with little or no access to improved forages or supplements. This typically results in slow and inconsistent growth rates of young goats targeted for slaughter. At the inception of this project, these low liveweight (LW) goats had no commercial value (NCV) and represented an inefficiency in the production system in that they required a longer-period of grazing to attain a target LW (> 25 kg) of commercial value, increasing grazing pressure on the rangelands, increased costs associated with additional musters and trucking and increased whole-of-life greenhouse gas emissions. However, with goat meat prices at near historical highs, investment in alternative management practices, including the provision of supplements to increase LW gain (LWG), may be a viable option for Rangeland goat producers. The rapid uptake of exclusion fencing has provided the infrastructure framework within which more strategic management of Rangeland goats is now possible. The decision on which supplement to use will depend on the local and seasonal availability of the supplement, cost of supplement (including transport), LWG in response to supplement type and intake and the quality and quantity of the existing basal diet (i.e. the deficiency which the supplement will address) which will determine the likely productivity response to a supplement. There is limited information available to assist producers make decisions on what supplement to feed Rangeland goats.

Supplement dose-response experiments have been used extensively in cattle research to provide northern Australian cattle producers with practical information on the likely response of cattle to a given intake of a supplement, and the effect of supplementation on intake of the basal diet. This information has then been used to generate a simple to use relative-cost of supplement calculator to aid producers in their supplementation decision making (McLennan, 2002; NAP3.122). A similar approach was proposed in this project so that Rangeland goat producers simply input the starting and final target LW of the goats, along with the price of the supplement to be used and the relative-cost of supplement calculator will provide an estimate of the likely supplement requirements (g/day), predicted growth response, the cost to achieve 1 kg of additional LWG, the cost per day of the supplement offered and the total supplement cost to reach a target LW, which can be compared against other supplement options.

This project reviewed the available literature regarding nutritional requirements of Rangeland goats, conducted supplement dose-response experiments to generate response equations to a number of different protein and energy supplements and used these response equations to develop a supplement relative-cost of supplement calculator for use by producers to support them to make informed decisions on the likely relative cost-effectiveness of a range of supplements for young entire male Rangeland goats. A number of recommendations are made for future research, development and adoption activities related to improving the nutritional management to increase productivity of Rangeland goats whilst sustaining the feed-base and environment.

2 Objectives

The objectives of this project were to:

1. Report on findings of a review of unpublished and published data on the nutritional requirements of goats, with emphasis on goats managed under Rangeland/semi-arid environments for meat production used to guide formulation of nutritional treatments to be used in supplement dose response experiments. (**COMPLETED**)
2. Complete a collation of intake and growth responses (and equations) of Rangeland goats of different stages of maturity to a range of supplements (protein, energy) when fed different basal diets used to generate a relative-cost of supplement calculator. (**COMPLETED**)

3. Deliver an easy-to-use excel-based relative-cost of supplement calculator available for download by goat producers to assist them make decisions regarding supplementation. (**COMPLETED**)
4. Recommend pathways to adoption, new extension materials and publications, and assistance in the development of on-farm validation methods/projects (**COMPLETED**).
5. Submit a final report outlining the learnings from the project and recommended next steps. (**COMPLETED**)

3 Methodology

3.1 Literature review

A comprehensive review of the available literature on the nutritional requirements of Rangeland goats was undertaken by Assoc. Prof. Barry Norton (The University of Queensland). The review largely references peer-review scientific publications and the feeding standards (for example, AFRC [1998], NRC [2007] and NRDR [2007]) most commonly used to estimate the nutritional requirements of goats; a total of 79 sources of information were referenced. The review provides,

- a description of previous studies on feeding management of Rangeland goats,
- estimates of the nutritional (energy, protein, fibre) requirements for maintenance and gain of LW and the maximum potential LWG of Rangeland goats,
- a description of the practical issues (age and sex, photoperiod, activity, physiological status) that influence intake, nutritional requirements and LWG of Rangeland goats, and
- recommendations for future research on nutritional management of Rangeland goats.

3.2 Supplement dose-response experiments

General design of experiments

Three supplement dose-response experiments and a single protein response experiment were conducted. The experimental procedures and subsequent modifications were reviewed and approved by The University of Queensland Animal Ethics Committee (SAFS/294/18/MLA).

All experiments used young entire male Rangeland goats sourced from southwest Queensland; goats were vaccinated for clostridial diseases and caseous lymphadenitis and treated for internal parasites on arrival, with monitoring of faecal egg counts occurring every 4 to 6 weeks during experiments. Goats were held in both group outdoor pens and individual indoor pens. Enrichment included wooden sleepers, trampolines, half 200 L drums and gym balls in outdoor pens, and chains, and plastic balls and milk bottles attached to ropes suspended from panels in individual pens.

Mitchell grass hay (*Astrebla* spp.) was used as a basal hay which was fed *ad libitum* in Experiments 1, 2 and 3a, and at a fixed percentage of LW in Experiment 3b. In Experiments 1, 2 and 3a, supplements were offered at a percentage of LW adjusted after weighing each week, while in Experiment 3b the complete rations were offered *ad libitum*. All experiments were approximately 70-days in duration, with LW, body condition score, hay and supplement intake, digestibility of dry matter (DMD) in the diet, plasma metabolites and rumen parameters measured. Upon completion of, or concurrent with, each of the three experiments goats were held in group pens and grown-out on high quality diets (described in detail in Appendix 2).

Average daily LWG was estimated from the linear regression of LW measured each week against time (days) over the entire experimental period. Hay, supplement and total intake were calculated on a LW basis each week and the mean value across the entire experiment was used in subsequent calculations. For ease and consistency, metabolizable energy (ME) content of the total diet consumed was estimated from Equation 1.12A in NRDR (Freer et al. 2007; ME = 0.172 * DMD (%) - 1.707) for each goat, and a conversion factor of 6.25 was used to calculate crude protein (CP) content from measured nitrogen (N) content of the various ingredients and rations.

Response equations were generated using actual supplement intake (rather than supplement offered) of the individual goat for each measured variable parameter. Quadratic and linear co-efficients were tested, with the highest order significant ($P \leq 0.05$) polynomial accepted as the most appropriate fit to the data. Where no significant co-efficients were observed the response of the variable to supplement intake was deemed non-significant. Significant responses to supplements with a different polynomial were assumed to be significantly different. Significant responses to supplements with the same order polynomial were further tested to determine if the responses were significantly different between supplements. Significance was accepted at $P \leq 0.05$, and residual standard deviation and R^2 values were calculated for each significant response equation.

Results are presented in different formats, as different readers may have different requirements on how they might use the results generated in the experiment, and to allow comparisons with other published data. For example, results are presented on either a goat/day, kg LW/day or kg $LW^{0.75}$/day basis. Expression on a goat/day basis is of most relevance for industry application but a more accurate and relatively simple form of expression is on a kg LW/day basis, which accounts for differences in LW within the stage of the growth path studied in the current project (15 to 25 kg), whilst a kg $LW^{0.75}$.day accounts for differences in metabolic liveweight that might arise when comparing animals across different stages of the growth path and is theoretically the most appropriate form of comparison of responses, especially with other published data-sets, but is of little practical use for producers.

Experiment 1

Animals, location and dates

Entire male Rangeland goats (n=71; 17.4 ± 2.4 kg LW; mean ± standard deviation) with no permanent incisors were sourced from Buffel Park, Dirranbandi, QLD in August-2018 (Figure 1). The goats were weighed on site and ranged from 13 to 23 kg LW at selection. Faecal samples were collected at random from eight goats for faecal egg counts (FECs). The goats were transported to the Queensland Animal Science Precinct (QASP), The University of Queensland, Gatton, QLD (27°33'24.40"S; 152°20'32.39"E) in September-2018 and were provided with ear tags with a unique visual identification number, vaccinated (Glanvac6) and drenched (Panacur25) on arrival. Goats were held in an indoor animal house where airflow was provided via roller doors at either end of the shed that were left open at all times, except in the event of inclement weather, and permanently opened screened side windows. Wall-mounted industrial fans were turned on when the ambient temperature was forecast to exceed 30ºC. The experiment commenced on 26-September-2018 and the LW and intake measurement period concluded on 11-December-2018 (76-days) with blood and rumen sample collection occurring on 12- and 13-December-2018.

Figure 1. Young entire male Rangeland goats selected at Dirranbandi for use in Experiment 1.

Induction

Goats were initially held in small group (n=4/pen) pens for 5-days, paired pens for 5-days and then placed in individual pens (1 x 1.5 m) for 7-days. During this period any shy feeders or goats with poor temperament were identified and excluded from the experimental period. During the induction period goats were gradually transitioned from a mixture of Rhodes grass (*Chloris gayana*; 894 g OM, 86 g CP, 596 g NDF/kg DM) hay and lucerne chaff (*Medicago sativa*; 917 g OM, 191 g CP, 379 g NDF/kg DM) to Mitchell grass (*Astrebla* spp.; 896 g OM, 50 g CP, 646 g NDF/kg DM) *ad libitum* and cottonseed meal (125 g [as fed]/goat.day; 922 g OM, 525 g CP, 206 g NDF/kg DM) with Rumensin100 incorporated (100 mg/goat.day equivalent to 10 mg monensin/goat.day) for 7-days prior to allocation and commencement of the experimental period.

Experimental design and nutritional treatments

The original design was a randomised block design incorporating a dose response. The dose response involved feeding goats increasing amounts of four sources of N with *ad libitum* access to Mitchell grass hay. Goats (n=54 selected for the experiment; 17.3 ± 1.7 kg LW; mean ± standard deviation) were ranked (lightest to heaviest) and blocked (light, medium, heavy blocks; n=18/block) on LW at the commencement of the experimental period. Within each block, goats were randomly allocated to one of the supplements (4 supplements) x supplementation feeding allowances (4 allowances) with two goats within each block allocated to an unsupplemented control treatment (Mitchell grass chaff alone).

The sources of dietary N used in Experiment 1 represented different ‘types’ of N supplements that might be relevant to Rangeland goat producers in Australia. The intention was not to test every possible N supplement but a range of different supplement types. While access to specific supplements may change over time, the responses to types of supplements may be relevant to other similar supplements although it is acknowledged that responses are likely to be variable even with a supplement type (e.g. different responses may be expected from different protein meals). The N supplements and the initial allowances with which they were offered were,

- Urea and sulphate of ammonia,
  - representing a non-protein source of N
  - offered at 0.1, 0.2, 0.3 and 0.4 g DM/kg LW.day
- Lucerne chaff (LUC),
  - representing a farm grown legume (nutrient composition described above)
  - offered at 3, 6, 9 and 12 g DM/kg LW.day
- Cottonseed meal (CSM),
  - representing a protein meal that was potentially available in reasonable proximity to the Rangelands (nutrient composition described above; soon after completion of this experiment, CSM became unavailable in Australia)
  - offered at 3, 6, 9 and 12 g DM/kg LW.day
- Whole cottonseed (WCS),
  - selected as for CSM, except different nutritional composition (protein, lipid, energy), different physical properties, different price point, and different practical issues around feeding and storage)
  - 958 OM, 259 CP, 325 g ash-free NDF/kg DM
  - offered at 3, 6, 9 and 12 g DM/kg LW.day

After two weeks on the above treatments, observations were that goats were not adapting to the higher levels of urea and were not consuming the WCS above approximately 5 g DM/kg LW.day. It was therefore decided to alter the allowances of these two treatments. The revised experimental design was as follows,

- Control (Mitchell grass *ad libitum*) (n=6)
- Urea at 0.1 g DM/kg LW.day (n=6)
- LUC at 3, 6, 9, 12, 16 and 20 g DM/kg LW.day (n=3/allowance; LUC03, LUC06, LUC09, LUC12, LUC16, LUC20)
- CSM at 3, 6, 9 and 12 g DM/kg LW.day (n=3/allowance; CM03, CM06, CM09, CM12)
- WCS at 2, 3.3, 4.6 and 6 g DM/kg LW.day (n=3/allowance; WCS02, WCS03, WCS04, WCS06)

The Mitchell grass was sourced from the Barkly Tableland (Northern Territory) and chaffed to approximately 10 to 20 mm in length using a modified forage harvester (Gehl Bros.; Wisconsin, USA). Steam cut lucerne chaff (Rich River Chaff; Strathallan, VIC) and WCS were sourced from Riverina Stockfeeds (Oakey, QLD) and CSM was sourced from the Killarney Co-operative (Killarney, QLD); all three supplements were fed as received but adjusted for DM, as described above. Urea was sourced from Ridley Agri-products (Toowoomba, QLD) and the daily allocation was mixed with approximately 50 g of a 10% molasses solution (no additional Sulphur was added from week 3 onwards). A multi-mineral salt block (370 g NaCl/kg, 40 g P/kg, 148 g Ca/kg, 60 g molasses/kg, 400 mg Co/kg, 180 mg Zn/kg, 167 mg I/kg, 600 mg Mn/kg, 930 mg K/kg, 200 mg Mg/kg, 200 mg F/kg, 650 mg Fe/kg and 1100 mg S/kg) was sourced from Olsson's (Yennora, NSW).

All goats had access to Mitchell grass, the multi-mineral salt block and drinking water *ad libitum*. Mitchell grass and the daily allocation of supplements (including the urea-molasses mixture) were fed in separate feed bins, with the multi-mineral block available in the supplement feed bin at all times (or in a separate feed bin to Mitchell grass for the Control goats).

<u>Experimental methods</u>

Goats were weighed prior to feeding and allocated to pens and treatments as described above, and prior to feeding every 7-days throughout the experiment. Body condition score (1 to 5 scale) was measured at the commencement and conclusion of the experiment.

Daily supplement allowances were calculated after LW measurements each week. Daily allowances were prepared in bags and placed in front of each pen, with the exception of the urea-molasses mixture which was prepared fresh each day. Mitchell grass chaff was weighed into a large bin and also placed in front of each pen. Sub-samples of Mitchell grass and each of the supplements offered were collected each week for dry matter determination. Each morning any Mitchell grass or supplement residues were collected and stored separately for each goat; residues were bulked over 7-days for each goat. Goats were then offered their daily supplement allowance followed by Mitchell grass *ad libitum*, except for goats offered the urea-molasses who received the supplement after Mitchell grass was offered. Mitchell grass was replenished each afternoon. Bulked Mitchell grass and supplement residues were collected and weighed every 7-days and sub-samples collected.

Total faecal collections were made from all goats in the medium and heavy blocks on days 62 to 68 of the experimental period; collection harnesses could not be fitted securely to the smaller goats in the light block. The intention was to collect faeces over seven consecutive days, but incomplete collections occurred over the first 2-days. Collection harnesses were modified, and complete collections were made over the remaining 5-days. Harnesses were emptied twice daily and total daily faecal output was weighed each morning. The total daily faecal collection was bulked over 5-days, stored at 4^{o}C and total bulk faecal output was weighed, and sub-samples collected for DM determination.

Blood samples were collected from the jugular vein of all goats prior to feeding on the same morning. Blood was collected into lithium heparin and whole blood vacutainers via a 20-gauge needle. Samples were stored at -80^{o}C prior to analysis for the concentration of urea, phosphorus, calcium, total protein, glucose and creatinine on an Olympus A400 auto-analyser (Beckman Coulter Diagnostic Systems Division, Melville, NY, USA).

Rumen fluid (RF) was collected by stomach tube from goats allocated to the Control (n=5), Urea (n=3), CSM12 (n=3), LUC12 (n=3), LUC20 (n=3) and WCS6 (n=3) treatment levels. The pH of the rumen sample was measured, and duplicate sub-samples of RF were stored in 1N H_2SO_4 (8 mL RF + 1 mL acid) and in 20% metaphosphoric acid with internal standard (4 methyl n-valeric acid) (4 mL RF + 1 mL acid with internal standard). All samples were placed on ice prior to storage at -20^{o}C until analysis was conducted.

Experiment 2

<u>Animals, location and dates</u>

Entire male Rangeland bucks (n=80) with no permanent incisors were sourced from Bullindgie Pastoral Company, Dirranbandi, QLD in October-2019 and transported to QASP, Gatton, QLD. The goats were provided ear tags with a unique visual identification number, weighed, faecal sampled, vaccinated (Glanvac6) and drenched (Panacur25) 7-days after their arrival. The goats were 19.4 ± 2.2 kg LW (mean ± standard deviation; range 13.5 to 25.4 kg) 7-days after their arrival at QASP. Goats were held in a single outdoor group pen for 7-days and introduced to rolled-wheat (~100 g/head.day; 959 g OM, 117 g CP, 624 g starch, 202 g NDF/kg DM, 3.4 g Ca, 1.9 g Mg, 2.4 g P, 1.7 g S, 3.5 g Na and 3.8 g K/kg DM) in a self-feeder with barley straw (900 g OM, 38 g CP, 24 g Ca, 1.3 g Mg, 0.6 g P, 0.5 g S, 15 g K, 4.9 MJ ME/kg DM) and water available *ad libitum*. Goats were then moved to indoor individual pens (as described for Experiment 1) where they were transitioned to diets containing rolled-wheat, rolled-sorghum and lucerne pellets with Mitchell grass hay supplied *ad libitum* as a source of roughage. After 14-days in the individual pens the LW and body condition score of all goats was recorded and 54 goats were selected for inclusion in the experiment based on LW (19.9 ± 2.2 kg, range - 16.4 to 23.4 kg) and temperament (shy feeders, messy feeders and persistent escapees were excluded). The experiment commenced on 19-November-2019 and the LW and intake measurement period concluded on 28-January-2019 (70-days) with total faecal output collected over seven consecutive days (days 42 to 49) and rumen and blood samples collected soon after (days 51 and 52 respectively).

<u>Experimental design and nutritional treatments</u>

The experimental design was a randomised block incorporating a dose-response. The dose-response involved feeding individual goats increasing amounts of two starch-based feeds and one protein-based feed; all goats had *ad libitum* access to Mitchell grass hay and water. Goats (n=54) selected for the experiment were ranked (lightest to heaviest) and blocked (light, medium_light, medium_heavy, heavy blocks; n=13 or n=14/block) on LW at the commencement of the experimental period. Within each block goats were randomly allocated to one of the supplements (3 supplements) x supplementation feeding allowances (4 supplement levels) with one or two unsupplemented controls (Mitchell grass chaff alone). This resulted in a total of n=4 replicates for each amount of each supplement (n=48), and n=6 unsupplemented controls, with the individual goat considered the replicate.

The supplements used in Experiment 2 represented feed sources known to have different starch availability in the rumen (high and low for wheat and sorghum respectively) and a protein source that allowed linkage back to Experiment 1 (lucerne pellet; Lockyer Lucerne; 894 g OM, 206 g CP, 13 g Ca, 3.1 g Mg, 2.8 g P, 3.6 g S, 3.7 g Na and 23 g K/kg DM). The wheat and sorghum were rolled and balanced with urea and minerals to provide an equivalent composition to that reported for the Beef Finisher Pellet used in Phase 2 of Experiment 1 (Rumevite Beef Finisher pellet, Ridley Agriproducts; Appendix 3 for details). The rolled-wheat (959 g OM, 145 g CP, 3.4 g Ca, 1.9 g Mg, 2.4 g P, 1.7 g S, 3.5 g Na and 3.8 g K/kg DM) and rolled-sorghum (964 g OM, 146 g CP, 2.5 g Ca, 1.5 g Mg, 2.0 g P, 1.5 g S, 2.6 g Na and 3.1 g K/kg DM) rations were prepared at the Killarney Co-op (Killarney, QLD) (Table 1).

Table 1. Formulation of the rolled-wheat and rolled-sorghum rations.

Ingredient, kg/T (as is)	Rolled-wheat	Rolled-sorghum
Grain source	962.5	961.5
Vegetable oil	10.0	10.0
Gypsum	5.0	5.0
Limestone	7.0	7.5
Stockfeed urea	7.0	9.0
Salt	6.0	5.0
MgO[1]	1.5	1.0
TMV[2]	1.0	1.0

[1]Magnesium oxide [2]Trace minerals and vitamin mixture

Supplements were offered to entire male Rangeland goats at,

- lucerne pellets offered at 6, 12, 18 and 24 g DM/kg LW.day (LUC06, LUC12, LUC18, LUC24)
- rolled-sorghum offered at 6, 12, 18 and 24 g DM/kg LW.day (SOR06, SOR12, SOR18, SOR24)
- rolled-wheat offered at 6, 12, 18 and 24 g DM/kg LW.day (WHT06, WHT12, WHT18, WHT24)

The Mitchell grass hay was the same source as that used in Experiment 1 and was chaffed to approximately 20 to 40 mm in length using a horizontal mixer (Samurai 5, 450/90; Seko). A multi-mineral salt block (370 g NaCl/kg, 40 g P/kg, 148 g Ca/kg, 60 g molasses/kg, 400 mg Co/kg, 180 mg Zn/kg, 167 mg I/kg, 600 mg Mn/kg, 930 mg K/kg, 200 mg Mg/kg, 200 mg F/kg, 650 mg Fe/kg and 1100 mg S/kg) was sourced from Olsson's (Yennora, NSW). All goats had access to Mitchell grass and drinking water *ad libitum*, and Control goats had access to the multi-mineral block *ad libitum*. Mitchell grass and the daily allocation of supplements (including the multi-mineral block) were offered in separate feed bins.

Experimental methods

The experimental methods were largely as described for Experiment 1. The exceptions to this were the feeding of the SOR18, SOR24, WHT18 and WHT24 supplement allowances were divided into two approximately equal feeds at 800 and 1600 each day, and the collection of total faecal output, rumen fluid and plasma samples occurred in the middle of the experiment, as opposed to after the experiment as done in Experiment 1.

Experiment 3a

Animals, location and dates

Entire male Rangeland bucks (n = 77; 23.7 ± 4.8 kg LW) with no permanent incisors were sourced from Garmarren Station, Cunnamulla, QLD in September-2020 and transported to QASP, Gatton, QLD. The goats were heavier than previous years due to better seasonal conditions and limited supply of suitable goats in August and September. The goats were provided with unique ear tags, weighed, faecal sampled, vaccinated (Glanvac6) and drenched (Panacur25) 7-days after their arrival.

Goats were held in a single outdoor group pen for 7-days and introduced to goat pellets (Barastoc Goat Pellet, Ridley Agri-products; 153 g CP, 895 g OM, 11.9 MJ ME, 31 g Ca, 5 g P, 3.8 g Na, 4.9 g S/kg DM) with barley straw and water available *ad libitum*. Goats were then moved to indoor individual pens (as described for Experiment 1) where they were transitioned to with Mitchell grass hay supplied *ad libitum* as a source of roughage with pellet allowances increased every 2-days. After 14-days in the individual pens the LW and body condition score of all goats was recorded and 24 of the heavier goats were selected for inclusion in the experiment based on LW (24.9 ± 1.8 kg) and temperament (shy feeders, messy feeders and persistent escapees were excluded); lighter goats were used in Experiment 3b. The experiment commenced on 7-October-2020 with an additional week to adapt goats to the higher supplement allowances (14-October-2020), with the LW and intake measurement period concluded on 23-December-2020 (70-days) with total faecal output collected over seven consecutive days (days 21 to 28) and rumen and blood samples collected soon after (days 29 and 30 respectively).

Experimental design and nutritional treatments

The experimental design was a randomised block incorporating a dose-response. The dose-response involved feeding individual goats increasing amounts of a high-starch finisher pellet (BP; 890 g OM, 137 g CP, 11.9 MJ ME, 23 g Ca, 3.3 g P, 1.4 g S and 3.8 g Na/kg DM); all goats had *ad libitum* access to Mitchell grass hay (894 g OM, 27 g CP, 694 g ash-free NDF, 3.8 g Ca, 1.3 g Mg. 0.25 g P, 0.97 g S and 0.06 g Na/kg DM) and water. Goats (n = 24) selected for the experiment were ranked (lightest to heaviest) and blocked (light, medium_light, medium_heavy, heavy blocks; n = 6/block) on LW at the commencement of the experimental period. Within each block goats were randomly allocated to one supplement feeding amounts (4 supplement allowances; BP8 [8 g BP DM/kg LW.day], BP16 [16 g BP/kg LW.day], BP24 [24 g BP kg LW.day] and BPAL [BP *ad libitum*]) or as unsupplemented controls (Mitchell grass chaff alone). This resulted in a total of 4 replicates allocated to BP08, BP16 and BP24 treatments and n = 6 replicates allocated to unsupplemented controls and to BPAL, with the individual goat considered the replicate. Additional replicates were included in the controls and highest level of supplementation to account for the higher variation in intake and the higher importance of these extreme points in establishing the prediction equations. Control goats had *ad libitum* access to the multi-mineral salt block offered in Experiments 1 and 2. Mitchell grass and the daily allocation of supplements (including the multi-mineral block) were offered in separate feed bins.

Experimental methods

The experimental methods were largely as described for Experiment 1. The exceptions to this were the feeding of the BP24 and BPAL supplement allowances was divided into three approximately equal feeds at 800, 1030 and 1630 each day, and the collection of total faecal output, rumen fluid and plasma samples occurred in the middle of the experiment, similar to Experiment 2.

Experiment 3b

Animals, location and dates

Entire male Rangeland bucks used in the current Experiment were from the same source and underwent the same induction as that described for goats used in Experiment 3. After 14-days in the individual pens the LW and body condition score of all goats was recorded and 36 of the lowest LW goats were selected for inclusion in the experiment based on LW (18.8 ± 3.9 kg) and temperament (shy feeders, messy feeders and persistent escapees were excluded). The experiment commenced on 7-October-2020 with an additional two weeks to adapt goats to the higher supplement allowances (21-October-2020), with the LW and intake measurement period concluded on 30-December-2020 (70-days) with total faecal output collected over seven consecutive days (days 35 to 42) and rumen and blood samples collected soon after (days 43 and 44 respectively).

Experimental design and nutritional treatments

The experimental design was a randomised block incorporating a dose-response. The goats were ranked (lightest to heaviest) and blocked (light, medium_light, medium_heavy, heavy blocks; n = 9/block) on LW at the commencement of the experimental period. Within each block goats were randomly allocated to one of seven different pelleted rations which were fed *ad libitum*, with Mitchell grass hay offered at 7 g DM/kg LW.day to maintain rumen function. The experimental treatments were described based on target CP content of the pellet (CP9, CP11, CP14, CP17.5 and CP21) with monensin included in an additional two rations (CP9+ and CP21+). This resulted in a total of n = 4 replicates allocated to CP11, CP14, CP17.5 treatments and n = 6 replicates allocated to the remaining treatments, with the individual goat considered the replicate. Additional replicates were included in the lowest and highest CP content treatments to account for the higher variation in intake and the higher importance of these extreme points in establishing the prediction equation.

The pelleted rations were formulated to supply approximately 13 MJ ME/kg DM and CP content range from 90 to 210 g/kg DM (

Table 2). The rations were mixed at the Killarney Co-operative (Killarney, QLD) and 8 mm diameter pellets were prepared on a low-throughput extruder line by Ridley Aquaculture (Narrangba, QLD).

Table 2. Ingredients used in the formulation of pelleted rations.

Ingredient	**CP9 kg/T**[1]	**CP11 kg/T**	**CP14 kg/T**	**CP17.5 kg/T**	**CP21 kg/T**	**CP9+ kg/T**	**CP21+ kg/T**
Wheat[2]	0	70	70	70	70	0	70
Barley[2]	600	600	600	600	600	600	600
Soybean meal	0	40	110	170	230	0	230
Tapioca starch	350	240	170	110	50	350	50
Molasses	10	10	10	10	10	10	10
Salt	8	8	8	8	8	8	8
Limestone	10	10	10	10	10	10	10
MgO	1	1	1	1	1	1	1
Gypsum	0	0	2	3	5	0	5
Vegetable oil	20	20	20	20	20	20	20
TMV	1	1	1	1	1	1	1
Rumensin100	0	0	0	0	0	0.2	0.2
Total	1000	1000	1002	1003	1005	1000	1005

[1]On an as received basis; [2]Hammermilled; [3]Trace mineral and vitamin mix; [4]Rumensin100 added and mixed with TMV.

Experimental methods

The experimental methods were largely as described for Experiment 1. The exceptions to this were the feeding of the pellet allowances divided into three approximately equal feeds at 830, 1030 and 1700 each day with Mitchell grass hay offered at 800 and 1630, and the collection of total faecal output, rumen fluid and plasma samples in the middle of the experiment, similar to Experiments 2 and 3a.

3.3 Development of relative-cost of supplement calculator

Significant supplement dose-response equations generated in Experiments 1, 2 and 3a were used to develop a relative-cost of supplement calculator in an EXCEL worksheet with guidelines. The response equations used in the calculator were incorporated on an individual supplement basis regardless of the statistical significance of differences to other response equations within an experiment (i.e. separate equations were used for individual supplement even when the equations were not statistically different). To account for the different LWG of unsupplemented goats across each of the three experiments, the responses to each supplement were expressed as LWG above control (i.e. the intercept of all equations was set at 0).

The following background information and constraints to the use of the relative-cost of supplement calculator are provided,

1. The calculator is used to provide an estimate of the relative cost of different supplements and the number of days required to reach a target liveweight,
2. The calculator is based on the approach taken by McLennan (2002) in the MLA funded project (NAP3.122),
3. The calculator uses the cost of supplements delivered to the farm; it is not a budget tool and does not include any other costs associated with feeding supplements (i.e. labour, infrastructure, fuel),
4. The supplements included in the calculator are limited to those tested in the feeding experiments undertaken in the MLA funded project B.GOA.0127 but similar supplements could be substituted on a like-for-like basis,
5. The LWG of unsupplemented goats was set to 0 by removing the Y-intercept (i.e. = 0) from all equations, resulting in calculated values representing the response above control for each Experiment. This method was chosen to normalise response equations across Experiments,
6. All calculations are based on average liveweight and intake between start and the target liveweight, and don't allow for adaptation to diets, assume complete consumption of supplement and don't include allowances for wastage and are assumed to be constant (linear growth phase) within the 15 to 25 kg range of LW,
7. Data is derived from goats in individual pens, as such adjustments may be required for grazing goats where additional energy would be required for activity,
8. The following assumptions are made,
    a. Goats are young entire male Rangeland goats in the growth (15 to 25 kg LW) not a pre-weaning (< 12 kg LW) or finishing (> 30 kg LW) phase of the growth path
    b. Target maximum growth rates do not exceed the limits measured in the Experiments (included in the calculator)
    c. Edible pasture biomass is not limiting
    d. Basal pasture quality is low (< 5% CP, < 6 MJ ME/kg DM)

The above background and guidelines for inputting start and target LW, and cost and DM of supplement are provided in a separate worksheet within the excel workbook.

3.4 Dissemination activities

Industry presentations

05-Oct-2019 - 'Goat Industry Day' (MLA), The University of Queensland, Gatton, QLD

24-Sep-2020 - 'We've Goat This' (Australian Association of Animal Sciences)

15-Oct-2020 - 'Goat Field Day' (AgForce), Cunnamulla, QLD

30-May-2021 - 'Going into Goats', Surat, QLD

'Goats On The Move' articles

May-2019 - Supplementation tested

May-2019 - Feeding facts

August-2020 - Supplement calculator under development

September-2021 - Supplement calculator developed for pilot testing

Scientific papers

Leo-Penu CLO, Beasley AM, Poppi DP, Norton BW, Eyre KE, McLennan SR and Quigley SP. Liveweight gain and metabolizable energy requirements of young entire male Australian Rangeland goats in response to supplementation. Submitted to *Animal Production Science*.

4 Results

4.1 Literature review

The full review of the literature pertaining to nutritional requirements of Rangeland goats is presented in Appendix 2. The main points from the review include,

- the various international feeding standards and nutritional models largely treat goats similar to sheep (the exception is the work presented in the NRC which is based on Sahlu et al. [2004] which uses a meta-analysis approach to define nutrient requirements),
- 400 kJ ME/kg $LW^{0.75}$.day is estimated as the maintenance ME requirement of a Rangeland goat
- 20 to 30 MJ ME/kg LW gain for a growing meat or indigenous (Rangeland) goat,
- 29, 58 and 87 g metabolizable protein/day for maintenance, 100 and 200 g/day LW gain of a 20 kg goat,
- 200 g ADF/kg DM is the minimum dietary fibre content for a Rangeland goat,
- non-feed factors influencing the use of nutrients for maintenance and gain of LW of Rangeland goats include temperature, photoperiod, activity/range, maturity, sex, genotype and physiological state (while the method of estimation will also influence the calculated values),
- maximum growth rates were estimated to be 190 g/day (20 g/kg $LW^{0.75}$.day) when fed a high quality concentrate diet under penned conditions during a period of increasing photoperiod,
- entire males have higher LW gain than castrates and does from birth to 180 days of age,
- supplementation of does prior to kidding will reduce kid mortality, potentially due to increased quality and quantity of colostrum available to kids,
- supplementation of kids pre- and post-weaning will increase LW gain of kids above unsupplemented kids during both periods, and
- whilst not specifically addressing the costs of achieving these higher growth rates, the review does acknowledge that not all feeding and management strategies are likely to be cost-effective; the profitability of nutritional strategies are likely to be a function of the price and market specification for goats, the cost of the feed (and feeding) and the magnitude of the response to the new feeding management system.

4.2 Supplement dose response experiments

The below results describe the key response relationships and rumen and plasma parameters only for each Experiment. Response equations and significant differences are presented in Appendix 1.

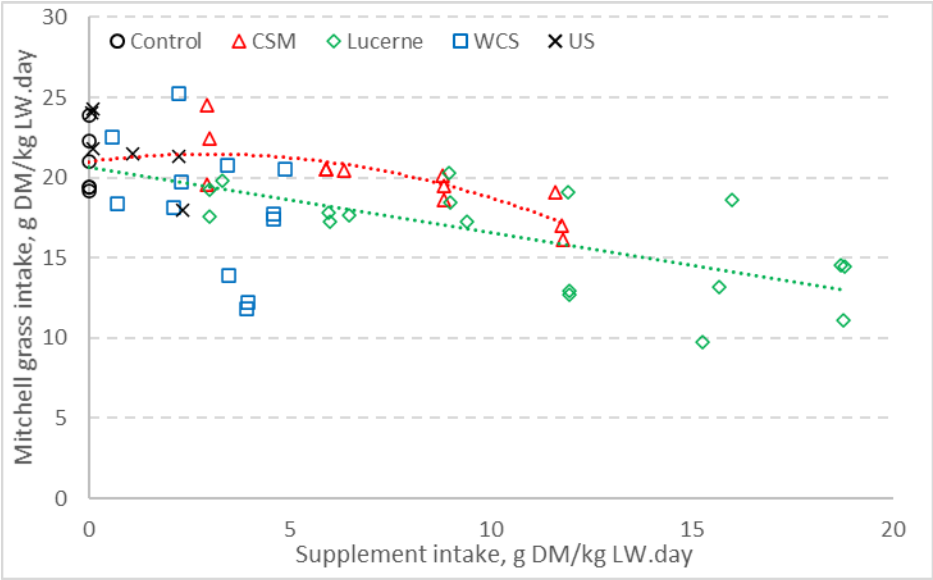
Experiment 1

<u>Intake of supplements, Mitchell grass hay and metabolisable energy</u>

Complete supplement intake was observed for goats offered CSM and lucerne chaff supplements. Urea intake was variable but, in general, most goats consumed their full allocation after week two adjustments were made. Initially WCS was completely consumed but this gradually decreased over two weeks and was extremely variable with either full or no consumption recorded, even after allowances were revised down after week two. There was little evidence of supplementation stimulating intake of the Mitchell grass hay in this experiment with supplements tending to be either additive to, or a substitute for, Mitchell grass (Figure 2). Total DM intake ranged from 16 to 35 g/kg LW.day (Figure 2). Unsupplemented goats and goats supplemented with urea consumed an average of 21 and 22 g DM/kg LW.day respectively. Goats offered CSM12 had an average total intake of 29 g DM/kg LW.day whilst goats offered LUC16 and LUC20 had an average total intake of 31 g DM/kg LW.day. The lowest total DM intake (21 g/kg LW.day) was observed in goats offered the WCS supplement where incomplete supplement intake was compounded by a reduction in Mitchell grass intake. The intake of NDF declined as a proportion of total DM intake for goats consuming the CSM and lucerne supplements but remained within the range of 9 to 18 g/kg LW.day (0.9 to 1.8% of LW) (Figure 3).

Mineral block intake averaged 3.4 g/day across the experiment but was highly variable (0 to 30 g/day measured at different stages). Measurements were only made so that comparisons could be made with the manufacturers recommended intakes (5 g/day). Mineral block intake is excluded from all intake and digestibility calculations and results presented within the current report.

The average DMD ranged from 45% (control) to 65% (CSM12) (Figure 4) which is comparable to values reported for sheep and cattle fed similar diets across previous studies. Urea supplementation had no effect on DMD, while high variability in DMD in response to WCS supplementation was likely a result of the variable and low intakes of both the supplement and the Mitchell grass hay by goats offered this supplement. The DMD increased in a curvilinear fashion with CSM supplementation and a linear fashion with lucerne chaff supplementation. Estimated ME content of the diets ranged from 6.1 (control) to 8.3 and 9.5 MJ ME/kg DM for LUC20 and CSM12 respectively. Metabolisable energy intake increased in a curvilinear fashion with intake of CSM and a linear fashion in response to lucerne chaff on both a daily and relative to LW basis. Response to WCS is excluded from the ME relationship due to concerns over the reliability of the estimated DMD data for goats fed this supplement due to the low and highly variable intake of WCS and Mitchell grass hay.



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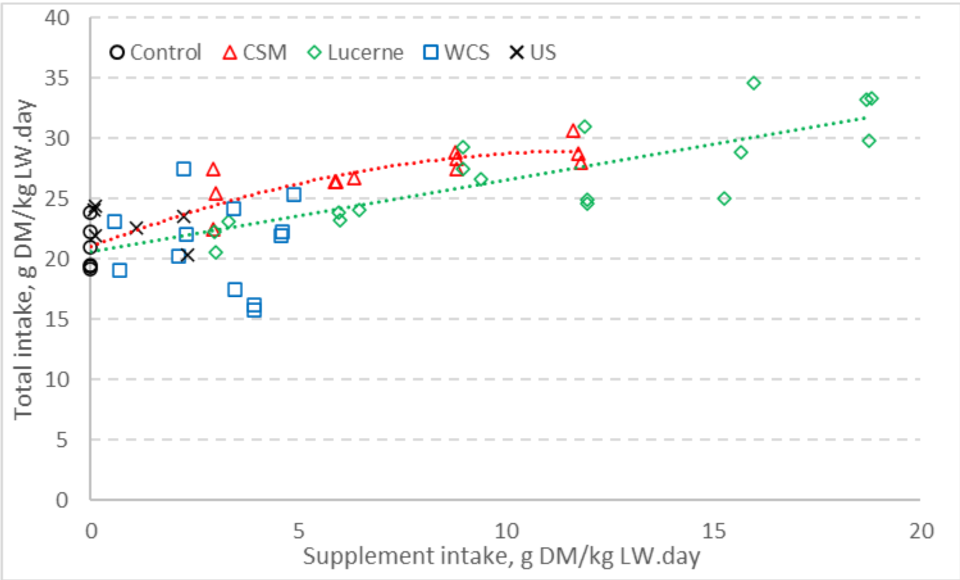

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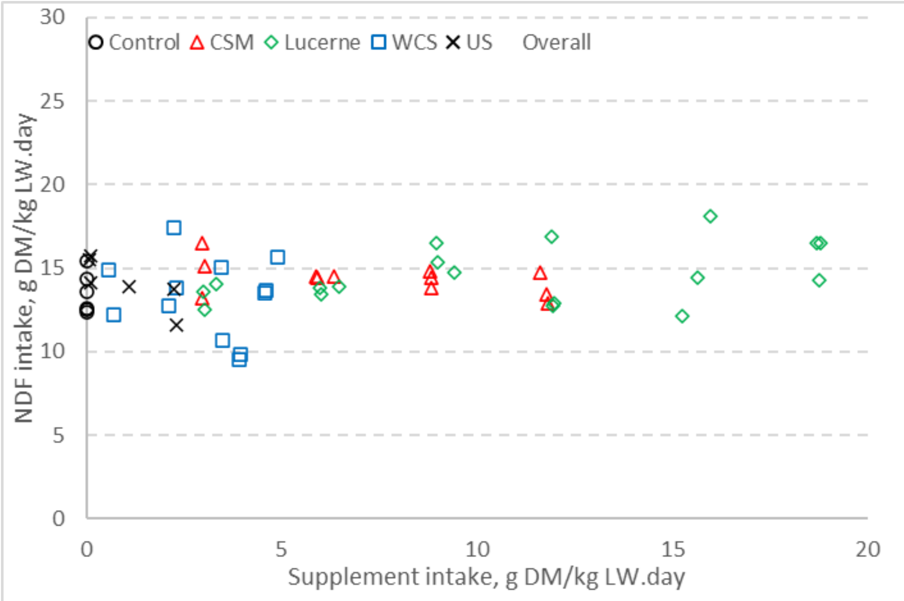
Figure 2. Mitchell grass hay (a.) and total (b.) dry matter (DM) intake in response to increasing intake of cottonseed meal (CSM), lucerne, whole cottonseed (WCS) and urea (US) supplements fed to entire male young Rangeland goats relative to liveweight (LW). Each symbol represents an individual goat. Significant ($P \leq 0.05$) relationships are presented for CSM (……) and lucerne (……) supplements.



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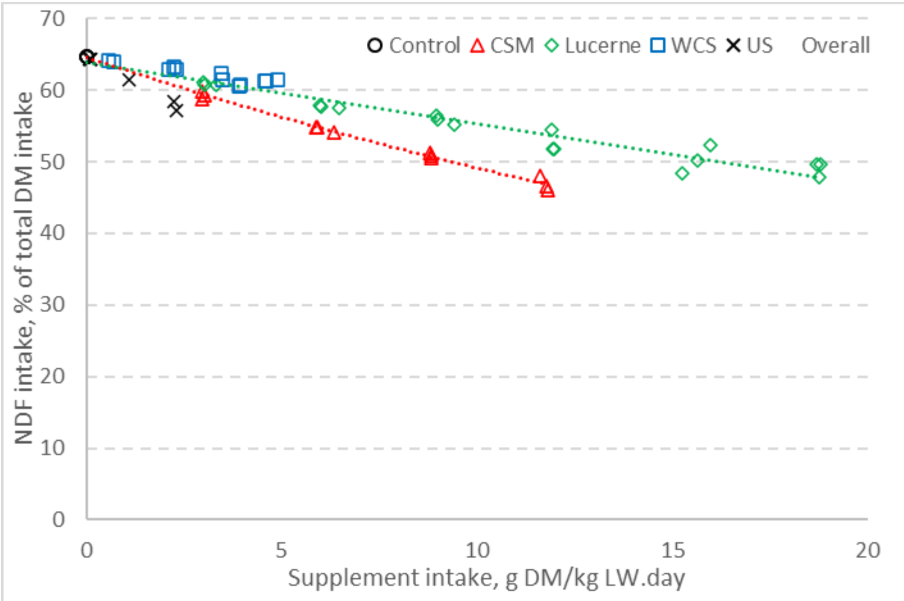
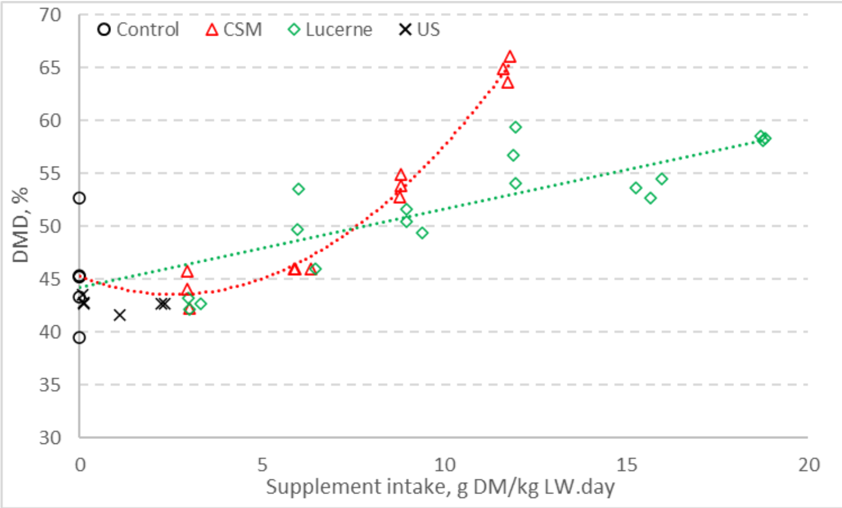


b.

Figure 3. The intake of ash-free neutral detergent fibre (NDF) in response to increasing intake of cottonseed meal (CSM), lucerne, whole cottonseed (WCS) and urea (US) supplements fed to entire male young Rangeland goats relative to liveweight (LW) (a.) and as a proportion of total dry matter (DM) intake (b.). Each symbol represents an individual goat. Significant (P ≤ 0.05) relationships are presented for CSM (……) and lucerne (……) supplements.



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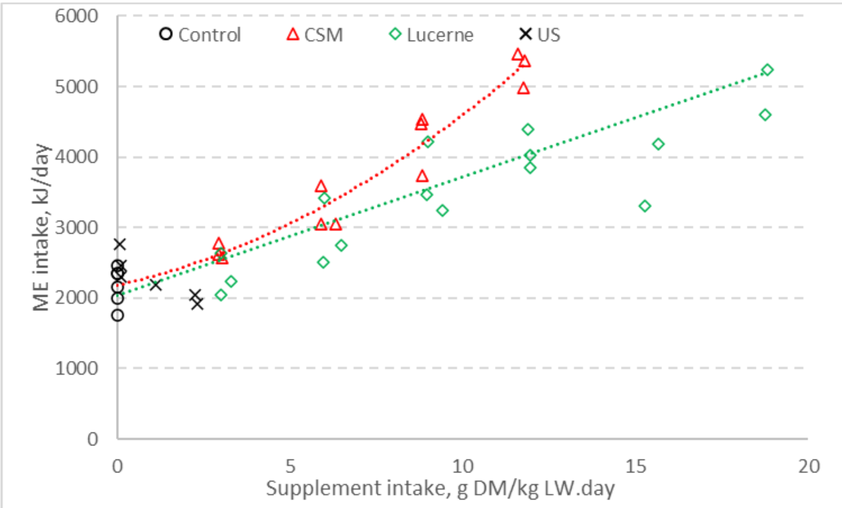

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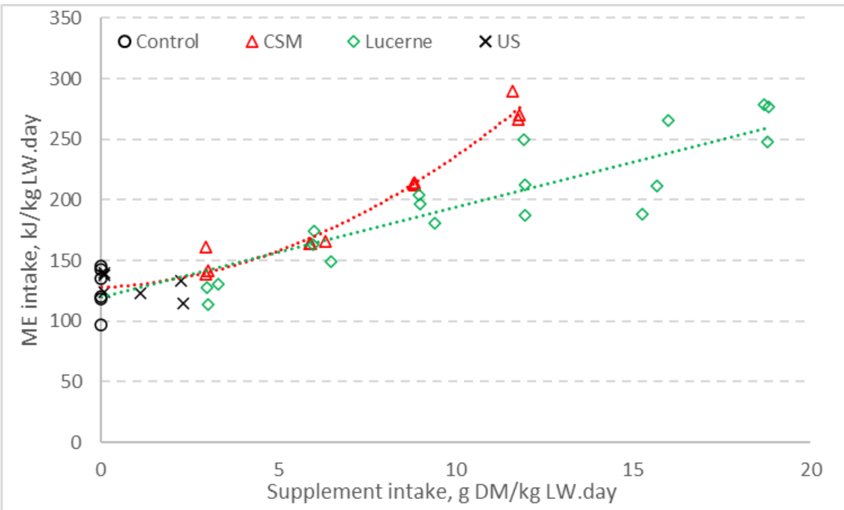

c.

Figure 4. Digestibility of dry matter (DMD) in diet consumed (a.) and estimated metabolizable energy (ME) intake per day (b.) and relative to liveweight (LW) in response to increasing intake of cottonseed meal (CSM), lucerne and urea (US) supplements fed to entire male young Rangeland goats relative to LW. Each symbol represents an individual goat. Significant ($P \leq 0.05$) relationships are presented for CSM (……) and lucerne (……) supplements. Goats offered the whole cottonseed supplement were excluded due to low and variable intakes of both the supplement and the Mitchell grass hay.

Liveweight gain

Goats consuming Mitchell grass alone gained an average of 7 g/day, whilst goats that were supplemented with urea-molasses gained an average of 17 g/day (Figure 5). The highest average LWG was for goats offered the CSM09 and CSM12 supplements (approximately 60 g/day). Goats offered the LUC12, LUC16 and LUC20 supplements grew at an average of 45 g/day regardless of the amount of lucerne chaff consumed. The response of LWG to lucerne chaff intake was lower than the response to CSM intake at an approximately equivalent CP intake, suggesting the higher ME content and ME intake of goats consuming the CSM supplement was responsible for the additional LWG, although differences in amount of protein bypassing degradation in the rumen may also have influenced this response. Goats fed the WCS supplement had the lowest and most variable rates of LWG due to rejection of the supplement and/or depressed Mitchell grass and, hence, total DM and ME intake. There was significant variation within and between supplement allowances across all supplements with a LWG range of -29 to 91 g/day. There was little difference in average LWG of goats allocated to the light, medium and heavy blocks whilst on treatment diets. Despite this, several unsupplemented goats or goats with low supplement allowances in the light LW block displayed LW loss after seven weeks and received intervention feeding with approximately 10 g lucerne chaff/kg LW.day for the remainder of the experiment. In addition, one control goat, one urea goat and one WCS06 goat in the medium block also displayed LW loss after seven weeks and intervention feeding with lucerne chaff was initiated. Liveweight data for these goats is included up to the week at which the intervention commenced, after which the data were excluded from the analysis. The response relationships presented in Figure 5 (a) were used in the generation of the relative-cost of supplement calculator.

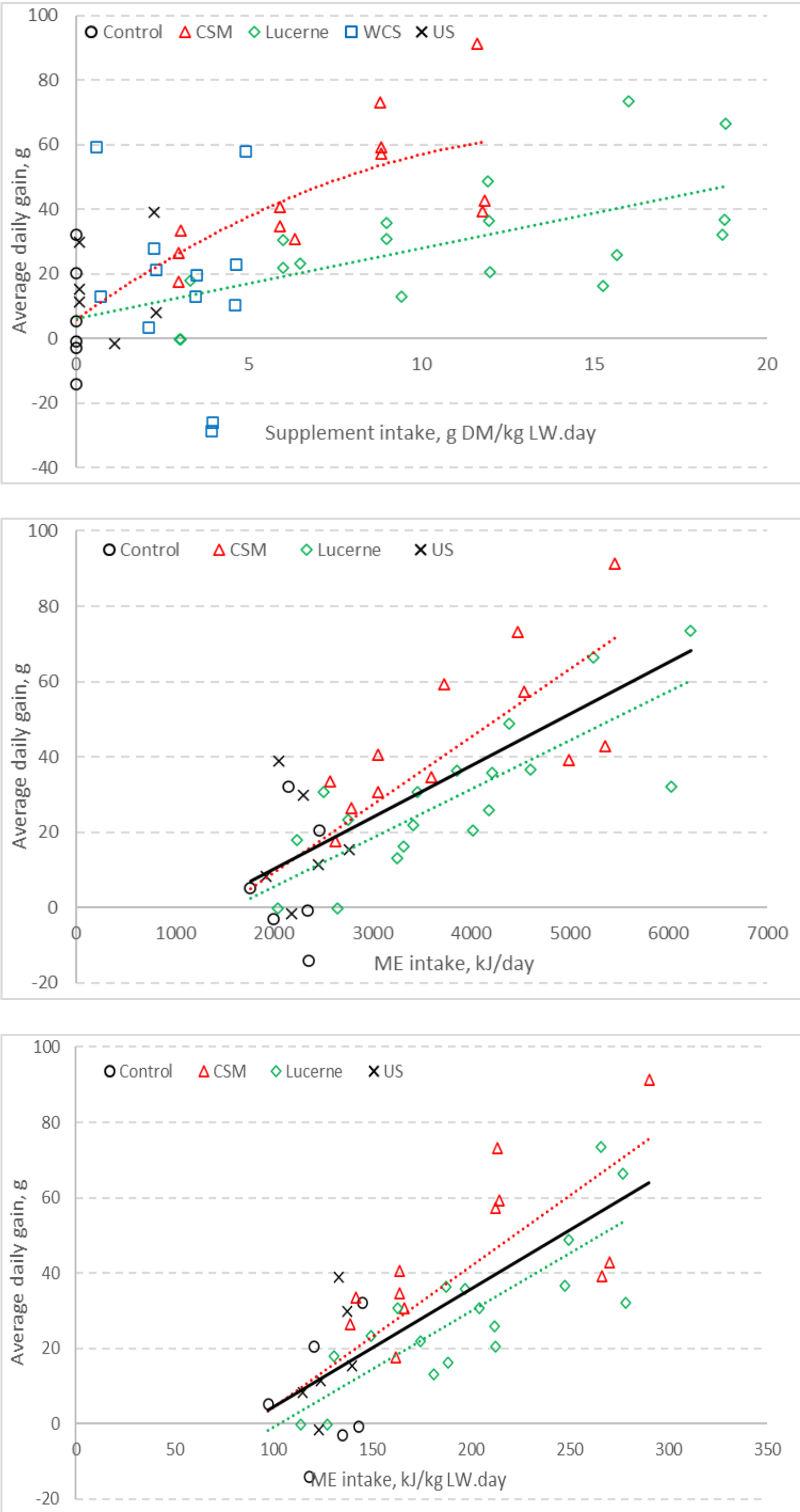

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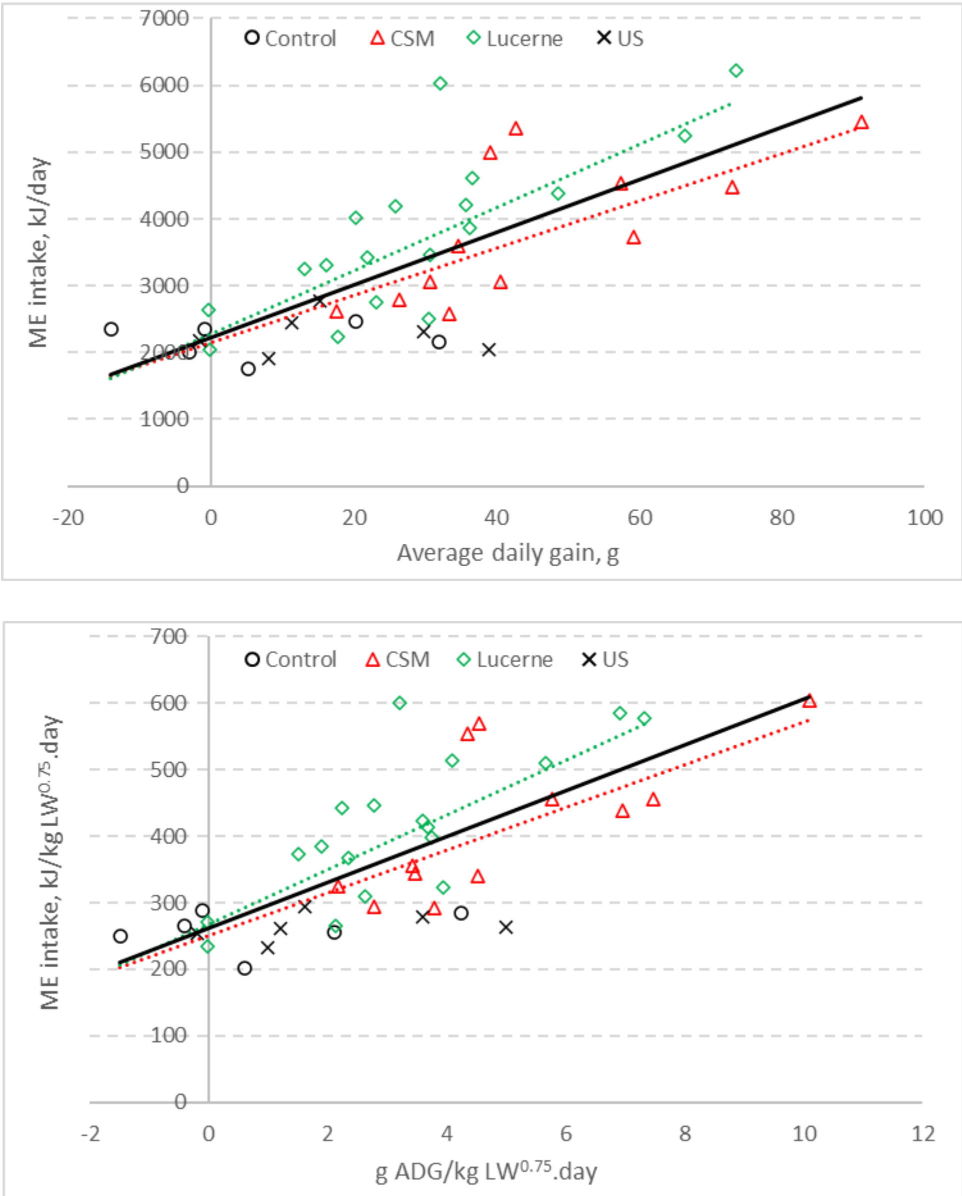
Figure 5. Liveweight (LW) gain of young entire male Rangeland goats in response to increasing intake of cottonseed meal (CSM), lucerne and urea (US) supplements relative to LW (a.) and to estimated metabolizable energy (ME) intake per day (b.) and relative to LW (c.). Each symbol represents an individual goat. Significant ($P \leq 0.05$) relationships are presented for CSM (……) and lucerne (……) supplements, and all data combined (____). Goats offered the whole cottonseed supplement were excluded due to low and variable intakes of both the supplement and the Mitchell grass hay.

The ME requirements for maintenance of LW were estimated to be ~2230 kJ/day or 260 kJ/kg $LW^{0.75}$.day, using a single equation for goats fed the Mitchell grass alone or supplemented with urea, CSM and lucerne (Figure 6). The ME requirements for average daily gain of LW were estimated to be 39 kJ/g ADG or 34.5 kJ/g ADG when adjusted for metabolic weight ($LW^{0.75}$). Whilst of little practical value data are presented in terms of g ADG/kg $LW^{0.75}$ to allow comparisons with other values presented in the literature and feeding standards.



a.

b.

Figure 6. Metabolisable energy requirements for maintenance and gain of liveweight (LW) per day (a.) or relative to metabolic LW ($LW^{0.75}$) of young entire male Rangeland goats with increasing intake of cottonseed meal (CSM), lucerne and urea (US) supplements. Significant ($P \leq 0.05$) relationships are presented for CSM (……) and lucerne (……) supplements, and all data combined (____). Goats offered the whole cottonseed supplement were excluded due to low and variable intakes of both the supplement and the Mitchell grass hay.

<u>Rumen parameters</u>

The concentration of ammonia-N in the rumen fluid was above that required for microbial activity in ruminants and was higher in goats allocated to the highest supplement allowances compared to unsupplemented goats (Table 3). The molar proportion of acetic, propionic and butyric acids in the rumen fluid were unaffected by supplementation and were within the expected range for ruminants fed diets of this nature (i.e. Mitchell grass with N supplements). Rumen pH tended to be higher than expected (6.5 to 7.0) for these diets but was unaffected by the source or amount of supplement consumed. The higher pH might be attributed to challenges in collecting samples and the presence of saliva within the sample.

Table 3. The pH, ammonia-N (NH_3N) concentration and molar proportion of acetic, propionic and butyric acids (mean ± standard error of the mean) in the rumen fluid of young entire male Rangeland goats fed Mitchell grass hay (control) and Mitchell grass hay with urea, cottonseed meal (CSM12) and lucerne chaff (LUC12, LUC20) supplements[1].

Treatment	Replicates	NH_3N, mg/L	pH	Acetic acid, %	Propionic acid, %	Butyric acid, %
Control	3	89 ± 37	7.2 ± 0.2	81 ± 0.7	12.1 ± 0.6	4.4 ± 0.5
Urea	3	77 ± 11	7.3 ± 0.1	79 ± 0.3	13.8 ± 0.3	4.7 ± 0.1
CSM12	3	184 ± 26	7.3 ± 0.1	76 ± 1.2	14.0 ± 0.2	5.4 ± 0.5
LUC12	3	114 ± 17	7.5 ± 0.0	77 ± 1.0	14.6 ± 0.0	4.4 ± 0.5
LUC20	3	137 ± 7	7.4 ± 0.1	75 ± 0.6	15.0 ± 0.3	4.4 ± 0.2

[1]Full details of treatments are provided in materials and methods section, where goats allocated to the following treatments were offered the following supplement allowances, CSM12 offered 12 g CSM DM/kg LW.day, LUC12 offered 12 g lucerne chaff DM/kg LW.day and LUC20 offered 20 g lucerne chaff DM/kg LW.day. Data are mean ± standard error of the mean.

Concentration of metabolites in plasma

The mean concentration of metabolites measured in the plasma of goats in this experiment (Table 4) was within the normal range for goats (MSD Vet manual online, 2021) and other ruminant species fed similar diets (Quigley and Poppi, 2013). Outlying minimum values tended to be observed in lower LW control or WCS supplemented goats. The concentration of urea in the plasma tended to increase in response to increased supplement and, hence, N intake but the concentration of all other metabolites measured were relatively constant in response to supplement intake regardless of the supplement consumed (response equations are not included in this report).

Table 4. Concentration of metabolites in the plasma of young entire male Rangeland goats fed Mitchell grass with increasing amounts of protein supplements[1]

Parameter	Mean ± SEM[2]	Minimum	Maximum
Glucose, mmol/L	3.23 ± 0.07	1.84	4.36
Urea, mmol/L	5.31 ± 0.42	0.45	10.81
Creatinine, umol/L	54.23 ± 1.8	27.7	81.2
Urea:Creatinine	104.73 ± 9.87	15.76	217.9
Ca,mmol/L	2.42 ± 0.04	1.21	2.42
P, mmol/L	2.08 ± 0.08	1.20	3.35
Total Protein, g/L	66.57 ± 1.42	32.5	75.8

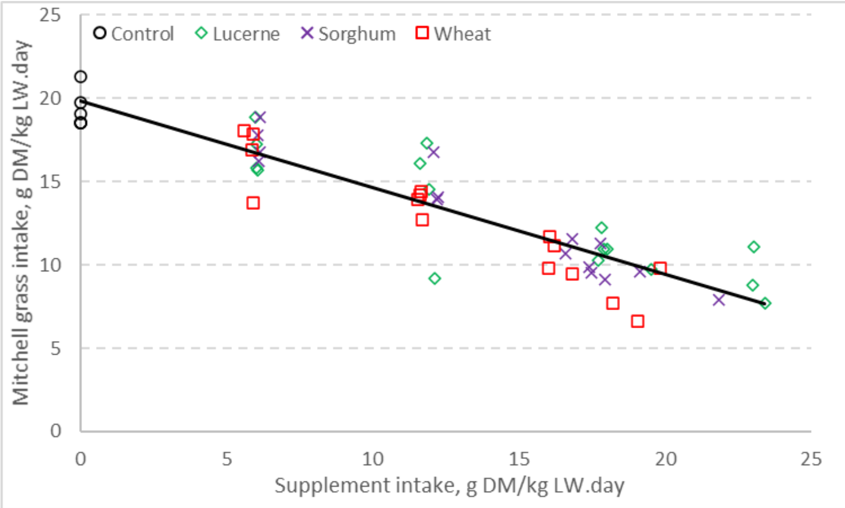
[1]Overall mean data for n=41 goats presented; data excludes goats offered WCS supplements and one goat offered 12 g CSM DM/kg LW.day that presented high haemolysis in the sample; [2]Standard error of the mean.

Experiment 2

Intake of supplements, Mitchell grass hay and metabolisable energy

Complete supplement intake was observed for goats offered lucerne pellet supplement but average maximum sorghum and wheat supplements across the experiment were 19 g DM/kg LW.day which was lower than the target of 24 g DM/kg LW.day for both supplements. There was little evidence of supplementation stimulating intake of the Mitchell grass hay in this experiment with supplements tending to be either additive to, or a substitute for, Mitchell grass (Figure 7). Total DM intake ranged from 19 (unsupplemented goats) to 31 g/kg LW.day (Figure 7). Mitchell grass hay, lucerne pellet and sorghum and wheat supplement intake (at 6 and 12 g DM/kg LW.day) was stable across the experiment, however a reduction in sorghum and wheat intake was observed as the experiment progressed resulting in an overall reduction in mean supplement and total DM intake at higher allowances (Figure 7).

The average DMD ranged from 45% (control) to 55% and 68% for the lucerne and energy (sorghum and wheat) supplements respectively (Figure 8) which is comparable to values reported for sheep and cattle fed similar diets across previous studies. The DMD increased in a curvilinear fashion with sorghum and wheat supplementation, with no significant difference between the two supplements, and a linear fashion with lucerne pellet supplementation. Estimated ME content of the diets ranged from 5.6 (control) to 7.9, 9.8 and 10.6 MJ ME/kg DM for the highest allowances of lucerne, sorghum and wheat respectively. Metabolisable energy intake increased in a linear fashion with intake of all supplements, with the response to lucerne different to the response to the sorghum and wheat supplements on both total daily and relative to LW basis. The intake of NFD declined with increasing intake of grain supplements but increased with increasing lucerne supplement intake (Figure 9).



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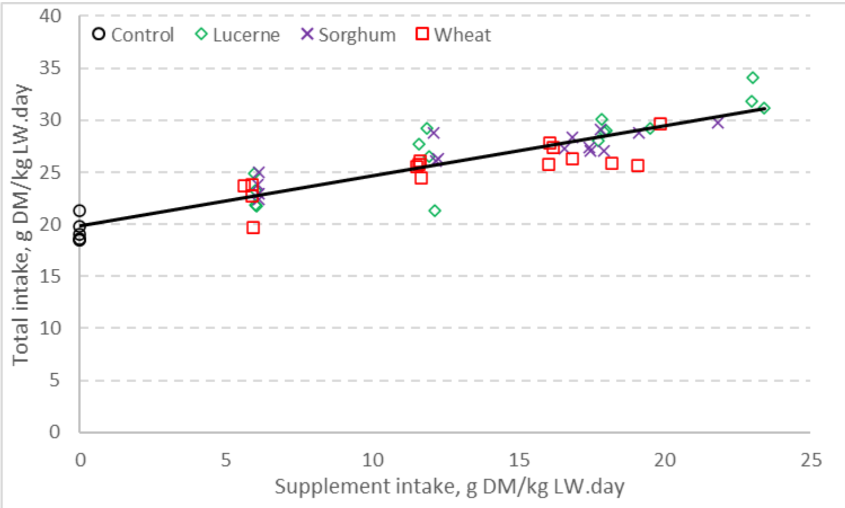

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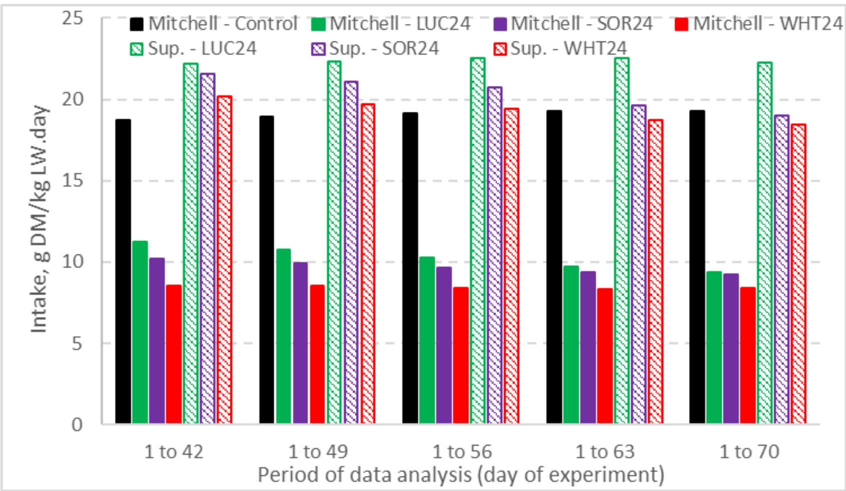

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Figure 7. Mitchell grass hay (a.) and total (b.) dry matter (DM) intake in response to increasing intake of lucerne, sorghum and wheat supplements fed to entire male young Rangeland goats relative to liveweight (LW), and the change in average intake across the experiment (c.). Each symbol represents an individual goat. There was no significant difference between supplements, with the overall response presented ($P \leq 0.05$; ___).

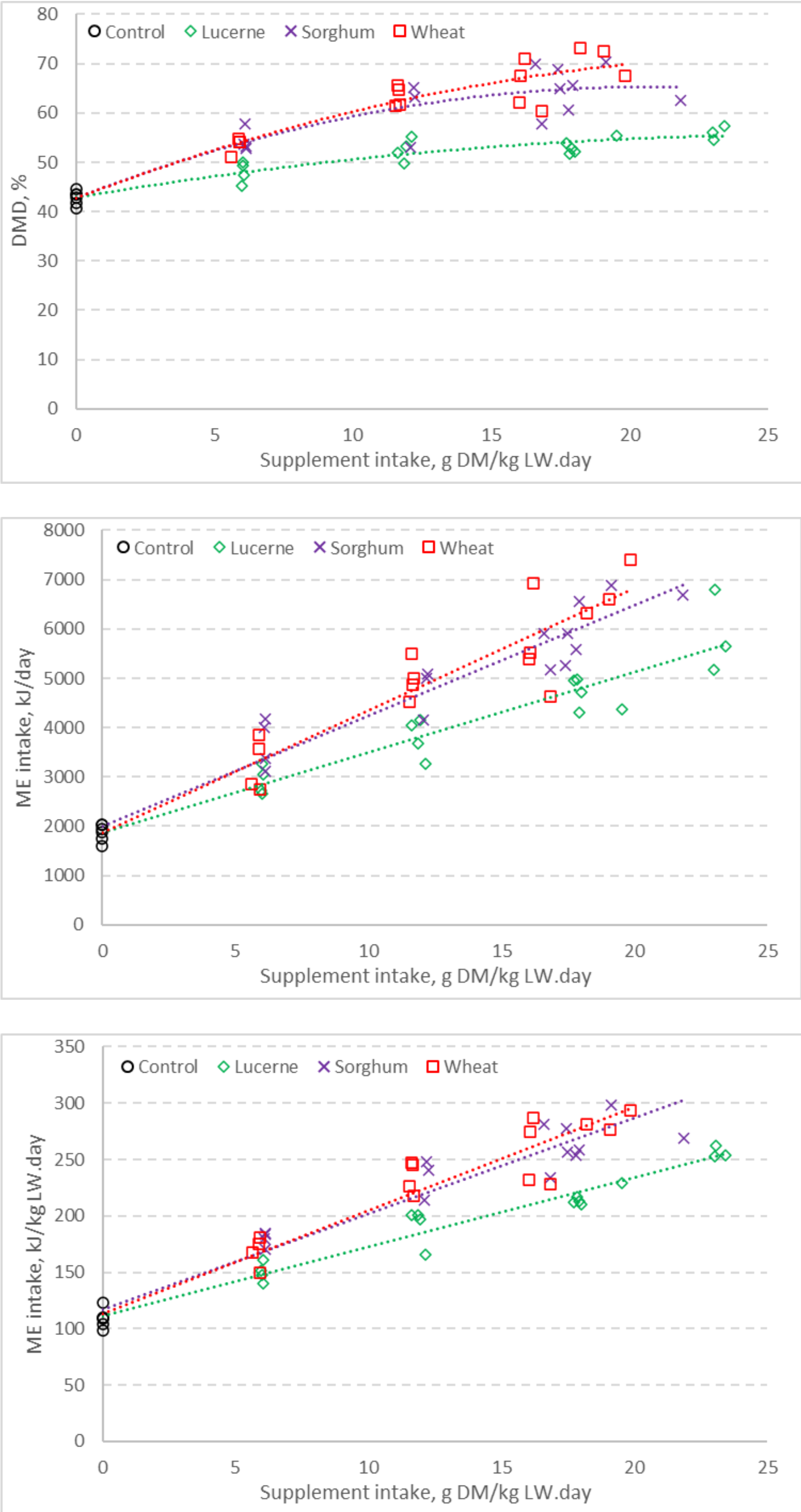

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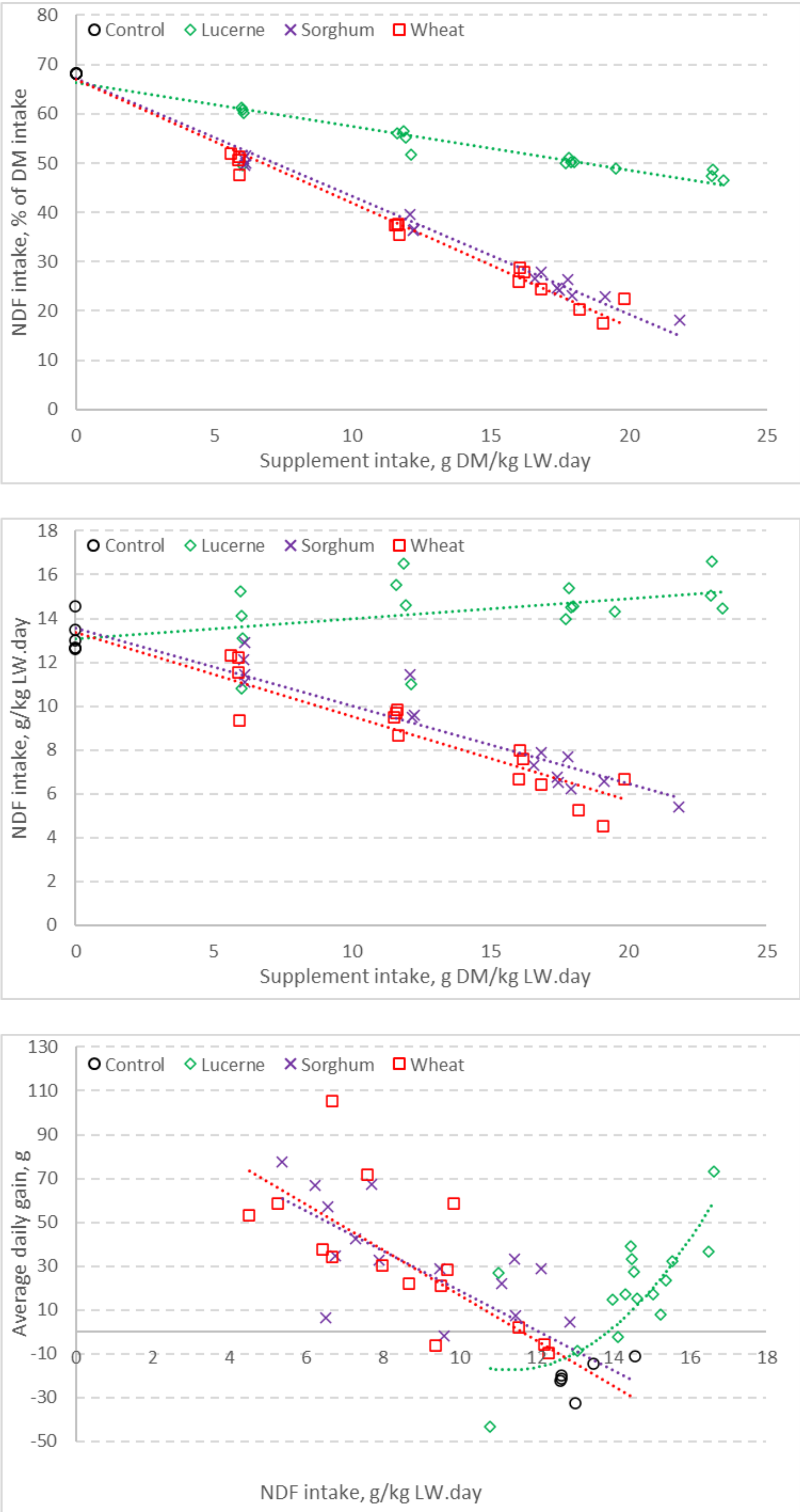
Figure 8. Digestibility of dry matter (DMD) in diet consumed (a.) and estimated metabolizable energy (ME) intake per day (b.) and relative to liveweight (LW) in response to increasing intake of lucerne, sorghum and wheat supplements fed to entire male young Rangeland goats relative to LW. Each symbol represents an individual goat. Significant ($P \leq 0.05$) relationships are presented for lucerne (……), sorghum (……) and wheat (……) supplements.



a.

b.

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Figure 9. The intake of ash-free neutral detergent fibre (NDF) in response to increasing intake of lucerne, sorghum and wheat supplements fed to entire male young Rangeland goats relative to liveweight (LW) (a. and b.) and the relationship between NDF intake and LW gain (c.). Each symbol represents an individual goat. Significant (P ≤ 0.05) relationships are presented for lucerne (……), sorghum (……) and wheat (……) supplements.

Liveweight gain

Average LWG (g/day) of goats tended to decline as the experiment progressed with the greatest decline evident in goats fed the highest allowances of sorghum and wheat and this appeared to be related to a decline in supplement intake over the final four weeks of the experiment (Figure 10). The reason for this decline in intake of the high energy supplements is unknown but could have a behavioural or metabolic basis. Goats consuming Mitchell grass alone gained an average of -20 g/day (Figure 11). The highest average LWG was for goats offered the Wheat supplements (approximately 70 g/day). Goats offered the LUC24 and SOR24 supplements grew at an average of 37 and 45 g/day. The response of LWG to lucerne intake was lower than the response to sorghum and wheat intake at an approximately equivalent CP intake, suggesting the goats were more responsive to supplementation with starch rather than CP, provided CP is not limiting. There was significant variation within and between supplement allowances across all supplements with a LWG range of -43 to 106 g/day. There was little difference in average LWG of goats allocated to the light, medium and heavy blocks whilst on treatment diets. Two goats were removed from the experiment in week 6 (SOR12) and week 8 (WHT12) due to a cessation of supplement intake; despite the moderate supplement amounts and the long period of prior exposure these were assumed to be cases of sub-acute acidosis (SARA). The SARA may have resulted from the pattern of feeding (fixed feeding schedules resulting in rapid consumption of the supplement allowance) rather than issues with adaptation of the rumen environment or an excessive total amount of rapidly fermentable starch in the diet. The response relationships presented in Figure 11 (a) were used in the generation of the relative-cost of supplement calculator.

The ME requirements for maintenance of LW were estimated to be ~3450 kJ/day or 373 kJ/kg $LW^{0.75}$.day, using a single equation for goats fed the Mitchell grass alone or supplemented with lucerne, sorghum and wheat (Figure 12). The ME requirements for gain of LW were estimated to be 43 kJ/g ADG or 36 kJ/g ADG when adjusted for metabolic weight ($LW^{0.75}$).

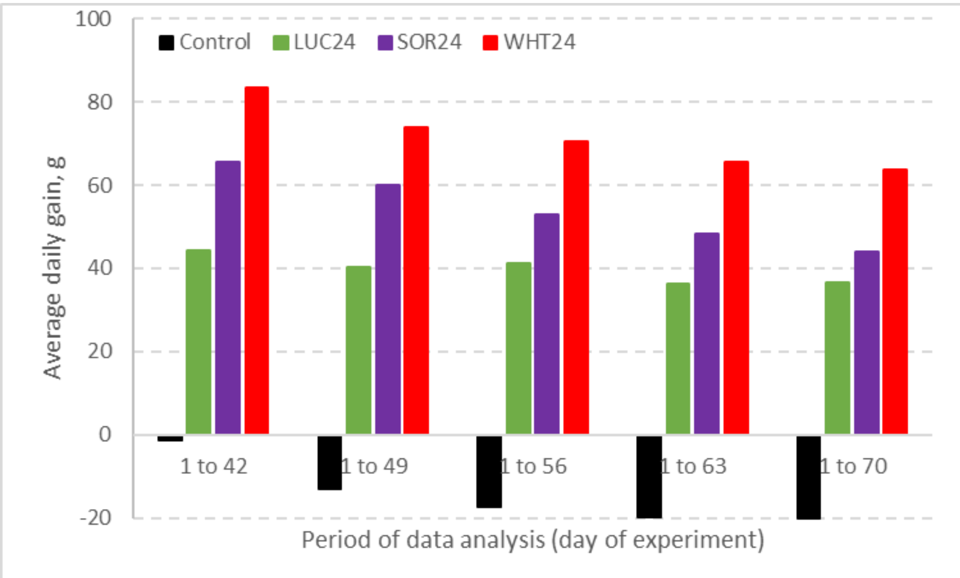
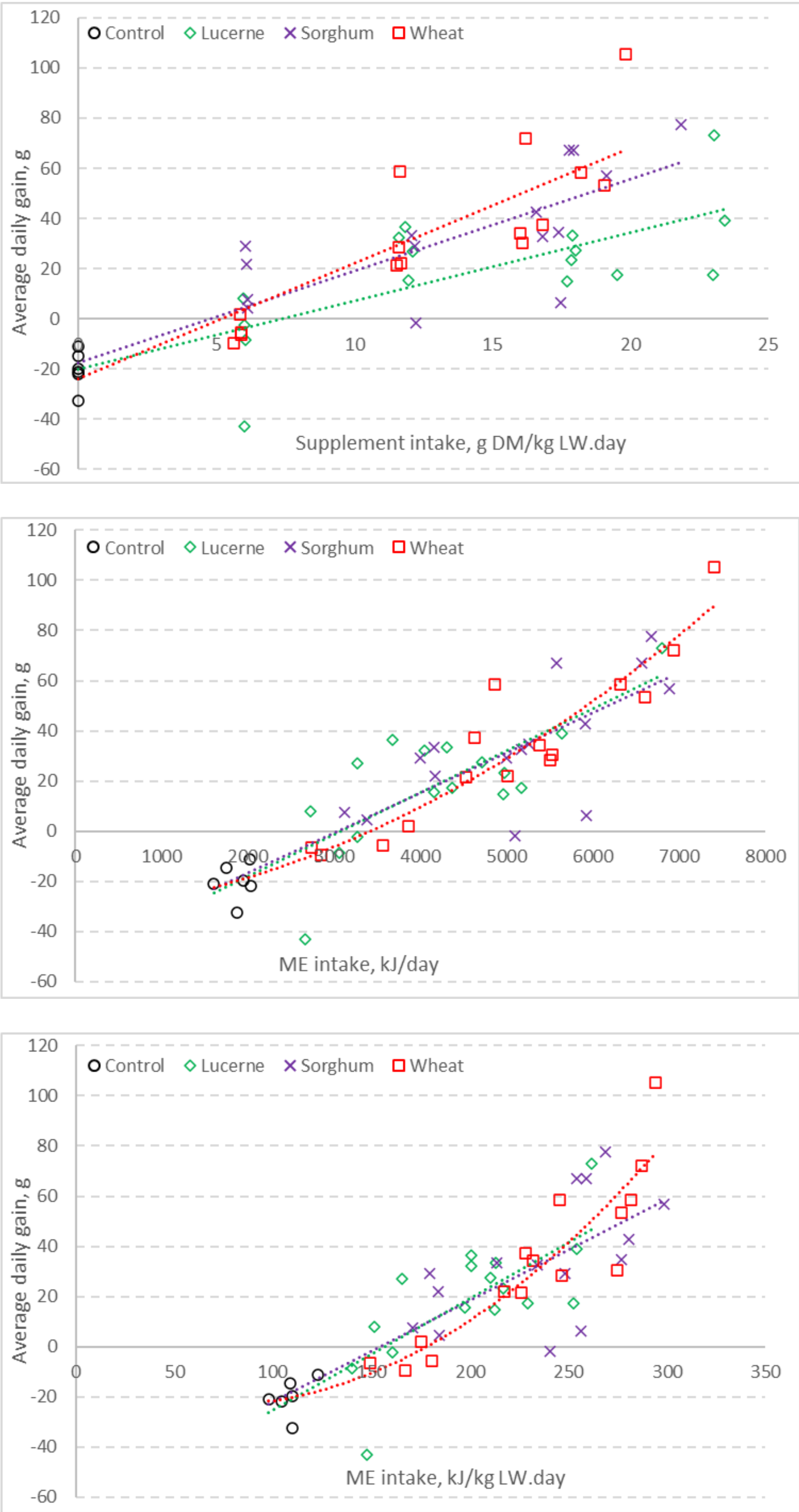


Figure 10. The change in average liveweight (LW) gain of young entire male Rangeland goats in response to increasing intake of lucerne, sorghum and wheat supplements fed relative to LW at different stages of the experiment. Data are for unsupplemented goats and goats allocated to the highest supplement allowances for each supplement type (LUC24 offered 24 g lucerne DM/kg LW.day, SOR24 offered 24 g sorghum DM/kg LW.day and WHT24 offered 24 g wheat DM/kg LW.day).

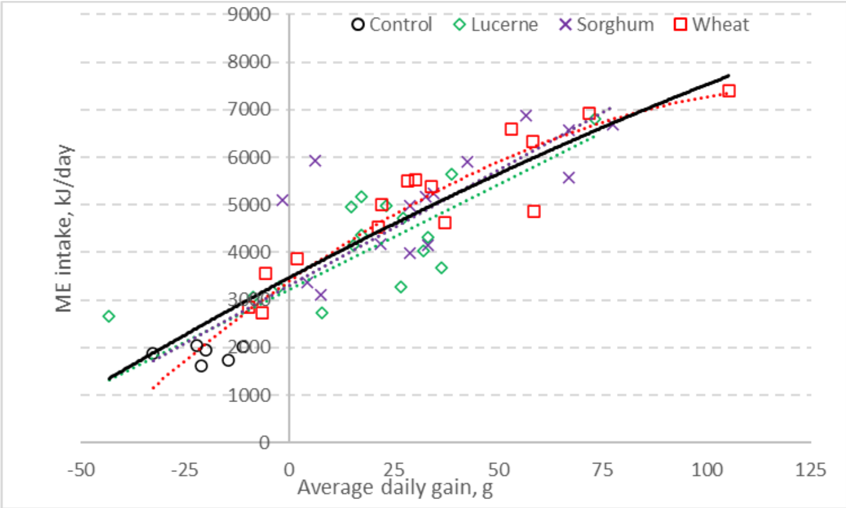


a.

b.

c.

Figure 11. Liveweight (LW) gain of young entire male Rangeland goats in response to increasing intake of lucerne, sorghum and wheat supplements fed relative to LW (a.) and to estimated metabolizable energy (ME) intake per day (b.) and relative to LW (c.). Each symbol represents an individual goat. Significant ($P \leq 0.05$) relationships are presented for lucerne (……), sorghum (……) and wheat (……) supplements.



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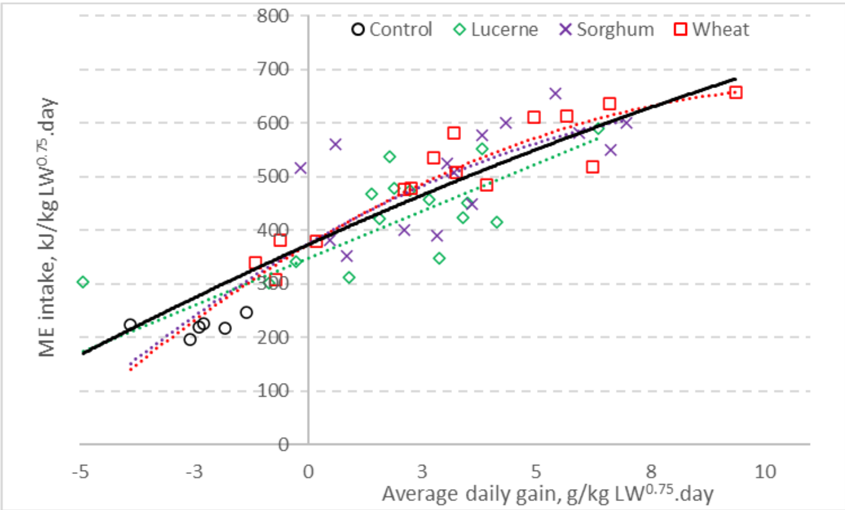


b.

Figure 12. Metabolisable energy requirements for maintenance and gain of liveweight (LW) (a.) or relative to metabolic LW (g average daily gain (ADG)/kg $LW^{0.75}$) of young entire male Rangeland goats with increasing intake of lucerne, sorghum and wheat supplements. Significant ($P \leq 0.05$) relationships are presented for lucerne (……), sorghum (……) and wheat (……) supplements, and all data combined (___).

Rumen parameters

The concentration of ammonia-N in the rumen fluid of supplemented goats was above that required for microbial activity in ruminants (50 mg/L) but was below this threshold in unsupplemented goats (Table 5). The concentration of ammonia-N was higher in the rumen fluid of goats fed the lucerne supplement compared to the sorghum and wheat supplements which was expected given the higher N content and N intake of lucerne compared to the two grain supplements. Rumen pH was within the expected range for ruminants fed these diets. The molar proportion of acetic acid was lower, and the molar proportions of propionic and butyric acids were higher in the rumen fluid of goats consuming the sorghum and wheat supplements as expected, with lucerne supplementation having no effect on the molar proportion of short-chain fatty acids when compared to unsupplemented goats.

Table 5. The pH, ammonia-N (NH_3N) concentration and molar proportion of acetic, propionic and butyric acids (mean ± standard error of the mean) in the rumen fluid of young entire male Rangeland goats fed Mitchell grass hay (control) and Mitchell grass hay with lucerne (LUC24), sorghum (SOR24) and wheat (WHT24) supplements[1].

Treatment	**Replicates**	**NH_3N, mg/L**	**pH**	**Acetic acid, %**	**Propionic acid, %**	**Butyric acid, %**
Control	6	43 ± 12	6.7 ± 0.1	82 ± 1.0	12.4 ± 0.7	4.5 ± 0.6
LUC24	4	148 ± 10	6.9 ± 0.1	74 ± 1.0	16.5 ± 0.7	5.2 ± 0.4
SOR24	4	106 ± 26	6.4 ± 0.1	60 ± 3.9	22.9 ± 1.8	13.1 ± 2.6
WHT24	4	63 ± 4	6.4 ± 0.1	60 ± 0.9	21.8 ± 1.8	12.5 ± 1.8

[1]Full details of treatments are provided in materials and methods section, where goats allocated to the following treatments were offered the following supplement allowances, LUC24 offered 24 g lucerne DM/kg LW.day, SOR24 offered 24 g sorghum DM/kg LW.day and WHT24 offered 24 g wheat DM/kg LW.day. Data are mean ± standard error of the mean.

Concentration of metabolites in plasma

The mean concentration of metabolites measured in the plasma of goats in this experiment (Table 6) was within the normal range for goats (MSD Vet manual online, 2021) and other ruminant species fed similar diets (Quigley and Poppi, 2013). The concentration of urea in the plasma increased in a curvilinear fashion in response to lucerne and, hence, N intake but did not respond to sorghum or wheat intake (Figure 13). The concentration of aspartate transaminase, bicarbonate and bile acids in the plasma also increased in a linear fashion with increasing lucerne intake but all other metabolites measured were relatively constant in response to supplement intake regardless of the supplement consumed.

Table 6. Concentration of metabolites in the plasma of young entire male Rangeland goats fed Mitchell grass with increasing amounts of lucerne, sorghum and wheat supplements[1]

Parameter	Mean ± SEM[2]	Minimum	Maximum
Albumin, g/L	35.1 ± 0.3	26.9	41.9
Aspartate aminotransferase, U/L	83.6 ± 3.8	52.5	197.9
Bicarbonate, mmol/L	25.5 ± 0.3	19.5	30.3
Calcium, mmol/L	2.2 ± 0.0	1.8	2.7
Creatine kinase, U/L	144.1 ± 7.4	62.3	365.6
Creatinine, µmol/L	73.9 ± 1.6	54.3	109.3
Y-glutamyltransferase, U/L	46.1 ± 1.9	17.7	106.5
Glucose, mmol/L	3.9 ± 0.1	3.2	5.2
Inorganic phosphorus, mmol/L	2.2 ± 0.1	1.2	3.2
Magnesium, mmol/L	1.0 ± 0.0	0.8	1.7
Total bilirubin, µmol/L	2.3 ± 0.1	0.6	3.9
Total protein, g/L	65.0 ± 0.6	56.8	78.4
Triglycerides, mmol/L	0.2 ± 0.0	0.1	0.5
Urea-N, mmol/L	3.5 ± 0.3	0.7	7.7
Globulin, g/L	29.9 ± 0.4	24.4	38.9
Bile acids, µmol/L	21.4 ± 5.3	4.8	282.8
Non-esterified fatty acids, mmol/L	0.1 ± 0.0	0	0.7
β-hydroxybutyrate, mmol/L	0.2 ± 0.0	0.1	0.5
Glutamate dehydrogenase, U/L	11.2 ± 1.3	2.8	42.3
Sodium, mmol/L	145.9 ± 0.5	135	158
Potassium, mmol/L	4.9 ± 0.1	3.9	6.9
Chloride, mmol/L	109.5 ± 0.4	99	118

[1]Overall mean data for n=52 goats presented; data excludes two goats removed from the experiment due to cessation of supplement intake ; [2]Standard error of the mean.

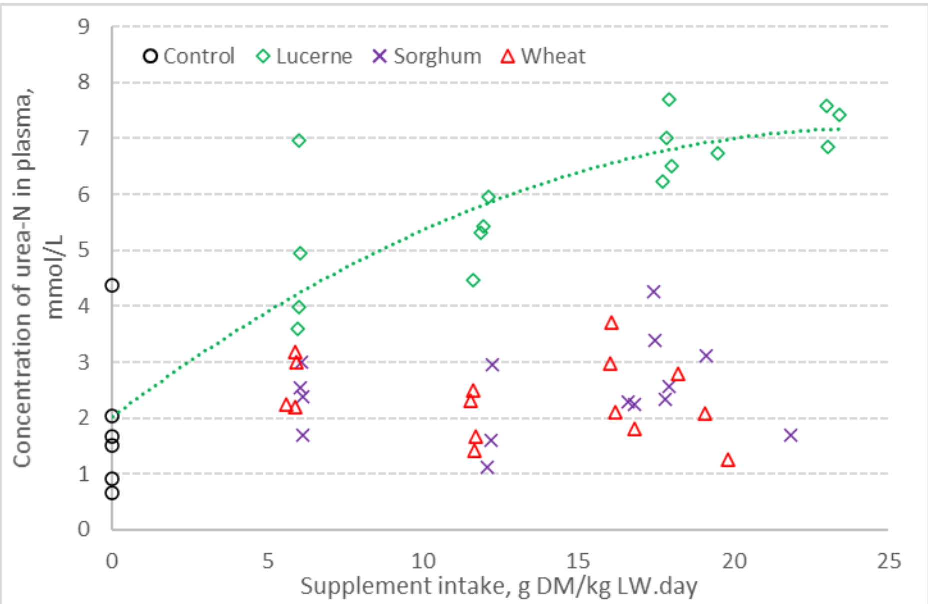


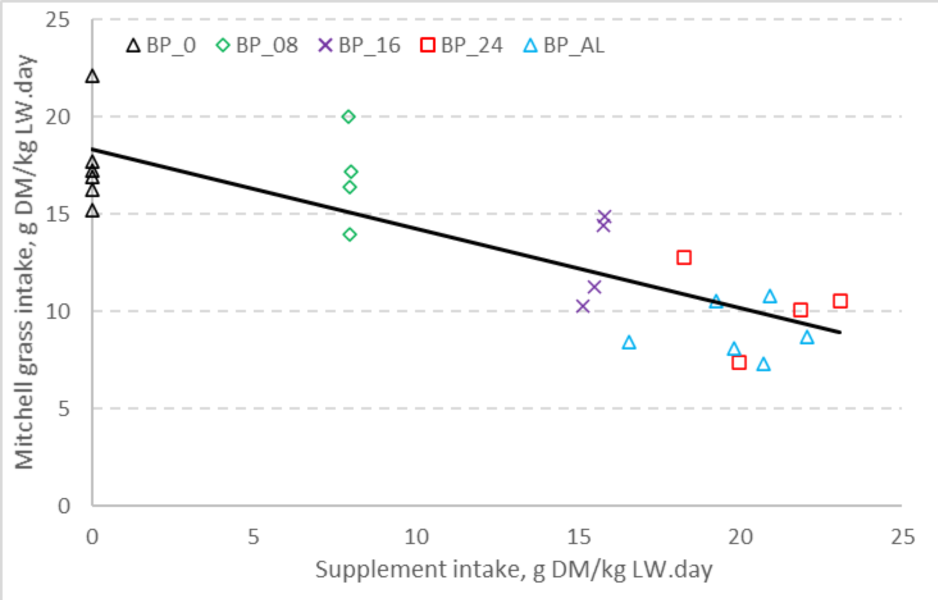
Figure 13. The concentration of urea-N in the plasma of young entire male Rangeland goats fed Mitchell grass hay or Mitchell grass hay with increasing intake of lucerne, sorghum and wheat supplements. Significant ($P \leq 0.05$) relationship is presented in response to lucerne intake (……).

Experiment 3a

Intake of pellets, Mitchell grass hay and metabolisable energy

Complete pellet intake was observed for goats offered the pellets at 8 and 16 g DM/kg LW.day but not when offered 24 g DM/kg LW.day. For goats offered the pellets at 24 g DM/kg LW.day and *ad libitum*, the average pellet intake over the 70-day experimental period was 20 g DM/kg LW.day. There was little evidence of supplementation with pellets stimulating intake of the Mitchell grass hay in this experiment with the pellets substituting for Mitchell grass (Figure 14). Total DM intake ranged from 18 (unsupplemented goats) to 30 g DM/kg LW.day at the highest pellet intakes (Figure 14). The average intake of Mitchell grass hay and pellets were relatively stable across the experiment, compared with the progressive decline of wheat and sorghum intake observed at high allowances in Experiment 2, although large fluctuations in intake of pellets did occur by individual goats. This was assumed to be related to the rapid consumption of pellets resulting in SARA, as observed with two goats in Experiment 2. The intake of NDF declined as a proportion of total DM intake for goats as pellet intake increased but remained relatively constant and within the range of 10 to 16 g/kg LW.day (1 to 1.6% of LW) (Figure 15).

The average DMD ranged from 46% (control) to 68% when pellets were offered *ad libitum* (Figure 16) which is comparable to values reported for sheep and cattle fed similar diets across previous studies. The DMD increased in a linear fashion with intake of pellets in this experiment. Estimated ME content of the diets (EQN 1.12A, $M/D = 0.172*DMD - 1.707$; Freer et al. 2007) ranged from 6.3 (unsupplemented) to 10 MJ ME/kg DM when pellets were offered *ad libitum*. Metabolisable energy intake increased in a linear fashion with intake of pellets on both a total daily amount and relative to LW basis, as expected (Figure 16).



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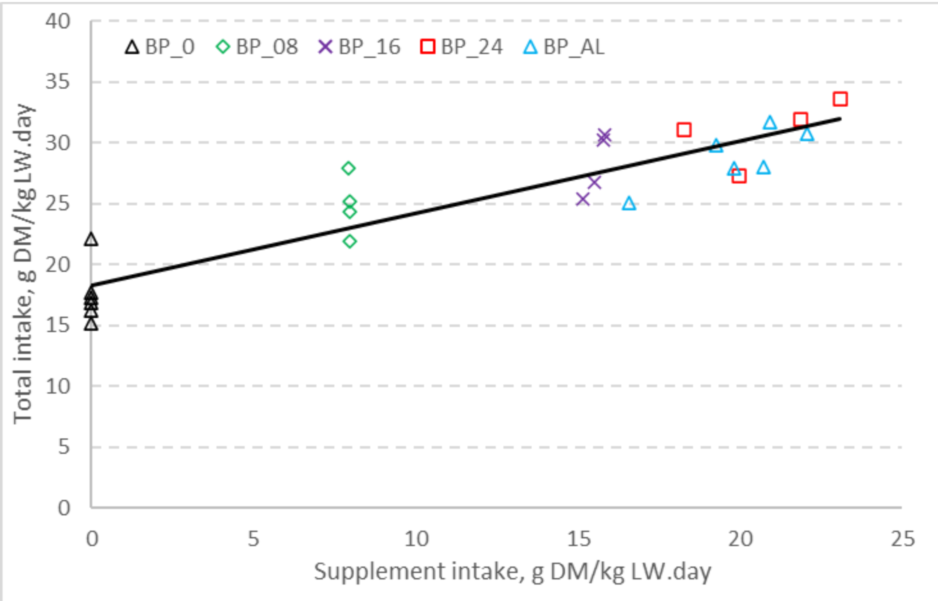
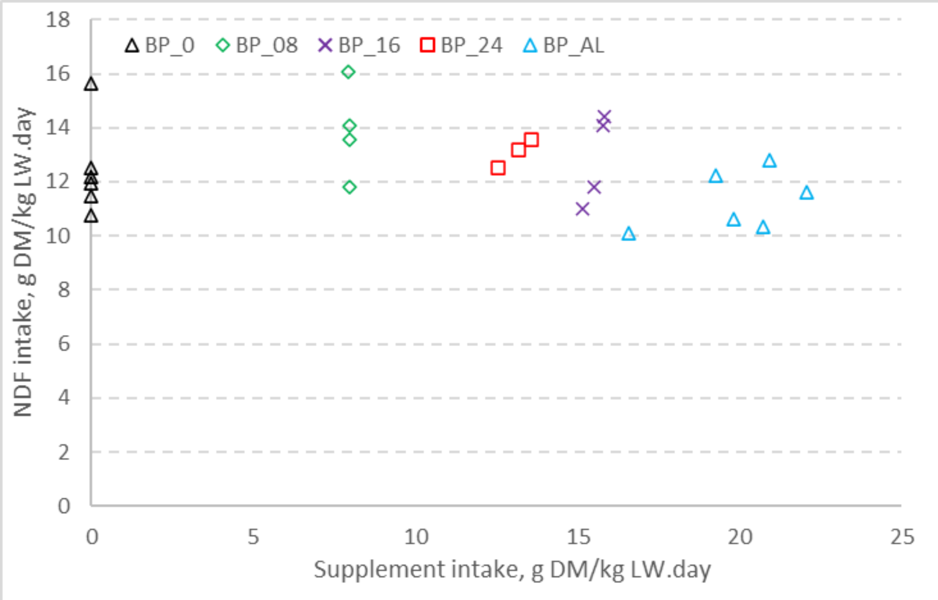


b.

Figure 14. Mitchell grass hay (a.) and total (b.) dry matter (DM) intake in response to increasing intake of lucerne, sorghum and wheat supplements fed to entire male young Rangeland goats relative to liveweight (LW), and the change in average intake across the experiment (c.). Each symbol represents an individual goat with the overall response presented ($P \leq 0.05$; ___).



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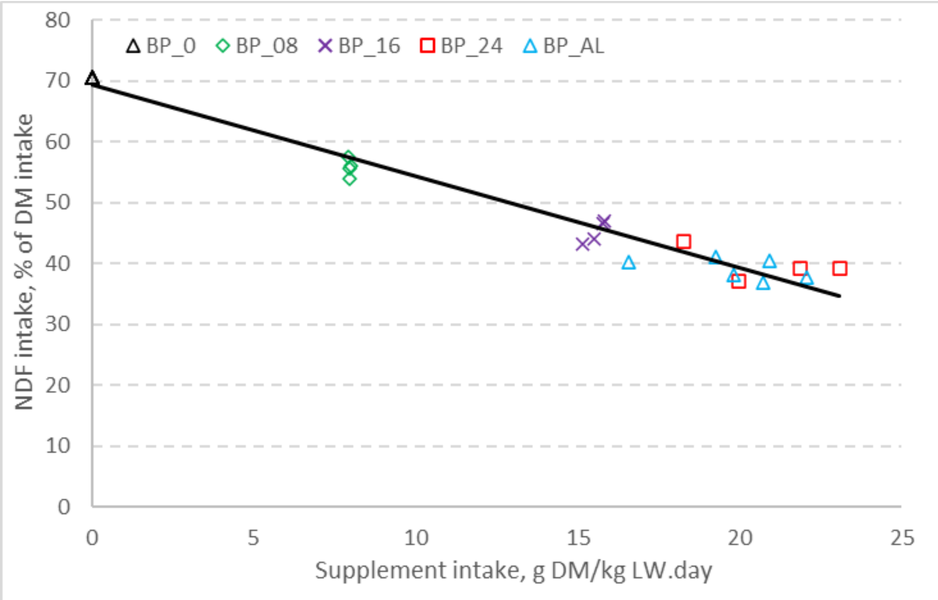
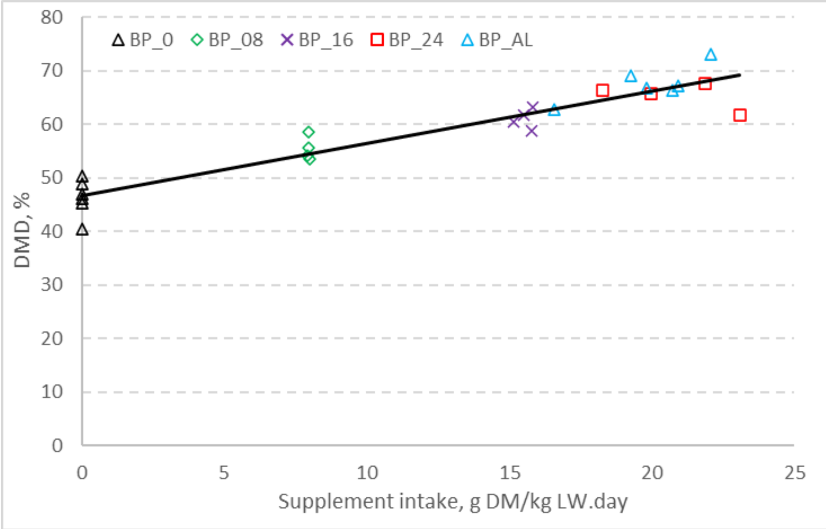


b.

Figure 15. The intake of ash-free neutral detergent fibre (NDF) in response to increasing intake of commercial starch-based pellet fed to entire male young Rangeland goats relative to liveweight (LW) (a.) and as a proportion of total dry matter (DM) intake (b.). Each symbol represents an individual goat with the overall response presented ($P \leq 0.05$; ___).



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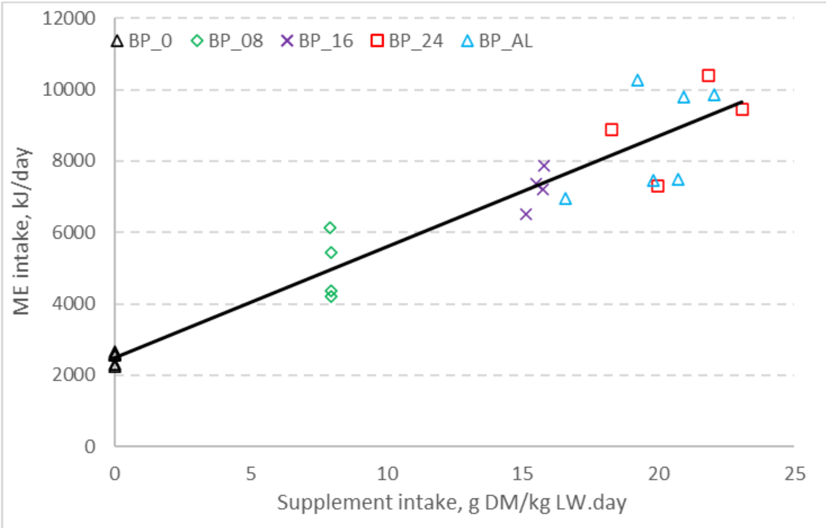

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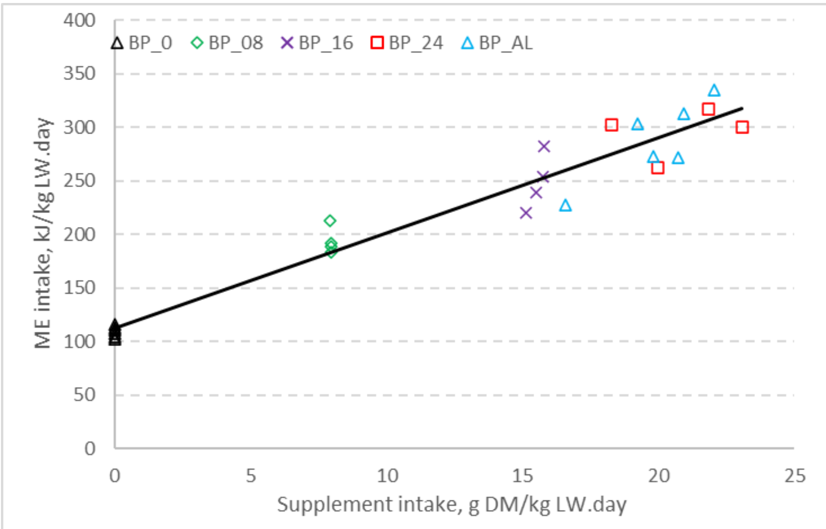


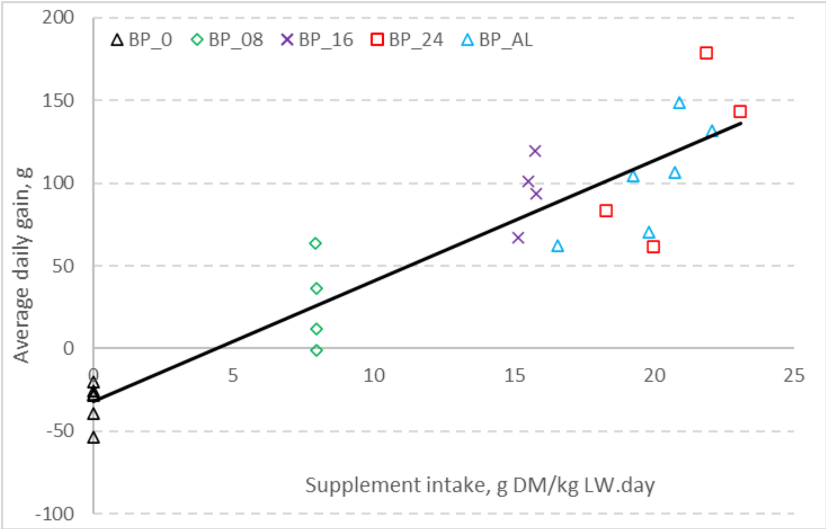
c.

Figure 16. Digestibility of dry matter (DMD) in the diet consumed (a.) and estimated metabolizable energy (ME) intake per day (b.) and relative to liveweight (LW) (c.) in response to increasing intake of a commercial energy-based pellet. Each symbol represents an individual goat with the overall response presented ($P \leq 0.05$; ___).

Liveweight gain

Goats consuming Mitchell grass alone gained an average of -32 g/day (Figure 17). The highest average LWG was for goats offered the pellets at 24 g DM/kg LW.day or *ad libitum* (115 and 105 g/day respectively) There was significant variation in LWG at each supplement treatment allowance despite comparable supplement and total DM intake at each treatment level. The response relationships presented in Figure 17 (a) were used in the generation of the relative-cost of supplement calculator.

The ME requirements for maintenance of LW were estimated to be ~4024 kJ/day or 364 kJ/kg $LW^{0.75}$.day, using a single equation for goats fed the Mitchell grass alone or supplemented with a commercial energy-based pellet (Figure 18). The ME requirements for gain of LW were estimated to be 40 kJ/g ADG or 34 kJ/g ADG when adjusted for metabolic weight ($LW^{0.75}$).



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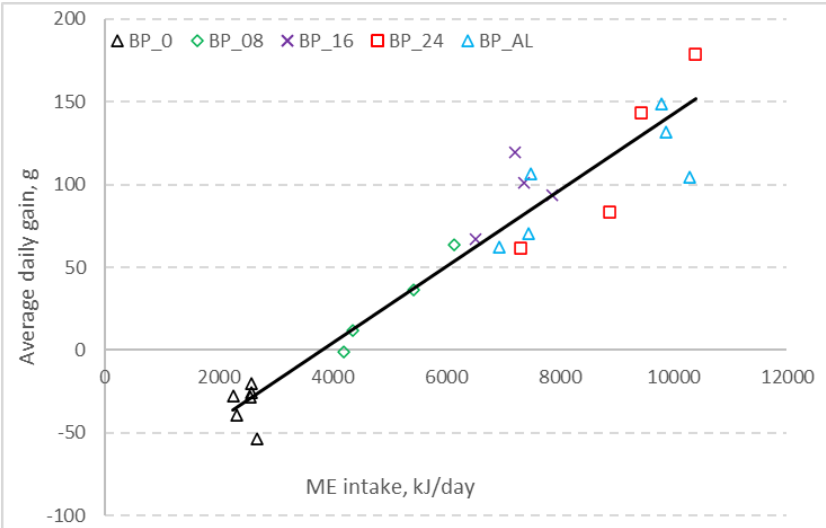

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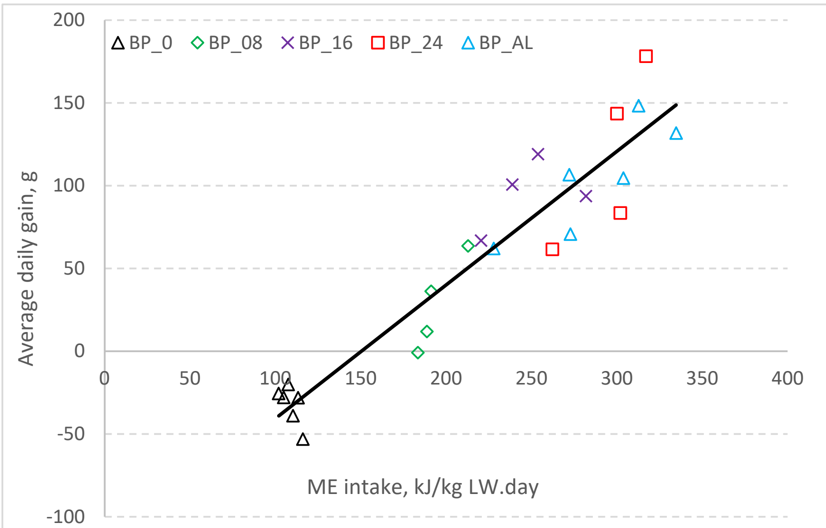
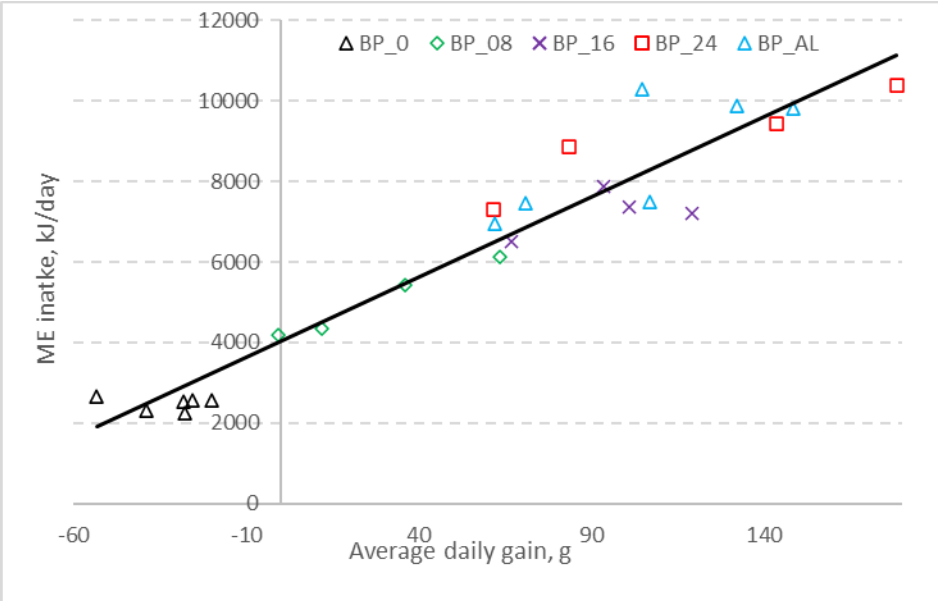


c.

Figure 17. Liveweight (LW) gain of young entire male Rangeland goats in response to increasing intake of a commercial energy-based pellet fed relative to LW (a.) and to estimated metabolizable energy (ME) intake per day (b.) and relative to LW (c.). Each symbol represents an individual goat with the overall response presented ($P \leq 0.05$; ___).



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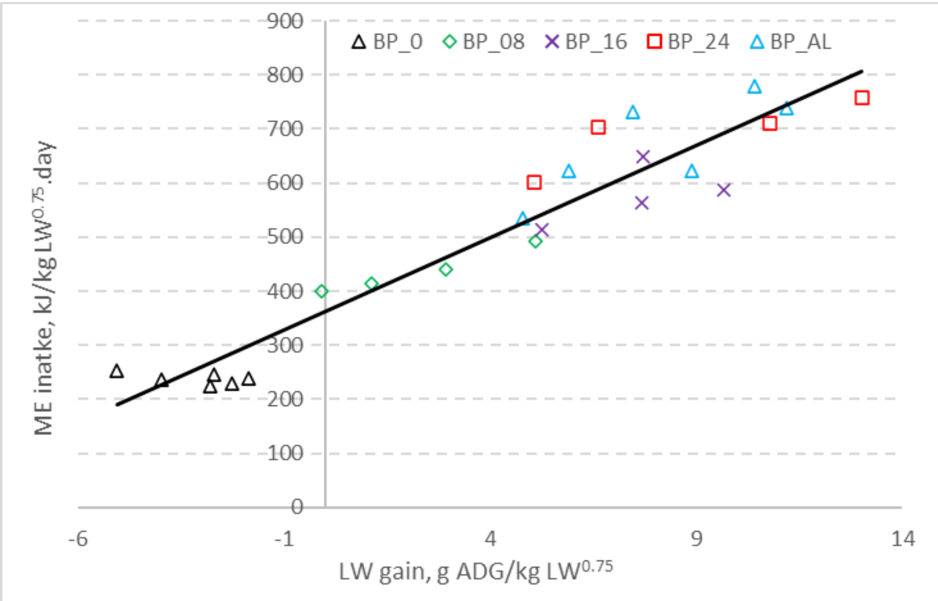


b.

Figure 18. Metabolisable energy requirements for maintenance and gain of liveweight (LW) (a.) or relative to metabolic LW (g average daily gain (ADG)/kg $LW^{0.75}$) of young entire male Rangeland goats with increasing intake of a commercial energy-based pellet fed relative to LW. Each symbol represents an individual goat with the overall response presented ($P \leq 0.05$; ___).

Rumen parameters

The concentration of ammonia-N in the rumen fluid of supplemented goats was above that required for microbial activity in ruminants (50 mg/L) for goats feed pellets at 16 and 24 g DM/kg LW.day but below this threshold at all other feeding levels (Table 7). The concentration of ammonia-N in rumen fluid was generally lower in this Experiment than the concentration reported in Experiments 1 and 2 and whilst the CP content of the Mitchell grass was marginally lower in the current experiment it was somewhat surprising that even goats with *ad libitum* access to pellets, and comparable pellet intake to the 18 and 24 g DM/kg LW.day treatments, had a very low concentration of ammonia-N in the rumen fluid. Rumen pH was within the expected range for ruminants fed these diets, although this needs to be considered within the context of a pre-feeding sample collection. The molar proportion of acetic acid tended to decline with increasing pellet intake, with corresponding increases in propionic and butyric acids evident, as expected.

Table 7. The pH, ammonia-N (NH_3N) concentration and molar proportion of acetic, propionic and butyric acids (mean ± standard error of the mean) in the rumen fluid of young entire male Rangeland goats fed Mitchell grass with increasing amounts of commercial energy-based pellets[1].

Treatment	Replicates	NH_3N, mg/L	pH	Acetic acid, %	Propionic acid, %	Butyric acid, %
BP_0	3	29 ± 5.1	6.9 ± 0.1	78 ± 1.4	17.3 ± 1.0	5.3 ± 0.6
BP_08	3	30 ± 4.8	6.7 ± 0.1	73 ± 6.6	21.1 ± 6.1	5.2 ± 1.4
BP_16	3	60 ± 15.5	6.9 ± 0.1	73 ± 6.0	17.9 ± 3.7	7.2 ± 2.3
BP_24	3	51 ± 12.8	6.9 ± 0.1	65 ± 3.0	26.3 ± 3.7	5.9 ± 1.4
BP_AL	3	28 ± 7.0	6.7 ± 0.1	69 ± 2.1	22.9 ± 1.7	6.3 ± 2.4

[1]Full details of treatments are provided in materials and methods section, where goats were allocated to 0 (BP_0), 8 (BP_08), 16 (BP_16), 24 (BP_24) g pellet DM/kg LW.day and pellets *ad libitum* (BP_AL). Data are mean ± standard error of the mean.

Concentration of metabolites in plasma

The mean concentration of metabolites measured in the plasma of goats in this experiment (Table 8) was within the normal range for goats (MSD Vet manual online, 2021) and other ruminant species fed similar diets (Quigley and Poppi, 2013) and were not significantly affected by pellet intake.

Table 8. Concentration of metabolites in the plasma of young entire male Rangeland goats fed Mitchell grass with increasing amounts of commercial energy-based pellets[1].

Parameter	Mean ± SEM[2]	Minimum	Maximum
Albumin, g/L	34.6 ± 0.3	31.3	37.1
Aspartate aminotransferase, U/L	70.2 ± 5.6	46.0	155.5
Bicarbonate, mmol/L	27.1 ± 0.4	24.4	31.4
Calcium, mmol/L	2.5 ± 0.0	2.3	2.7
Creatine kinase, U/L	99.9 ± 9.7	53.4	279.2
Creatinine, µmol/L	68.9 ± 3.4	46.6	113.2
Y-glutamyltransferase, U/L	41.3 ± 2.2	22.5	75.6
Glucose, mmol/L	4.2 ± 0.1	3.3	6.1
Inorganic phosphorus, mmol/L	2.2 ± 0.1	1.0	3.7
Magnesium, mmol/L	1.0 ± 0.0	0.8	1.1
Total bilirubin, µmol/L	1.7 ± 0.1	0.7	2.7
Total protein, g/L	70.1 ± 0.9	64.0	79.7
Triglycerides, mmol/L	0.2 ± 0.0	0.1	0.3
Urea-N, mmol/L	3.1 ± 0.3	1.4	6.7
Globulin, g/L	40.8 ± 12.6	6.0	259.3
Bile acids, µmol/L	0.1 ± 0.0	0.0	0.9
Non-esterified fatty acids, mmol/L	0.2 ± 0.0	0.1	0.3
β-hydroxybutyrate, mmol/L	12.1 ± 3.1	2.6	62.3
Glutamate dehydrogenase, U/L	0.5 ± 0.1	0.0	2.0
Sodium, mmol/L	144.9 ± 0.5	139.0	150.0
Potassium, mmol/L	5.3 ± 0.1	4.3	6.6
Chloride, mmol/L	107.4 ± 0.4	105.0	111.0

[1]Overall mean data for n=24 goats presented; [2]Standard error of the mean.

Experiment 3b

<u>Intake of pellets, Mitchell grass hay and metabolisable energy</u>

Average intake of Mitchell grass hay was 5.3 g DM/kg LW.day across the entire experiment and was unaffected by CP content of the pellets; this was less than the 7 g DM/kg LW.day offered across the entire experiment. Intake of pellets increased from 16 to 23 g DM/kg LW.day with increasing CP content of the consumed diet (Figure 19), and total intake increased from 22 to 28.4 g DM/kg LW.day. The average DMD ranged from approximately 70 to 80% and was unaffected by CP content of the diet (Figure 20); the estimated ME content of the consumed diet (EQN 1.12A, M/D = 0.172*DMD – 1.707; Freer et al. 2007) was 11 MJ ME/kg DM (the ME content of the pellets alone was estimated to be 13.2 MJ/kg DM based on an *in vitro* analysis of the nutritional composition of the pellets). The proportion of NDF in the diet consumed ranged from 10 to 22% and was also unaffected by the CP content of the diet. This NDF intake was at the very lower end of the scale to maintain rumen function but was required to maintain a high ME intake; an alternative approach would have fed a higher quality roughage source at a higher allowance (10 g DM/kg LW.day) which would have not diluted out the ME content of the diet as much as the lower quality Mitchell grass. Intake of ME increased in a linear fashion with CP intake over the range tested within the current experiment (Figure 21) and this was a function of an increase in DM intake in response to increasing CP content rather than an effect on ME content of the pellets or Mitchell grass *per se*.

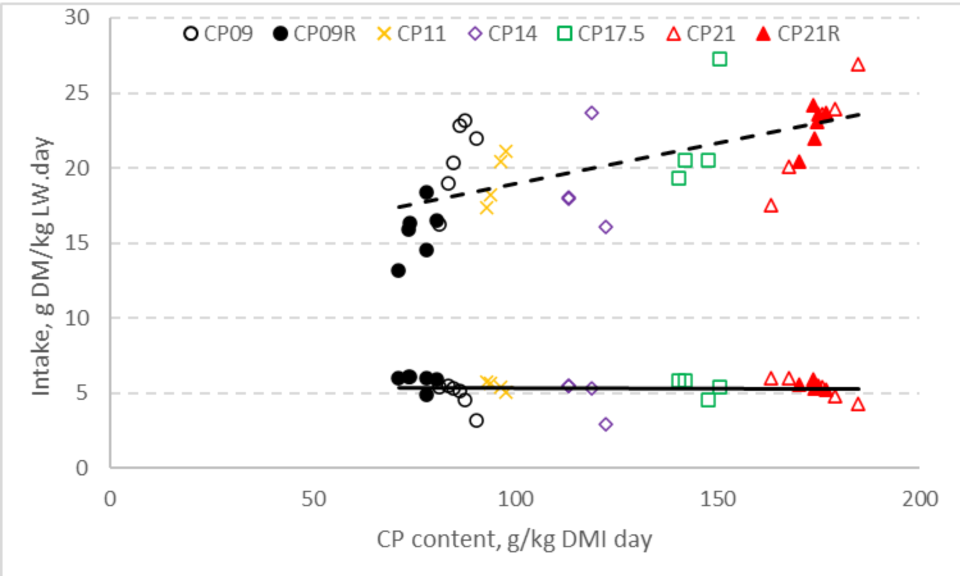
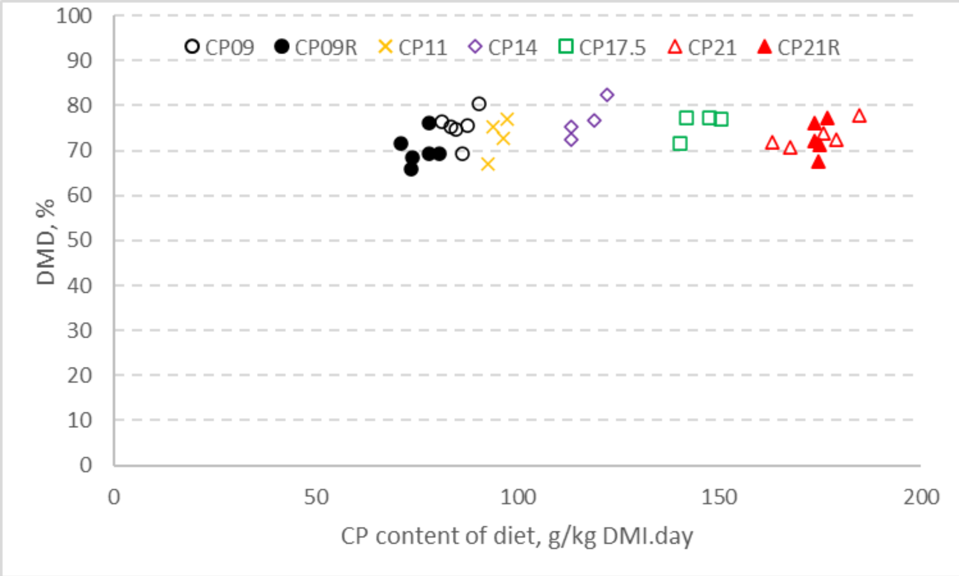


Figure 19. Mitchell grass (___) and pellet (_ _ _ _ _) intake of young entire male Rangeland goats in response to increasing crude protein (CP) content of the consumed diet. Each symbol represents an individual goat with the overall response presented; Treatment abbreviations describe the target CP content (%) without and with rumensin (R).



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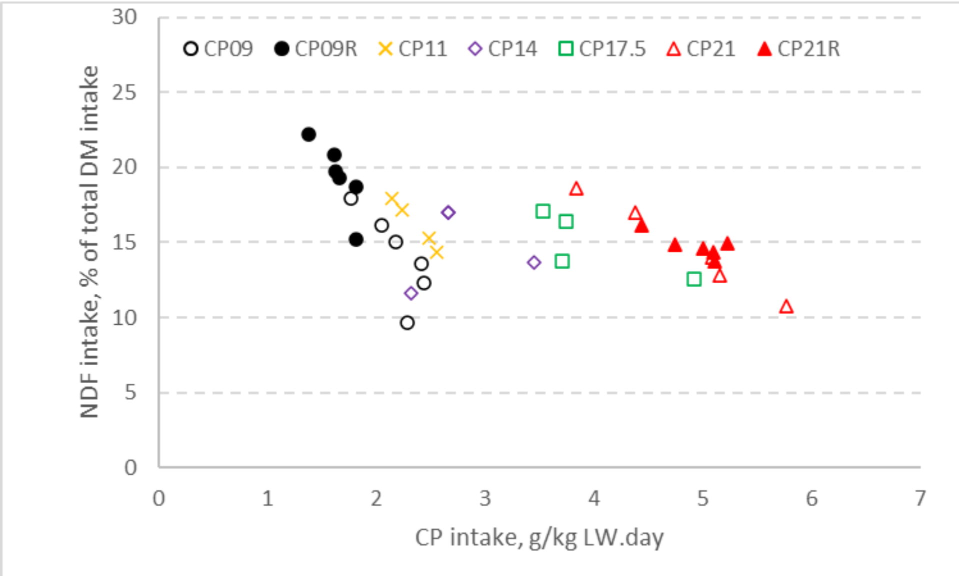
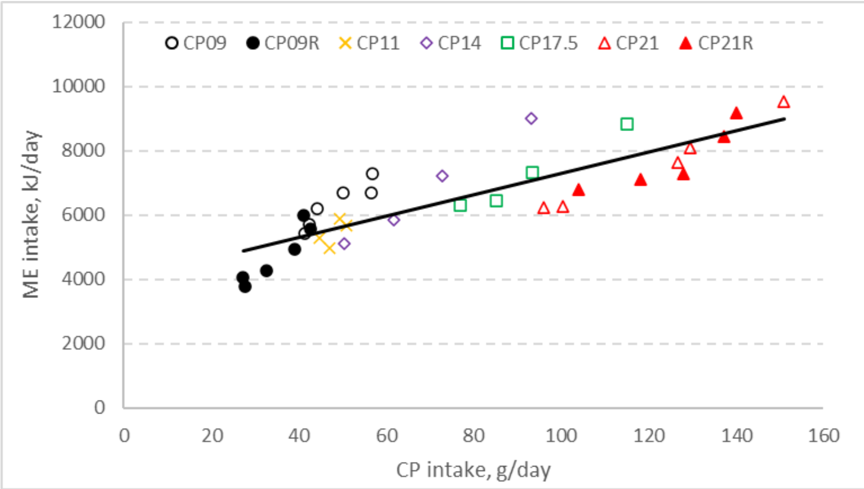


b.

Figure 20. Digestibility of dry matter (DMD) (a.) and proportion of ash-free neutral detergent fibre (NDF) in the diet consumed by young entire male Rangeland goats in response to increasing crude protein (CP) content of the consumed diet. Each symbol represents an individual goat with the overall response presented; Treatment abbreviations describe the target CP content (%) without and with rumensin (R).



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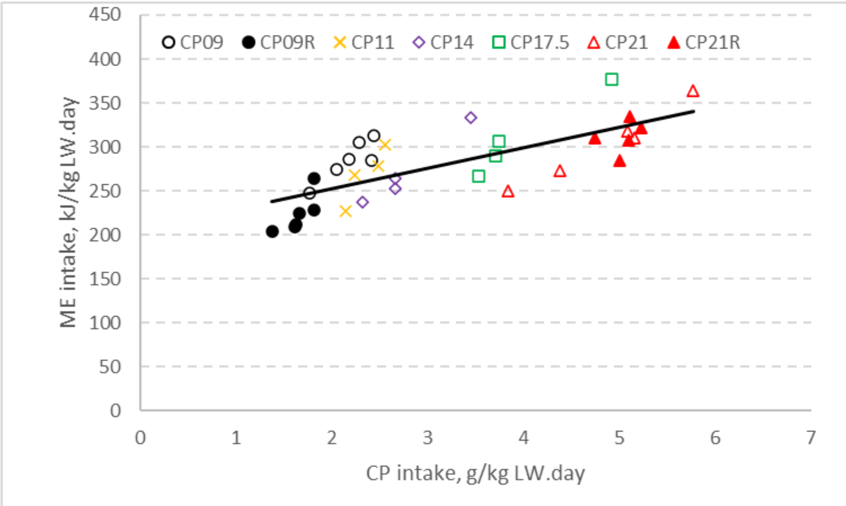

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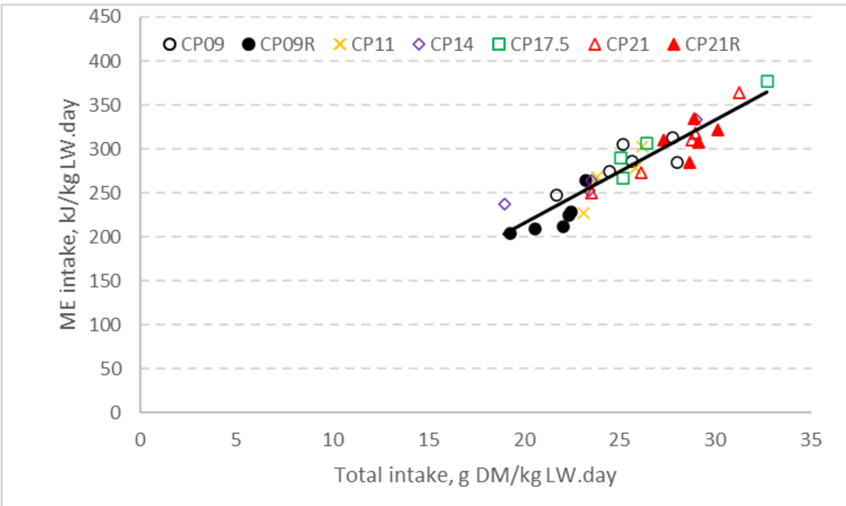

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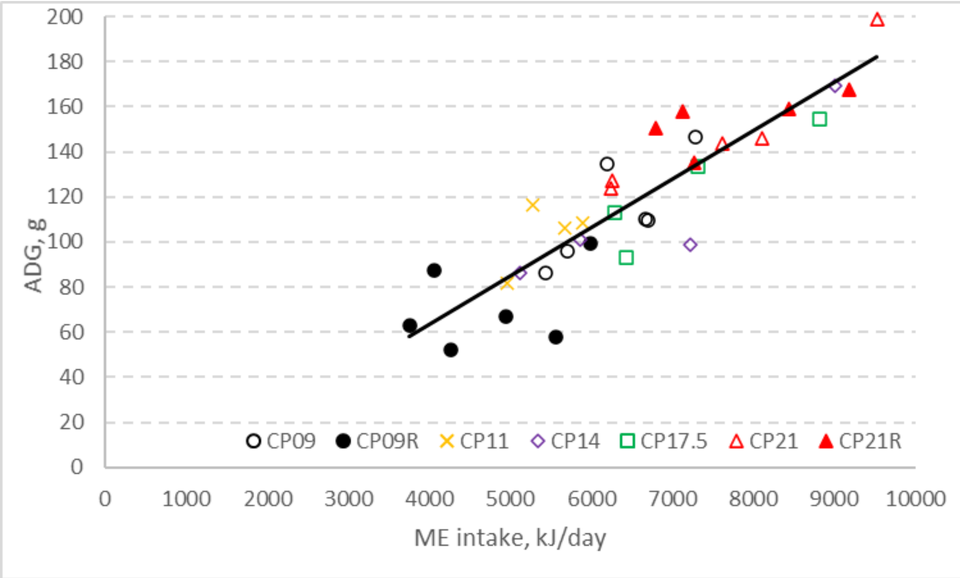
Figure 21. Metabolisable energy intake of young entire male Rangeland goats in response to increasing crude protein (CP) content of the consumed diet on a daily (a.) or relative to liveweight (LW) basis (b.) and in response to total dry matter (DM) intake (c.). Each symbol represents an individual goat with the overall response presented; Treatment abbreviations describe the target CP content (%) without and with rumensin (R).

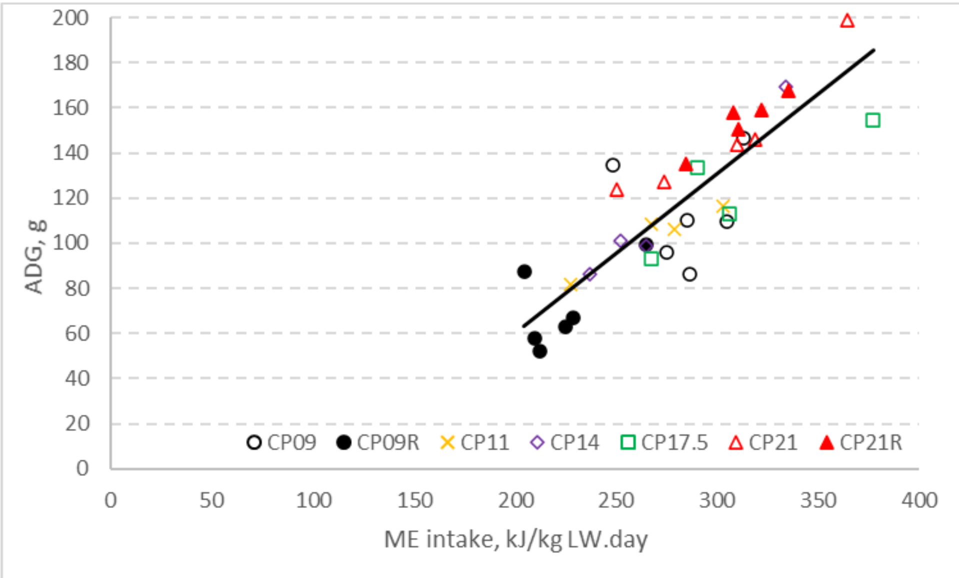
Liveweight gain

Liveweight gain ranged from 60 to 150 g/day for goats consuming diets of 70 g CP to 180 g CP/kg DM or 200 to 400 kJ ME/kg LW.day (Figure 22, Figure 23). The inclusion of rumensin in the ration had no effect on LWG of goats offered the ration with the highest CP content (210 g CP/kg DM; ~150 g/day). Whilst there was a difference in LWG of goats offered rations with and without rumensin at the lowest CP content this was more likely due to an issue with the preparation of the rations (90 g CP/kg DM with rumensin v 100 CP/kg DM without rumensin) resulting in a 30 g/day higher LWG in goats consuming the higher CP content ration without rumensin compared with the lower CP content ration with rumensin.

The ME requirements for maintenance of LW were estimated to be ~2200 kJ/day or 275 kJ/kg $LW^{0.75}$.day, using a single equation for goats fed the energy-based pellet with increasing CP content (Figure 24); it is noted that the actual ME requirement for maintenance of LW may be different to this as the response did not extend to LW maintenance in this experiment. The ME requirements for gain of LW were estimated to be 37 kJ/g ADG or 30 kJ/g ADG when adjusted for metabolic weight ($LW^{0.75}$). If we assume a ME requirement for maintenance of 363 kJ/g ADG.$LW^{0.75}$ (based on response equation of Experiment 3a) then the ME requirement for LWG was 23 kJ/g ADG.$LW^{0.75}$ which is comparable to the requirements estimated by Ash and Norton (1987). The interaction between ME and CO intake and LWG is presented in Figure 25.

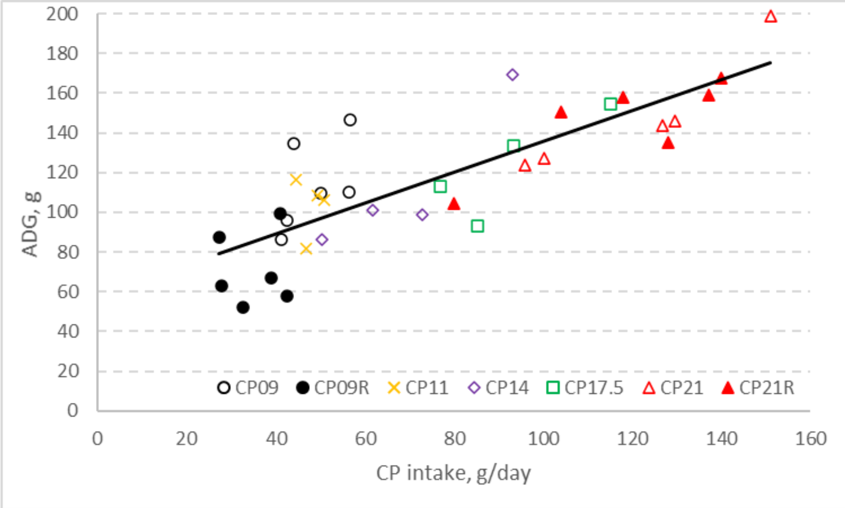


a.

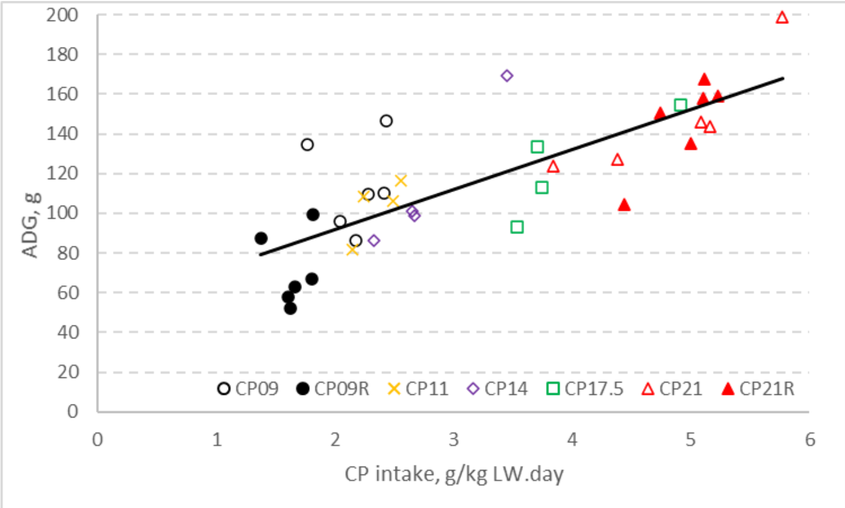


b.

Figure 22. Liveweight (LW) gain of young entire male Rangeland goats in response to increasing metabolizable energy (ME) intake of an energy-based pellet with increasing crude protein (CP) content estimated on a per day (a.) and relative to LW (b.) basis. Each symbol represents an individual goat with the overall response presented; Treatment abbreviations describe the target CP content (%) without and with rumensin (R).



a.



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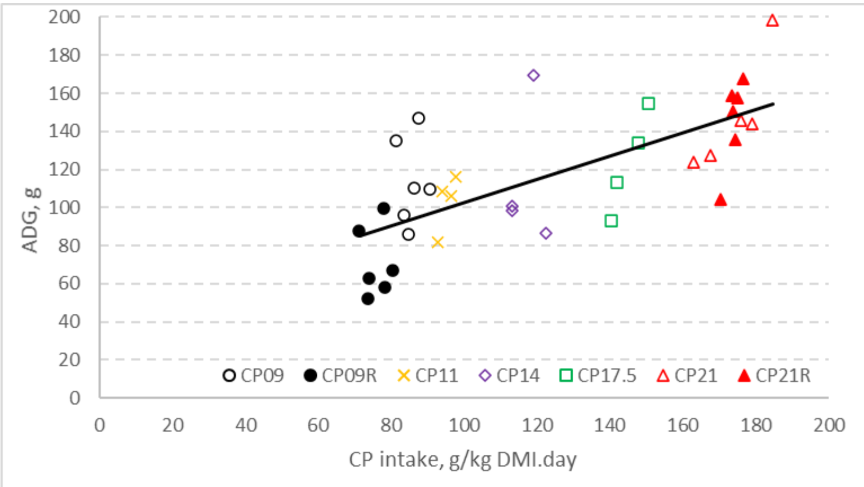
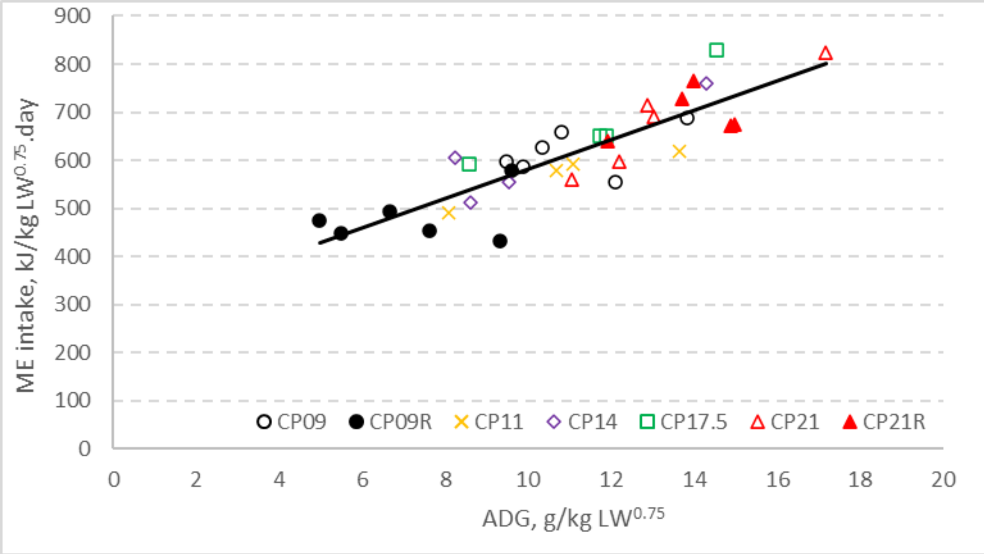


c.

Figure 23. Liveweight (LW) gain of young entire male Rangeland goats in response to increasing crude protein (CP) intake of an energy-based pellet with increasing CP content estimated on a per day (a.), relative to LW (b.) and diet content (c.) basis. Each symbol represents an individual goat with the overall response presented; Treatment abbreviations describe the target CP content (%) without and with rumensin (R).



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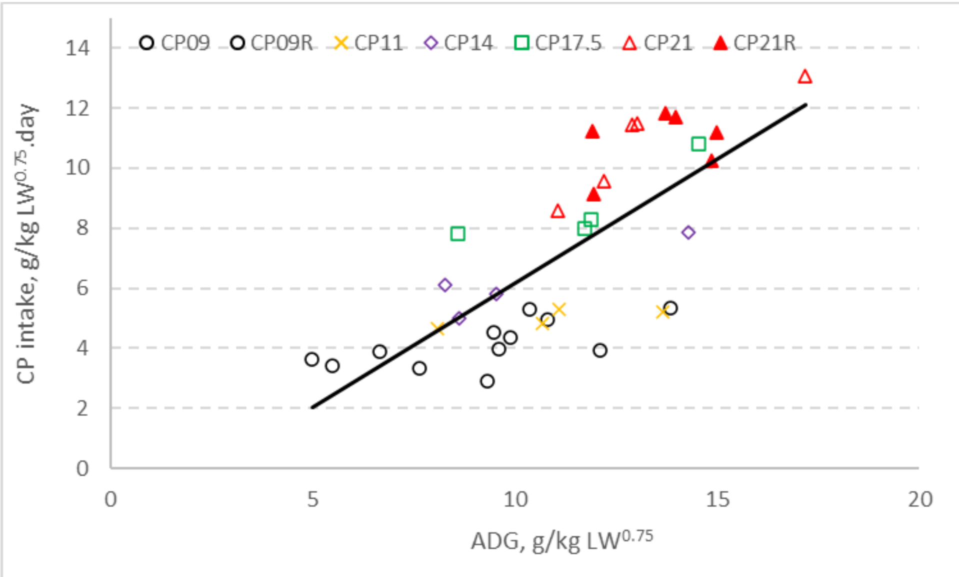


b.

Figure 24. Metabolisable energy (ME; a.) and crude protein (CP; b.) requirements for maintenance and gain of liveweight (LW) relative to metabolic LW (g average daily gain (ADG)/kg $LW^{0.75}$) of young entire male Rangeland goats fed an energy-based pellet with increasing CP content. Each symbol represents an individual goat with the overall response presented; Treatment abbreviations describe the target CP content (%) without and with rumensin (R).

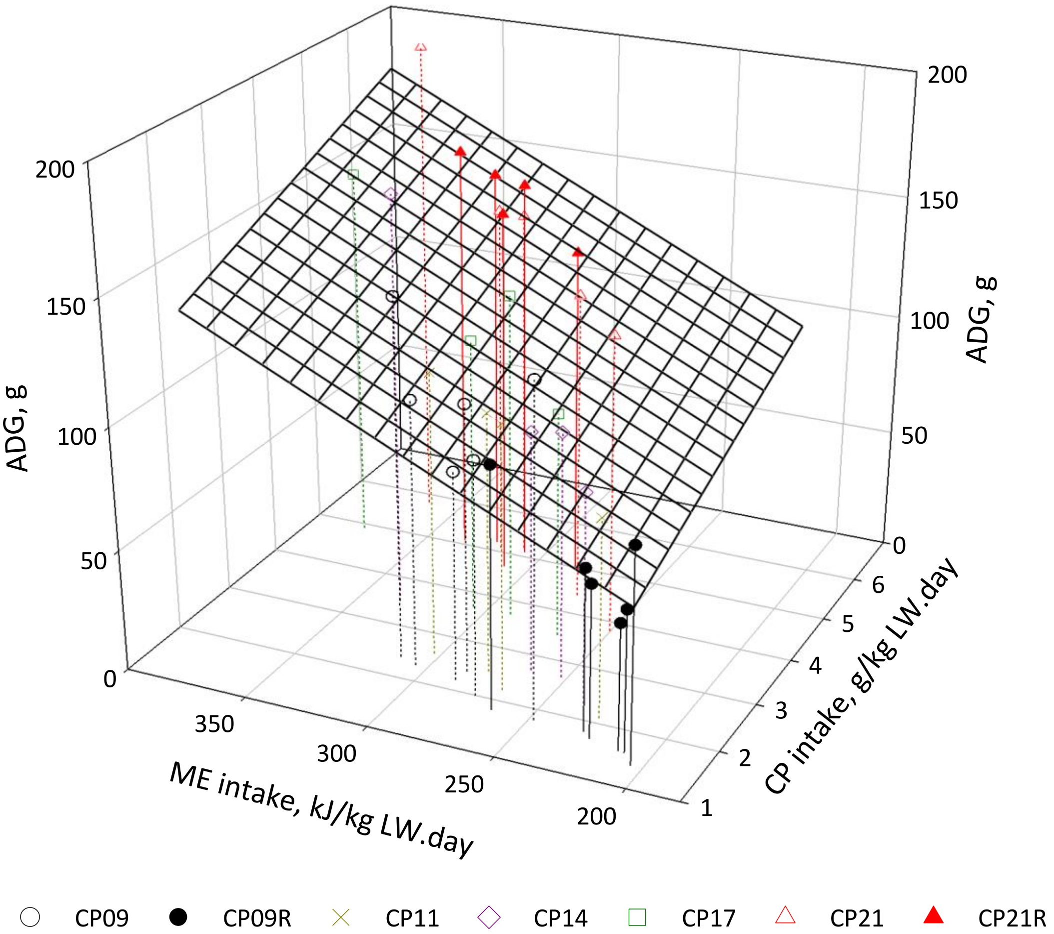


Figure 25. Relationship between crude protein (CP) and metabolizable energy (ME) intake and average daily liveweight (LW) gain (ADG) of young entire male Rangeland goats fed energy-based pellets with increasing CP content without and with rumensin (R) and Mitchell grass hay.

Rumen parameters

The concentration of ammonia-N in the rumen fluid of supplemented goats was above that required for microbial activity in ruminants (50 mg/L) for goats feed all treatments with the exception of the CP11 pellet treatment (Table 9) which was less than 50 mg/L; the reason for this low concentration in these goats is unknown. Rumen pH was within the expected range for ruminants fed these diets, although this needs to be considered within the context of a pre-feeding sample collection. The molar proportion of acetic, propionic and butyric acids was relatively consistent between CP treatment diets; however the proportion of acetic acid was lower and the molar proportion of propionic was higher in the rumen fluid of goats fed these treatments compared to the values reported in the other Experiments reflecting the higher proportion of rapidly fermentable carbohydrate in the current experiment. The inclusion of rumensin in the high CP treatment resulted in a high proportion of propionic acid in the rumen fluid of the goats.

Table 9. The pH, ammonia-N (NH_3N) concentration and molar proportion of acetic, propionic and butyric acids (mean ± standard error of the mean) in the rumen fluid of young entire male Rangeland goats fed energy-based pellets with increasing crude protein (CP) content and Mitchell grass hay[1].

Treatment	Replicates	NH_3N, mg/L	pH	Acetic acid, %	Propionic acid, %	Butyric acid, %
CP09R	6	55 ± 15	6.9 ± 0.2	62 ± 3	26 ± 2	9 ± 1
CP09	6	84 ± 9	6.5 ± 0.3	66 ± 5	22 ± 4	11 ± 1
CP11	4	37 ± 8	6.8 ± 0.1	65 ± 4	25 ± 2	9 ± 2
CP14	4	151 ± 129	6.2 ± 0.4	69 ± 2	19 ± 7	10 ± 4
CP17.5	2	176 ± 35	7.0 ± 0.1	63 ± 5	23 ± 2	10 ± 1
CP21	6	186 ± 63	6.9 ± 0.1	58 ± 1	23 ± 2	13 ± 1
CP21R	5	79 ± 26	6.8 ± 0.1	59 ± 2	31 ± 3	7 ± 1

[1]Full details of treatments are provided in materials and methods section, where goats were allocated to diets containing 9 (CP09), 11 (CP11), 14 (CP14), 17.5 (CP17.5), 21 (CP21) g CP/kg pellet with (R) or without rumensin. Data are mean ± standard error of the mean.

Concentration of metabolites in plasma

The mean concentration of metabolites measured in the plasma of goats in this experiment (Table 10) was within the normal range for goats (MSD Vet manual online, 2021) and other ruminant species fed similar diets (Quigley and Poppi, 2013) and were not significantly affected by pellet intake. The exception to this was the concentration of globulin in plasma which was elevated across all treatments, and was often beyond confidence limits of the assay even after dilution. The reason for this elevated globulin concentration is unknown at this stage.

Table 10. Concentration of metabolites in the plasma of young entire male Rangeland goats fed Mitchell grass with increasing amounts of commercial energy-based pellets[1].

Parameter	Mean ± SEM[2]	Minimum	Maximum
Albumin, g/L	34.3 ± 0.3	31.2	40.2
Aspartate aminotransferase, U/L	102.9 ± 8.7	56.1	278.9
Bicarbonate, mmol/L	25.0 ± 0.4	17.6	30.1
Calcium, mmol/L	2.5 ± 0.0	2.3	2.8
Creatine kinase, U/L	102.8 ± 6.6	53.3	211.8
Creatinine, µmol/L	56.1 ± 1.6	42.7	91.5
Y-glutamyltransferase, U/L	53.7 ± 2.4	24.6	84.4
Glucose, mmol/L	4.4 ± 0.1	3.4	5.2
Inorganic phosphorus, mmol/L	2.2 ± 0.1	0.8	3.5
Magnesium, mmol/L	1.0 ± 0.0	0.9	1.2
Total bilirubin, µmol/L	1.3 ± 0.1	0	2.3
Total protein, g/L	64.7 ± 0.7	55.9	74.8
Triglycerides, mmol/L	0.2 ± 0.0	0.1	0.3
Urea-N, mmol/L	4.2 ± 0.4	1.2	9.1
Globulin, g/L	225 ± 21	6	354
Bile acids, µmol/L	0.1 ± 0.0	0	0.3
Non-esterified fatty acids, mmol/L	0.2 ± 0.0	0.1	0.7
β-hydroxybutyrate, mmol/L	63.1 ± 9.1	3.8	270
Glutamate dehydrogenase, U/L	0.3 ± 0.1	0	3
Sodium, mmol/L	145.2 ± 0.4	140	150
Potassium, mmol/L	4.7 ± 0.1	3.5	5.6
Chloride, mmol/L	110.0 ± 0.4	105	118

[1]Overall mean data for n=35 goats presented; [2]Standard error of the mean.

4.3 Development of the relative-cost of supplement calculator

Equations describing the relationship between LW gain (g/day) and supplement intake (g DM/kg LW.day) (Figure 26) from Experiments 1, 2 and 3a were used to generate the relative-cost of supplement calculator. The calculator allows the producer to input type of supplement, cost of supplement ($/T delivered), start and target LW (kg) of goats and a target LW gain (g/day) within the limits established in the supplement dose response experiments. A range of scenarios can be tested which compare relative supplement costs to achieve a common LW gain (g/day) or to achieve the maximum potential LW gain for each supplement. The output can be visualised numerically (Figure 27) or visually (Figure 28). For example, under a scenario where a producer wants to feed a 15 kg entire male Rangeland goat to 25 kg and the maximum rates of LW gain for each supplement are inputted, the calculator demonstrates that the most expensive supplement option (commercial starch-based pellets) on a $/T and c/goat.day basis is the least expensive option on a $/kg LW gain and $/target LW basis, as a result of the higher LW gain and the shorter feeding period. Under such a scenario, a producer needs to weigh the cost of the supplement itself against the quicker turn-off rate, which will have further implications on other feeding associated costs (labour, fuel, infrastructure), land condition (stocking rates), herd structure and cash flow.

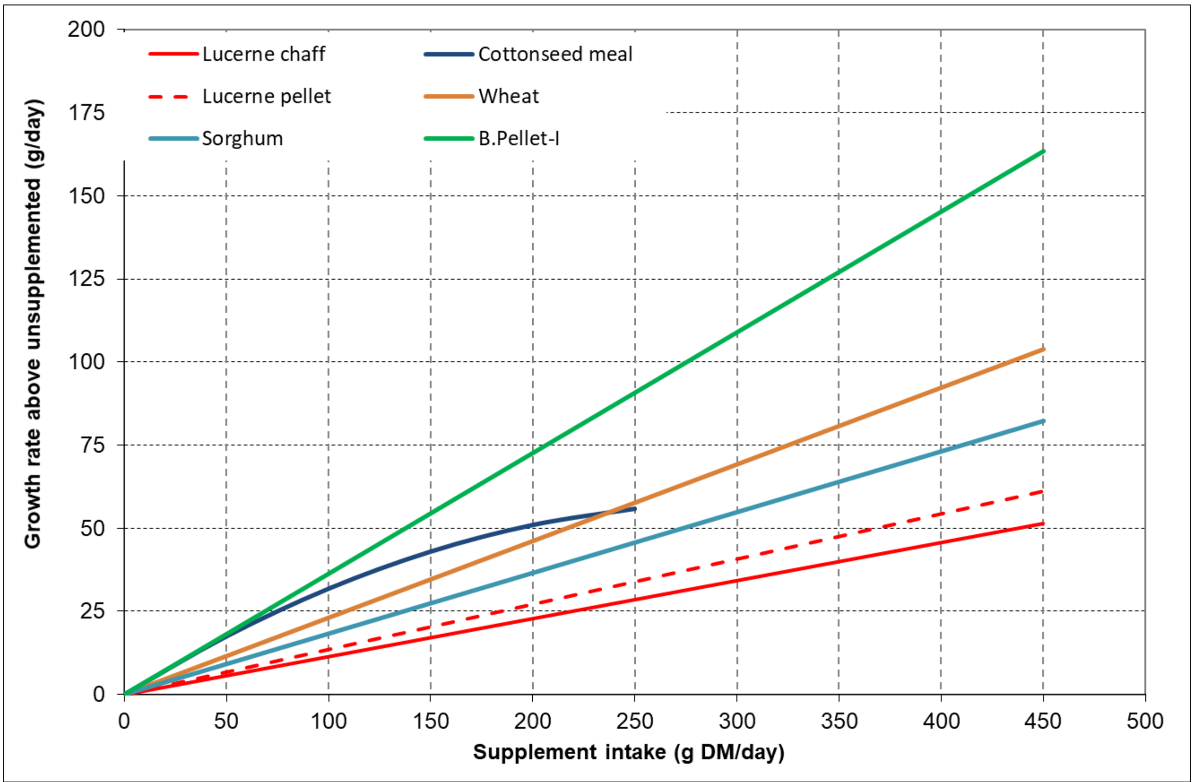


Figure 26. Response of liveweight gain to supplement intake of entire male Rangeland goats fed a range of supplements for which significant relationships existed. Responses are presented for each supplement, even when no significant difference between responses to specific supplements may have existed, to allow for inpu-tting different supplement costs. All responses were presented as response above unsupplemented goats to allow for pooling across experiments. Data presented is for a young entire male Rangeland goat 15 kg LW with a target of 25 kg LW (mean 20 kg LW) with the maximum LW gain response included for each supplement, rather than the same LW gain response across all supplements.

Relative supplement cost - additional growth above unsupplemented goats										
ENTER DATA IN CELLS WITH RED FONT ONLY (DO NOT ENTER DATA IN BLUE SHADED CELLS)										
Supplement	Cost of supplement	DM Content	Goat liveweight start	Goat liveweight target	Additional growth rate required (above unsupplemented)	Maximum additional growth rate (above unsupplemented)	Cost of supplement	Cost of supplement	Number of days required to reach target liveweight	Total supplement cost to reach target liveweight
	($/tonne delivered)	(%)	(kg)	(kg)	(g/day)	(g/day)	(cent/day)	($/kg additional LWG)		($)
Lucerne chaff	550	90	15	25	50	51	27	5.4	200	54
Cottonseed meal	500	90	15	25	55	57	13	2.4	182	24
Lucerne pellet	600	90	15	25	60	67	29	4.9	167	49
Wheat (+ minerals)	450	95	15	25	105	105	22	2.1	95	21
Sorghum (+ minerals)	450	95	15	25	85	85	22	2.6	118	26
B.pellet-I	650	95	15	25	165	165	31	1.9	61	19

Figure 27. Relative-cost of supplement calculator (EXCEL vers. 20211010). The calculator is based on the concept and design developed by McLennan (2004).

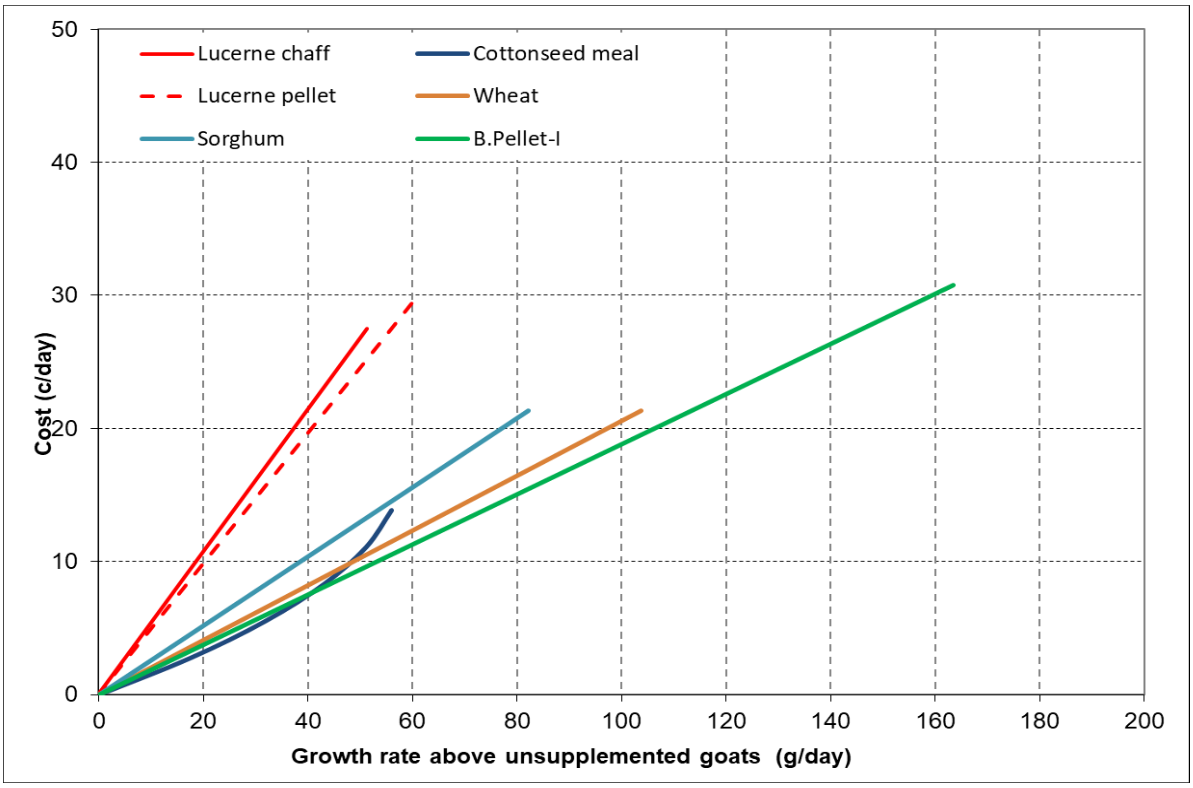


Figure 28. Relative comparison of supplement costs to achieve a given target liveweight gain, or relative liveweight gain at a given supplement cost, for young entire male Rangeland goats fed a range of supplements (as described in Figure 26 caption).

The calculator has been provided to two producers for pilot testing and feedback and is available to others upon request. No feedback has been obtained yet but recommendations will be incorporated into an updated version where possible. It is suggested that the calculator be available to producers via a hyperlink in the final report or on a Tips and Tools published on the MLA website.

4.4 Recommendations for future research

Validation of supplementation under field conditions

The current project generated response relationships between nutrient intake and LWG of young entire male Rangeland goats in individual pens through a supplement dose response approach. Whilst the approach provides a reliable estimation of nutrient requirements under controlled conditions and establishes important principles related to nutrition of Rangeland goats, it has some limitations including the removal of an activity component on energy expenditure and the removal of the ability to selectively graze the basal diet. It is likely that under grazing conditions the magnitude of the responses may differ to those measured in the pens due to increased energy expenditure through grazing activity and a different basal diet (due to preferential grazing of different species in the Rangelands). As such, validation of the supplementation approach is recommended under commercial grazing conditions in the rangelands of south-west QLD. Such a research activity could be established as a Producer Demonstration Site (PDS) and could incorporate a number of research issues.

Given the responses measured in the experiments conducted within this project it is recommended that a high ME moderate CP pellet be used as the supplement for ease of handling and measuring and to minimise wastage and selection within a loose mix. The target class of goat would be young male goats but the methodology would be equally applicable to maiden does to achieve critical mating weights for age/season or for recovery of condition of young does after first kidding.

The challenge with supplementation trials on-farm is the confounding effect of the paddock when different supplementation strategies are to be tested in different paddocks. Recent advances in remote livestock management present several opportunities to eliminate the paddock effect. Therefore, a number of potential methods to establish such an on-farm demonstration are:

1. Two paddock rotation
   Establish two adjacent approximately equal sized paddocks with comparable stocking rates and vegetation, and a common water point. Goats would be divided into two equal groups (supplemented and unsupplemented) on a LW basis. A number of self-feeders would be placed in one paddock and would be attached to the supplemented group of goats. Goats and self-feeders would be rotated between paddocks each month to dilute the paddock effect. Feeders would be filled with supplements as required with the number of bags added recorded each occasion, and unconsumed residues collected each month. Goats could be weighed each month at paddock rotations.

2. Auto-weighing and auto-drafting
   Establish a single paddock with a single water point at a trap yard. The trap yard would need to be split in half, with a single-entry spear and exit spears on exit from each side of the trap yard. One side of the trap yard would have supplements available, and the other would not. Goats would require RFID ear-tags. The goats would enter the trap yard via an entry spear with a RFID ear-tag reader, walk-over-weighing and a draft gate after weighing. RFID readers would be required on exit spears to confirm the accuracy of the draft and provide an indication of time spent in the trap/supplement yards. Feeders would be filled with supplements as required with the number of bags added recorded each occasion, and unconsumed residues collected each month. No manual weighing of goats would be required (unless for validation of auto-weighing data).

   The supplementation demonstration could be conducted two ways,

i. goats would be divided into two equal groups (supplemented and unsupplemented) on a LW basis and be drafted accordingly after weighing, or

ii. a threshold target LW could be set at the drafter and goats could be drafted to the unsupplemented yard if they are above the target LW and to the supplement yard if they are below the target LW. Such an approach has the added benefit that LW is tracked in near real-time and goats are automatically drafted accordingly. This would allow the PDS to simply close the exit spear on the unsupplemented goats once enough goats have reached the target LW for the required number of decks to the abattoir.

3. Smartfeeders

The development of portable smartfeeding technology allows for the provision of different amounts of different types of feeds to individual animals within a mixed mob based on individual RFID ear-tags. The use of such infrastructure at a water point would allow the allocation of individual goats to different types and/or amounts of supplements each day. Goats would be denied access to supplements if they were not allocated to receive a supplement and once they have consumed their daily allocation. Researchers at CQ University, are expected to have access to such equipment from 2022. This infrastructure records intake of supplement by individual goats but weighing of goats at regular intervals would be required.

Confinement feeding of Rangeland goats

Confinement feeding is used in the sheep industry largely for short-term production feeding (lambs to market specification, ewes to achieve critical mating or lambing weights) or to conserve the pasture and land resources (particularly during dry seasons). The additional advantages of confinement feeding include reduced energy expenditure (no grazing), ease of feeding in pens (as opposed to paddock supplementation), ease of monitoring animal weights and neonatal survival and confined space for the introduction of imported feeds (minimising the risk of weed or disease spread) (Andrews and Littler, 2019). Such a system would provide goat producers with the flexibility to manage their production, cash flow and rangelands in response to seasonal conditions or in response to rapid increases in goat numbers that may occur in good seasons, particularly with the adoption of exclusion fencing and the restrictions this places on grazing range of Rangeland goats.

The additional work presented in Appendix 3, whilst not specifically a prerequisite output from the project and not statistically analysed, demonstrates that high growth rates of Rangeland goats are achievable (1 to 1.4 kg/week) under certain conditions and the feed conversion efficiency is comparable to that obtained by lambs (albeit lower intake and lower LWG). These unreplicated findings must be viewed with some caution due to the lack of accuracy in the measures of feed intake. Nevertheless, the findings present an opportunity to further investigate the potential role a confinement feeding system may have on both the production of goat meat, and the sustainability of the rangeland feed-base and native ecosystems. A number of issues arose during the group feeding periods, in addition to the Experiments 1, 2 and 3a and 3b, which could be further explored through additional research which could be conducted on-farm and in pen studies at a research organisation. The research questions could be broadly grouped as follows,

Animal factors

- what stage of the growth path results in the highest feed conversion efficiency and profitability under confinement feeding?

- what are the most efficient genotypes (Boer F1, Rangeland, other crosses) and sexes (castrates, entires) for confinement feeding? What 'genotypes' of Rangeland goats have greater feed conversion efficiency under confinement feeding?
- what is the mature LW of Rangeland bucks?
- What compositional changes in LWG (i.e. lean vs fat) occur during the growth path?

Management factors

- what pre-confinement and early confinement feeding strategies are required to adapt the rumen of Rangeland goats to high starch rations required for high LWG?
- what is the optimum time of year for confinement feeding? Can artificial lighting be used to sustain intake and LWG and prolong the confinement feeding period (during periods of decreasing photoperiod)?
- what automated and/or remote sensor technologies can be deployed to improve goat and feeding management and monitoring in confinement feeding systems?

Environment factors

- what impact does confinement feeding of goats have on the health of the Rangeland ecosystems during both dry periods and recovery periods?
- what impact does confinement feeding have on whole-of-life greenhouse gas inventories of a goat production system?

Economic factors

- what are the price (goat and feed) thresholds for confinement feeding to be economically viable?
- what impact does the incorporation of confinement feeding and finishing into existing goat production systems have on whole-farm economics (taking into account labour, infrastructure)?

Sensitivity analysis of the economics of feeding Rangeland goats

The calculator developed in the current experiment provides a simple tool that allows producers to quickly assess the relative-cost of different supplements to reach a target LW; it is not an economic or budgeting tool. Bowen and Chudleigh (2021) have compared the rate of return of a Rangeland goat meat enterprise with that of other livestock enterprises in central-west QLD while Meat & Livestock Australia have a cost of production calculator (https://tools.mla.com.au/cop/). All of these resources are useful for different purposes, however none of these specifically address the profitability of feeding goats. An economic sensitivity analysis incorporating goat prices and feed costs would determine the thresholds at which feeding goats different feeds is an economically viable option for goat producers. Such information would under-pin the existing MLA cost of production calculator and be informative of how the production gains and rate of return described by Bowen and Chudleigh (2021) could be achieved.

Grazing behaviour of Rangeland goats

The distances travelled by Rangeland goats are largely unknown. This activity will have a large influence on energy expenditure and, hence, energy requirements which will have implications for feed budgeting and supplementation. The selective grazing behaviour of goats is an important characteristic in managing grazing pressure across the Rangelands, and whilst goats are regarded as preferential browsers the preferred browse species in the diet is difficult to define. An understanding of the preferred plant species composition in the diet and how this influences grazing pressure and supplementation requirements also contribute to practical considerations around infrastructure (fencing, water points), likely responses to supplements and the environment (maintaining land cover across different seasons and years). The adoption of exclusion fencing will create restrictions on the grazing range of Rangeland goats, and the impacts of this on grazing behaviour require investigation. The deployment of GPS trackers on a subset of goats would provide information on distances travelled by goats for grazing activities and the grazing pressure on different vegetation and land-types. The use of faecal DNA bar-coding would provide information on the composition of plant species in the diet of goats in response to season (Lee et al. 2018). It is proposed that research on grazing behaviour and plant species selection be undertaken through an on-farm PDS, and this may be integrated with other existing PDS activities (e.g., validation of supplementation).

Nutritional management to increase kid survival and growth rates

Significant research on the nutritional management of does during pregnancy and lactation, and kids from birth to weaning has been previously conducted. The use of ultra-sound scanning to identify non-pregnant does, and to segregate does on litter size would allow for more strategic nutritional management of the breeder flock. Nutritional supplementation of the doe might be relevant in late-pregnancy to increase the quality and quantity of colostrum to kids to increase kid vigour and survival, and after weaning to recover condition prior to the subsequent mating, whilst creep feeding prior to weaning will result in heavier LW at weaning. These principles have been established (Norton, Appendix 2) and as such could be directly implemented within PDS groups for testing under commercial conditions.

Methane emissions and carbon accounting of Rangeland goat enterprises

As Australia moves towards a CN2030 (carbon neutral by 2030) red meat sector it is important that carbon cycles are quantified for different animal species and different production systems. Such information is required both to guide future land and herd/flock management decisions related to carbon neutrality, which are likely to be a function of increased herd/flock efficiency, and to provide accurate and transparent information for carbon accounting systems. These carbon accounting systems are important in realising carbon credits and incomes for producers and increasing transparency in the red meat sectors and aim to achieve carbon neutrality by 2030. There is limited information on methane emissions and the impacts of the unique grazing behaviour of goats compared with other red meat species grazing in the Rangelands. This research may involve both measurement of methane emissions of goats grazing different diets, as well as modelling carbon flows in the Rangelands based on grazing behaviour, stocking rates and productivity (i.e. methane intensity; kg red meat produced/ha or /adult equivalent).

Selection of genotypes for higher growth rates within the Rangeland goat population

Findings from experiments and post-experiment studies in the present project demonstrated high variability in growth response of young entire male Rangeland goats at equivalent supplement (or ME) intakes. Whilst undoubtedly behavioural factors (e.g. bullying, shy/dominant feeders) and, potentially, carry-over factors (e.g. compensatory gain) influenced this variation, it is also plausible that genetic factors may have contributed to this variation. Holst et al. (1982, 1985) reported an approximately 10% increase in LW (birth, weaning and 5 months of age) of male Rangeland goats when selected on LW at 5 months of age, and adjusted for litter size and dam age, with a heritability of 0.35. Within a breed, goats reportedly have greater genetic diversity than within sheep and cattle breeds, with Rangeland goats having higher genetic diversity than Cashmere or Boer goats in Australia (Kijas et al. 2013). The variation in individual LWG measured here, coupled with the high genetic diversity, would suggest that rapid gains in productivity could be made if selection was applied on the basis of increased

LW at a specific age or time of year. The extensive nature of the Rangeland goat production systems makes intensive measurements to inform the selection of superior genotypes within the existing population a challenge. The development of genomic tools (e.g., single nucleotide polymorphism [SNP] chips, high throughput sequencing, high capacity bioinformatic processing) that are increasing in portability and decreasing in cost, may provide the tools to facilitate in-field genomic selection in the future. It is proposed that an analysis of the variation in genotypes and association with production traits (e.g. LW for age or LWG) within the Rangeland goat herd may be incorporated into any PDS work conducted in future.

4.5 Recommended adoption pathways

The key output available for adoption from the current project is the relative-cost of supplement calculator. It is proposed that a larger number of producers pilot-test the existing calculator in its current format. Some modifications on functionality may be required but an easy-to-use interface may also be incorporated. After final validation, it is proposed that the calculator would be available as a tool on the MLA website. Dissemination on the availability of the calculator could be via 'Goats on the Move' (potentially an issue late in 2021) and other goat industry days.

Validation of the biological and economic responses to supplementation under commercial conditions are required, and some suggestions on implementation are provided in Section 4.5 of this report. It is recommended that a number of PDS groups be established which implement supplementation under different management systems, environmental conditions/locations and types of supplements. It is likely that through implementation the PDS groups will identify additional researchable issues and hence research issues.

The other researchable issues identified in Section 4.4 could also be presented to GIRDAC and other producers (at industry forums) to prioritise these (and other research issues). It is likely that GIRDAC already have a process for prioritising research issues, and the above concepts could be included in future prioritisation activities.

5 Discussion

The project generated dose response intake and growth data for young entire male Rangeland goats fed a range of supplements and rations. The results of Experiments 1 to 3 demonstrate that goats fed a low quality Mitchell grass diet alone have low LW gain (Experiment 1) or LW loss (Experiments 2 and 3) (-32 to 7 g LWG/day) and this was consistent with the low intake (16 to 20 g DM/kg LW.day) or the low DMD (45%), low CP (40 g/kg DM) and high ash-free NDF (700 g/kg DM) content of the basal diet. The control diet therefore achieved its purpose of providing a nutritional status that facilitated an approximate maintenance of LW, as was expected from the calculations provided in Appendix 2. This was an important objective in the generation of the supplement dose responses across all experiments.

The LWG of young entire male Rangeland goats was presented in terms of responses to supplement intake, ME intake and NDF intake; additional responses were developed for N intake although these are not presented here for each experiment. The highest LWG was for goats fed the high ME pellet either as a supplement (Experiment 3a) or as the main component of the diet (Experiment 3b) and the wheat supplement (Experiment 2). The lower LWG were in response to what were defined as protein supplements (CSM and lucerne) while supplementation with urea provided very little response above unsupplemented goats. The LWG values for the energy supplements (80 to 120 g/day) and at the higher intakes of the protein supplements (40 g/day) were within the normal range reported in the literature for Rangeland goats (see Appendix 2 and Appendix 3). These values provide some ground-truthing of expected LWG of this class of goat for industry. It would appear that a maximum intake of starch-based concentrates was between 18 to 23 g DM/kg LW.day as, despite higher (24 g DM/kg LW.day or *ad libitum*) availability in Experiments 2 (sorghum, wheat), 3a (commercial starch-based pellet) and 3b (formulated pellets), average consumption over 70-days rarely exceeded these intakes. It is proposed that these may be the upper limits of starch-based concentrate feeding for Rangeland goats under these feeding conditions (i.e. when using a basal diet with a low CP and ME content, on a fixed feeding schedule, and in small individual pens).

The low intake of the WCS by goats in the current experiment was somewhat unexpected and unexplained; it is known that WCS is used as a supplement by some producers although intakes and LWG are not known. The total lipid intake from the consumption of WCS was unlikely to exceed the threshold at which a reduction in total DM intake was likely to occur. Whilst the low and variable intake of WCS may be seen as a self-regulating source of energy and protein, further work would be required to determine the LWG response over a larger number of animals than used in the current project.

The suspected cases of SARA were also unexpected, as on all occasions animals had been fed the starch-based supplement or ration for a number of weeks prior to the event, starch-based supplements or rations were always divided over two to three feeds each day, and roughage was always available. In these instances, it is suspected it was the fixed feeding schedule that resulted in rapid consumption of the starch source that was the problem; it is assumed if SARA was occurring it was related to feeding management rather than the actual feeds *per se*.

Goats sourced for Experiments 1 and 2 were free from internal parasites upon selection and arrival at QASP (< 50 egg per gram [epg]), whilst goats sourced for Experiments 3a and 3b had higher egg counts (350 epg; range 0 to 8000 epg). In all experiments goats were drenched on arrival at QASP and egg counts were conducted throughout the experiment with egg counts remaining below 50 epg during all experiments confirming that internal parasites did not influence the results.

The review of literature undertaken by Norton provides an excellent theoretical basis for developing nutritional recommendations for Rangeland goats in conjunction with the experiments conducted within the current project (including in Appendix 3).

Metabolisable energy for maintenance and gain of liveweight

The relationships between ME intake and LWG (expressed as g ADG/kg $LW^{0.75}$ for ease of comparison across experiments and with other published studies) demonstrate a major difference in the use of ME for maintenance and LWG in the young entire male Rangeland goats used in the current experiments. Within this project the relationship between ME intake and LWG was different in Experiment 1 compared to Experiments 2, 3a and 3b (Figure 29) with little difference between the latter three experiments. The reason for this discrepancy is unknown as similar procedures and formulae were used for all calculations, and the estimated ME content of the diets and the ME intake of the goats was within a comparable range to that in Experiments 2, 3a and 3b. The goats in Experiment 1 were lighter than goats used in the other Experiments, although only marginally so (17.3 [8.5], 19.9 [9.4], 24.9 [11.1] and 18.8 [9.0] kg starting LW [$LW^{0.75}$] for Experiments 1, 2, 3a and 3b respectively), and this should have been corrected by expressing data relative to metabolic liveweight ($LW^{0.75}$). Goats in Experiment 1 had significantly lower LWG than goats in the other Experiments, so this, coupled with the relatively high ME intake, resulted in a low efficiency of use of ME for LWG and hence ME for maintenance as this was estimated by regression.

The ME requirements for maintenance and LWG estimated in these Experiments (1, 2, 3a and 3b) are different to the relationships presented by Luo et al. (2004) (Figure 29, Figure 30) and to the absolute value presented by Alam et al. (1991). Luo et al. (2004) estimated a MEm of 500 kJ/kg $LW^{0.75}$ and a MEg of 18.6 kJ/g ADG for indigenous goats, while Alam estimated a requirement of 440 kJ/kg $LW^{0.75}$ and a MEg of 28 kJ/g ADG for New Zealand feral-crossbred kids less than 14 kg LW and 4 months of age at the commencement of the studies. In Experiments 2, 3a and 3b it was estimated that young entire male Rangeland goats had a MEm of 370 kJ/kg $LW^{0.75}$.day and a MEg of 35 kJ/g average daily gain. The estimates from the NRC (1981) are for 426 kJ/kg $LW^{0.75}$.day (range 365 to 482 kJ/kg $LW^{0.75}$) and from Ash and Norton (1987) are 376 kJ/kg $LW^{0.75}$.day (male and female Australian Cashmere goats 15 to 20 kg LW, 30 to 150 g LWG/day), while Norton (Appendix 2) recommends the use of 400 kJ/kg $LW^{0.75}$ as appropriate for most purposes based on the available literature. The efficiency of use of ME for LWG was lower in the experiments conducted within this project, with a value of 35 kJ/g ADG estimated for Experiments 2, 3a and 3b than that estimated by Ash and Norton (1987) for similar goats (age and genotype, although minimum LWG were much higher in these studies). The reason for the discrepancy between the current experiments and the work of Ash and Norton (1987), Alam et al. (1991) and Luo et al. (2004) are unknown but the results generated in this project for Experiments 2 and 3a were consistent in their estimations and extended over a far greater range of LWG values (~-50 to 170 g/day, -5 to 15 g ADG/kg $LW^{0.75}$) and goats at the lower end of this range (low LWG or LW loss) may have less efficient utilisation of ME for LWG than goats with higher LWG which were usually a function of the quality of the total diet consumed. In Experiment 3b, goats grew over a comparable range of LWG and ME intake to that reported by Ash and Norton (1987), however a difference in the efficiency of use of ME for maintenance and LWG was observed (Ash and Norton [1987], ME intake (kJ/kg $LW^{0.75}$.day) = 24.8 x g ADG/kg $LW^{0.75}$ + 376; Experiment 3b, ME intake (kJ/kg $LW^{0.75}$.day) = 30.6 x g ADG/kg $LW^{0.75}$ + 275). In Experiment 3b, when the ME required for maintenance was adjusted to that determined in Experiment 3a (364 kJ/kg $LW^{0.75}$.day), where negative and low LWG occurred, then the efficiency of use of ME for LWG becomes similar to that determined by Ash and Norton (1987) (i.e. ME intake (kJ/kg $LW^{0.75}$.day) = 23.1 x g ADG/kg $LW^{0.75}$ + 364). In the absence of a value for the ME requirements for maintenance of LW in Experiment 3b (due to higher ME intake and LWG than other experiments) it might be more appropriate to include the ME for maintenance of LW value from Experiment 3a which was conducted under identical conditions, with the same source of goats over the same period of time and same time of year as Experiment 3b. These results demonstrate the importance of an accurate estimate of ME required for maintenance in determining the efficiency of use of ME for LWG using a regression approach and justify the inclusion of lower quality diets and the additional goat replicates included in the extreme points of the dose responses established within the current experiments.

The data generated by Lou et al. (2004) was based on a regression analysis of published data sources for 'indigenous' goats under grazing and penned conditions and the dataset was cleaned to remove outlying data points with high residuals. It is unclear what the genetic composition and diversity of the 'indigenous' goats described by Luo et al. (2004) were, but these were assumed to be more comparable to the Rangeland goats used in the experiments undertaken in the current project, than the dairy or meat (>50% Boer) genotypes also described by Luo et al. (2004). In addition, the relationship derived by Luo et al. (2004) for indigenous goats was linear over a far greater range of LW and LWG than those investigated in the current experiment. It is unlikely that a linear relationship between ME intake and LWG (regardless of the basis of expression) would exist under practical feeding scenarios as at some point the genetic potential of the genotype must be reached at which point the efficiency of use of ME for LWG is likely to diminish resulting in a curvilinear relationship rather than a linear one. The fact that the experiments undertaken within the current project were conducted in individual pens (1 x 1.5 m) and a subsample of goats were unsupplemented and consuming low quality diets may also be a significant source of difference between the relationships generated in the current project and those reported by Luo et al. (2004). The estimates provided by Luo et al. (2004) from regression analysis are themselves higher than values estimated from fasting heat production (FHP) of goats of variable genetic background and physiological state (431 kJ/kg LW$^{0.75}$; Luo et al. 2004). Estimates reported by Alam et al. (1991) were derived from comparative slaughter and chemical composition analysis of the entire carcass of kids fed different amounts of the same diet.

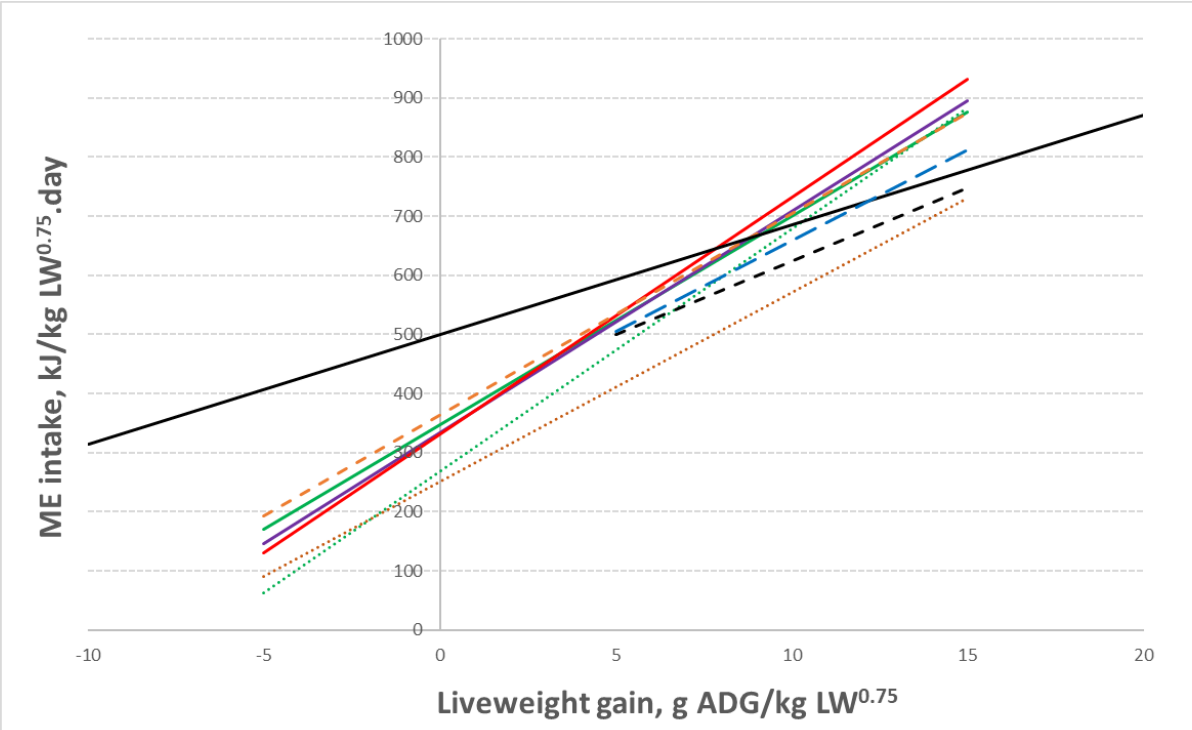
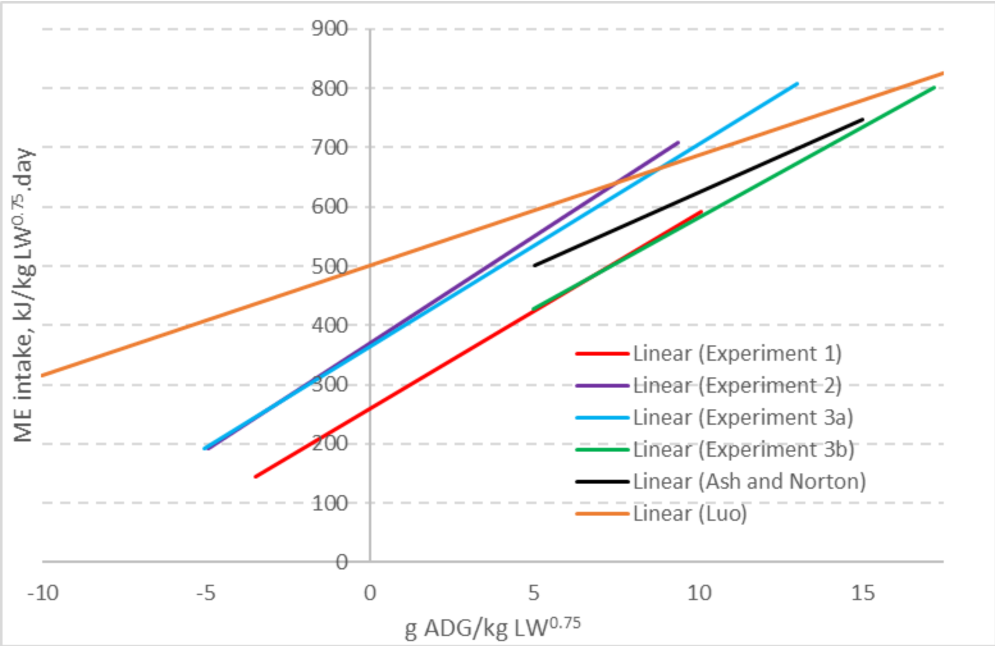
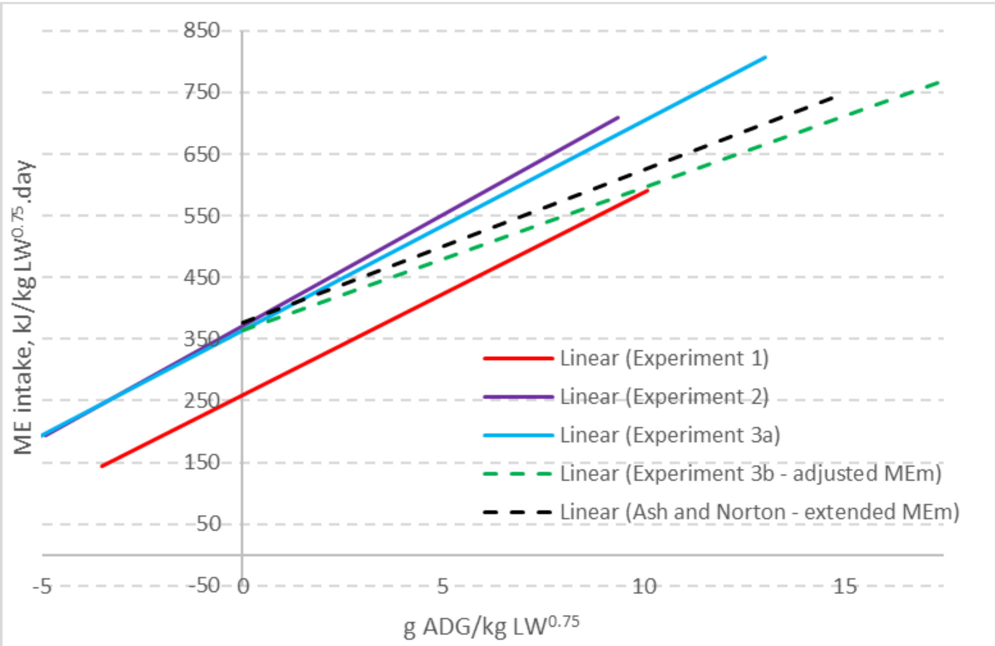


Figure 29. The relationship between metabolizable energy (ME) intake and average daily liveweight (LW) gain (ADG) of young entire male Rangeland goats generated in Experiments 1, 2, 3a and 3b of this report, and compared with the relationship for Indigenous goats (Luo et al. 2004). Each line represents significant LWG response equations generated for the various supplements used in the four experiments (Experiment 1, lucerne chaff [......] and cottonseed meal [......]; Experiment 2, lucerne pellets [___], sorghum [___] and wheat [___]; Experiment 3a, commercial starch-based pellets [_ _ _ _]; Experiment 3b, Formulated pellet [_ _ _]) and published elsewhere (Luo et al. 2004 [___]; Ash and Norton, 1987 [_ _ _ _]). Responses presented are for the measured or published range of values.



a.

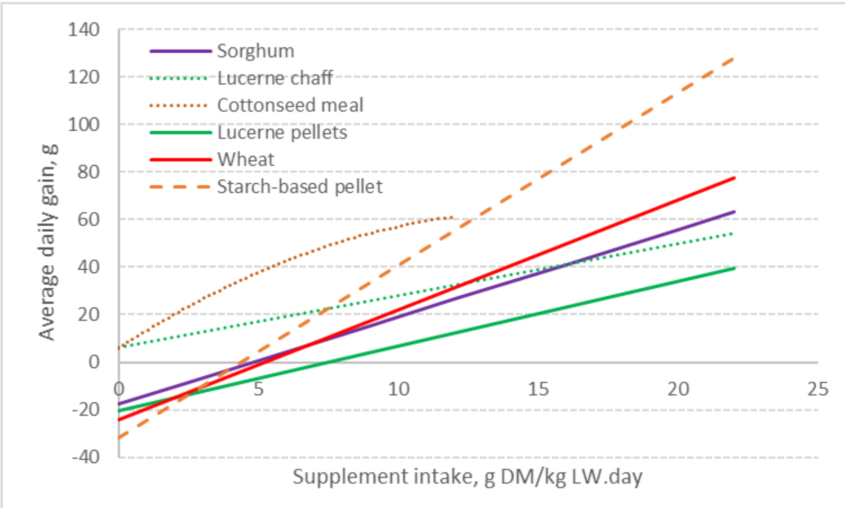


b.

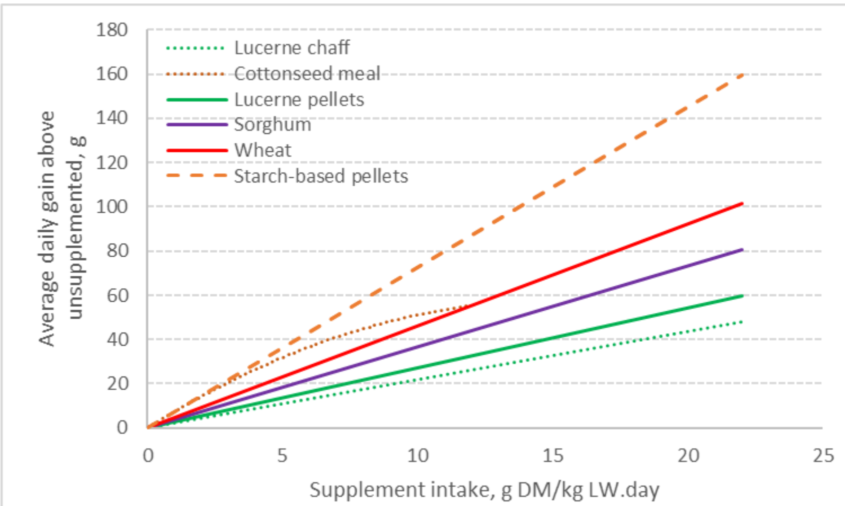
Figure 30. The relationship between metabolizable energy (ME) intake and average daily liveweight (LW) gain (ADG) of young entire male Rangeland goats generated in Experiments 1, 2, 3a and 3b of this report, and compared with the relationship for Indigenous goats (Luo et al. 2004) and Australian Cashmere goats (Ash and Norton, 1987) (a.) with intercepts adjusted for responses from Experiment 3b and Ash and Norton (1987) (b.).

Adjusted response equations

Despite the approximate maintenance of LW of unsupplemented goats there was some variability in the LWG of unsupplemented goats between experiments. To account for this when comparing responses across experiments the response to supplementation above unsupplemented values was used. For this purpose, all response equations were adjusted to a LWG of 0 for unsupplemented goats by removal of the Y-intercept from response equations. This approach was comparable to a co-variate analysis across the pooled dataset and allowed for a direct comparison of supplement responses between experiments (Figure 31). The results demonstrate that supplementation with the commercial starch-based pellet resulted in the highest LWG (above unsupplemented goats) and at lower supplement intakes a higher LWG might be expected in response to a protein meal (in this case cottonseed meal) compared to a legume (lucerne) or energy-based supplement (sorghum and wheat). However, at higher supplement intakes the energy sources generated higher LWG than the protein sources, with higher LWG when wheat was used as a supplement compared to sorghum, presumably due to the higher availability of starch in the wheat. The LWG responses to the lucerne supplements were consistently low regardless of the form of the supplement (pellet or chaff) and the reason for this is unknown at this stage.



a.



b.

Figure 31. Significant relationships between supplement intake and liveweight gain (LWG) of young entire male Rangeland goats expressed as actual responses (a.) or responses above unsupplemented goats (b.).

Relative-cost of supplement calculator

Equations describing the relationship between LW gain (g/day) and supplement intake (g DM/kg LW.day) (Figure 26) were used to generate the relative-cost of supplement calculator. The calculator provides producers with a tool to assist them make better informed decisions on what supplement may be economically viable under their own circumstances based on local availability and costs. The calculator takes into account both the cost of the supplement and the LWG response of goats and, hence, the time taken to reach a target LW. It allows a producer to compare supplements that might appear more expensive on a $/T or c/head.day basis but are less expensive on a $/head to reach target LW basis by virtue of the higher LWG and fewer days required to reach the target LW.

At the inception of the current project goats less than approximately 25 kg LW were of NCV. The calculator was developed to assist producers to make decisions on the relative costs and times required to reach a target LW of 25 kg for different supplements. Within the environment at the inception of the project, the economics of feeding goats were very simple as supplementation would take a goat of NCV (e.g. 15 kg LW) and convert it to a goat with a value of $100 to $120 (e.g. 25 kg LW or 11 kg hot carcass weight [HCWT] @ $9 to $10/kg HCWT). Even with variable costs included, feeding goats appeared a viable proposition (e.g. feed costs of $20 to $30/head to convert a NCV goat to one worth $100). In the current goat market environment, goats above 6.1 kg HCWT are marketable and there is no price differentiation based on HCWT or carcass composition. Nevertheless, the calculator still provides producers with a tool to compare the relative costs of supplements. A decision whether to supplement or not requires a more detailed economic analysis incorporating a sensitivity analysis to determine threshold values for the viability of supplementing goats (based on prices for goats and feeds).

Future research recommendations

High prices for goats and large-scale uptake of dog fencing in central and southwest QLD is driving an expansion in managed goat production systems. The current environment presents an opportunity for producers to implement strategic management practices that might increase the efficiency of their goat production systems. As these managed goat production systems develop, a demand for more information will follow as new challenges arise in the industry. As such research will be required to fill information gaps, and activities will be required that facilitate adoption. It appears that the MLA PDS model is well positioned to address both these issues, although some controlled experimentation is often required to establish principles, as done in the current project.

A range of recommendations were made for future research based on the findings of the current project, the Review of literature (Norton, Appendix 2), other literature and discussions with producers and industry bodies. The recommendations are largely focussed on feeding and nutrition studies but incorporate grazing behaviour, land management, genetics, carbon accounting, economics and the use of remote animal management technologies. Whilst the recommendations are framed in a way that would be applicable to growing goats, all the principles would be relevant to breeders. The application of best-bet breeder management, derived from previous research undertaken in the 1970s and 1980s would still be relevant today to increase kid vigour, kid survival and kid growth through to and after weaning.

6 Conclusions

6.1 Key findings

At low supplement allowances young entire male Rangeland goats are more responsive to a protein meal, however at higher supplement allowances these goats are more responsive to starch-based supplements. High rates of LWG (150 to 200 g/day; 1 to 1.4 week) are achievable for young entire male Rangeland goats with *ad libitum* access to a high ME and high CP concentrate ration, and a source of roughage and water. It appears the maximum concentrate intakes are likely to be approximately 20 g DM/kg LW.day, although higher intakes may occur under group feeding conditions. There is significant phenotypic variation in the Rangeland goat population, and this presents both challenges (in achieving consistent LWG and turning off goats at a consistent HCWT) and opportunities (to select and/or differently manage different genotypes). The relative-cost of supplement calculator demonstrates that the least-cost supplement may not always be the most beneficial in terms of number of days and feed costs to achieve a target LW. These decisions will be based on local availability and prices of feeds, and producers now have a tool that allows them to input local information to make more informed decisions on the relative benefits of various supplements. A number of potential areas for future research were identified throughout the project and these are described. A process of industry engagement would be useful to determine if support exists for any of the concepts identified as researchable issues.

6.2 Benefits to industry

This project has integrated theoretical concepts, historical literature and current feeding experiments to collate a large body of information on the nutritional management of Rangeland goats that will be of value to research, extension and adoption staff working with goat producers. The project also provides some ground-truthing of likely LWG of goats fed various supplements and rations. The project has produced a simple-to-use relative-cost of supplement calculator that will assist producers with decisions related to supplementation of Rangeland goats, by estimating the number of days and the feed cost ($/goat) to reach a target LW.

7 Future research and recommendations

A detailed list of potential research opportunities was presented in Section 4.4. The identified activities for adoption of research findings from the current project and further research opportunities include,

1. *Validation of the supplementation strategies* developed in the current project as a **PDS**. Such a research and demonstration activity would identify further research questions in relation to the practicalities of feeding Rangeland goats and would facilitate adoption of improved nutritional management by industry. A sensitivity analysis of the economics of feeding Rangeland goats, either under supplementation while grazing or in confinement systems could be included as a development activity within the PDS group.

2. Investigate the opportunity for *confinement feeding of Rangeland goats* (and their crosses) to increase production and to provide flexibility to conserve the rangeland feed resources (and ecosystem). Such an activity would build on the preliminary work undertaken in the current project that demonstrated that high LWG is possible and repeatable when Rangeland goats are fed in group pens. A range of research issues were identified that were broadly classified as animal, management, environmental and economic factors. Such an activity would lend itself to both **PDS** and more controlled pen studies. Questions raised in establishing and implementing the **PDS** may dictate many of the research activities to be undertaken within a more controlled environment.

3. Increased understanding of the *grazing behaviour of goats* in the managed systems of the rangelands would provide important information on energy expenditure (grazing distance), grazing distribution and grazing pressure and selection of different plant species. Such a research activity would build on the current project by providing data to better formulate diets for goats based on the composition of their rangeland diet and their energy expenditure. This activity would be suitable to a **PDS** group and would be of great interest to producers.

4. The current project demonstrated highly variable LWG responses of Rangeland goats when fed the same feeds. This variability may be a function of the genetic diversity within the Rangeland goat population and presents an opportunity where *selection for genotypes with higher LWG within the Rangeland goat population* may increase production whilst retain the adaptability and hardiness traits that Rangeland goats have developed to survive in the arid rangeland environments of Australia over the last 200 years. This work could easily be integrated within a **PDS** established under recommendations 1 and 2 above.

5. Whilst not directly related to the current project but relevant to the red meat industry, and its goal of carbon neutrality by 2030, is the requirement for research on *methane emissions and the carbon footprint of Rangeland goats* under managed production systems. Such information is essential to identify methane mitigation strategies, to minimise energy losses, to increase herd efficiency and to develop accurate carbon accounting assessment tools relevant to goat enterprises. This could be a combination of desktop, controlled pen studies and rangeland assessments.

8 Acknowledgements

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The three experiments described here were the result of the tireless efforts of a small team of researchers and students. We acknowledge the assistance of Dr Anne Beasley (co-advisor of Mr Cardial Leo-Penu), Dr Karen Eyre, Mr Cardial Leo-Penu (PhD candidate), Mr Bagus Satiwan, Mr Acep Abdullah, Mr Bonna Zulu, Ms Tia Breed and Dr David Innes across the various experiments. We thank Mr Peter Isherwood and Ms Katherine Raymont for their expert analysis of feed samples and patient supervision of students undertaking sample analysis, Mr Brian Bynon for biochemical analysis of plasma samples and Ms Lyn Knott for faecal egg counts. The experiments could not have been undertaken without access to world class animal research facilities, and we thank Ms Milou Dekkers (Manager) and the team at the Queensland Animal Science Precinct, The University of Queensland, Gatton for providing access to infrastructure for the conduct of this research.

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10 Appendices

10.1 Appendix 1. Response equations generated in experiments

Table 11. Effect of supplement intake (SI[1]) on dry matter (DM), ash-free neutral detergent fibre (NDF) and metabolizable energy (ME) intake, nutrient digestibility and liveweight (LW) gain (LWG) of entire male Rangeland goats fed Mitchell grass hay alone or supplemented with urea or increasing amounts of cottonseed meal (CSM), whole cottonseed (WCS) and lucerne (Luc) chaff (Experiment 1)[2].

Y	Supplement	Equation	R^2	Lin.	Quad.
Mitchell grass intake, g DM/kg LW.day	CSM	$Y = -0.05\ SI^2 + 0.3\ SI + 21.0$	0.50	*	*
	Luc	$Y = -0.41\ SI + 20.7$	0.60	*	n.s.
Total intake, g DM/kg LW.day	CSM	$Y = -0.05\ SI^2 + 1.3\ SI + 21.0$	0.83	*	*
	Luc	$Y = 0.59\ SI + 20.7$	0.76	*	n.s.
NDF intake, % of DM intake	CSM	$Y = -1.52\ SI + 64.3$	0.99	**	n.s.
	Luc	$Y = -0.86\ SI + 63.9$	0.96	**	n.s.
DM digestibility, %	CSM	$Y = 0.26\ SI^2 - 1.3\ SI + 45.3$	0.90	***	***
	Luc	$Y = 0.74\ SI + 44.2$	0.70	**	n.s.
ME intake, kJ/day	CSM	$Y = 13.3\ SI^2 + 108\ SI + 2183$	0.95	***	***
	Luc	$Y = 168\ SI + 2031$	0.80	***	n.s.
ME intake, kJ/kg LW.day	CSM	$Y = 0.95\ SI^2 + 1.3\ SI + 128$	0.95	***	***
	Luc	$Y = 7.48\ SI + 119$	0.80	***	n.s.
LWG, g/day	CSM	$Y = -0.25\ SI^2 + 7.6\ SI + 5.9$	0.68	*	*
	Luc	$Y = 2.18\ SI + 6.0$	0.49	*	n.s.

[1]SI, supplement intake, g DM/kg LW.day

[2]*P*-values are given for the linear (Lin.) and quadratic (Quad.) coefficients in the regression equations; *, $P < 0.05$; **, $P < 0.01$; n.s., non-significant; R^2, adjusted R-square.

Table 12. Effect of supplement intake (SI[1]) on liveweight gain (LWG), dry matter (DM), ash-free neutral detergent fibre (NDF), digestible organic matter (DOM) and metabolizable energy (ME) intake, nutrient digestibility, and energy utilisation of entire male Rangeland goats fed Mitchell grass hay alone or supplemented with increasing amounts of wheat (Wht), sorghum (Sor) and lucerne (Luc) pellets (Experiment 2)[2,3].

Y	Supplement	Equation	R^2	RSE	Lin.	Quad.
LWG, g/day	Wht	Y = -24.0 + 4.6 SI	0.83	15.4	***	n.s.
	Sor, Luc	Y = -17.0 + 3.0 SI	0.60	18.6	***	n.s.
LWG, g/kg MW.day	Wht	Y = -2.59 + 0.46 SI	0.83	15.4	***	n.s.
	Sor, Luc	Y = -1.82 + 0.30 SI	0.60	1.86	***	n.s.
Mitchell grass intake, g DM/kg LW.day	Wht, Sor, Luc	Y = 19.83 - 0.52 SI	0.83	1.60	***	n.s.
Total intake, g DM/kg LW.day	Wht, Sor, Luc	Y = 19.83 + 0.48 SI	0.81	1.60	***	n.s.
Starch intake, g/kg LW.day	Wht	Y = 0.39 + 0.59 SI	0.82	2.04	***	n.s.
	Sor	Y = 0.14 + 0.66 SI	0.94	1.31	***	n.s.
	Luc	Y = 0.17 + 0.01 SI	0.84	0.02	***	n.s.
NDF intake, g/kg LW.day	Wht	Y = 14.2 - 0.23 SI	0.46	1.76	***	n.s.
	Sor	Y = 14.4 - 0.29 SI	0.69	1.50	***	n.s.
DM digestibility, %	Wht	$Y = 83.5 - 40.8 (0.95^{SI})$	0.93	2.30	***	*
	Sor	$Y = 70.3 - 27.5 (0.91^{SI})$	0.86	3.76	***	*
	Luc	$Y = 58.4 - 15.\ 7 (0.93^{SI})$	0.89	1.74	***	*
Starch digestibility, %	Wht	$Y = 99.0 - 33.8 (0.42^{SI})$	0.89	5.33	***	***
	Sor	$Y = 91.1 - 25.9 (0.69^{SI})$	0.76	6.26	***	**
	Luc	Y = 66.7 + 0.7 SI	0.60	4.99	***	n.s.
NDF digestibility, %	Wht	Y = 49.9 - 0.3 SI	0.26	3.51	*	n.s.
	Luc, Sor	Y = 52.6 - 0.5 SI	0.44	3.97	***	n.s.
DOM intake, g/kg LW.day	Wht, Sor, Luc	Y = 9.2 + 0.4 SI	0.84	1.37	***	n.s.
ME content, MJ/kg DM	Wht	$Y = 13.6 - 7.9 (0.94^{SI})$	0.93	0.56	***	*
	Sor	Y = 5.9 + 0.2 SI	0.80	0.79	***	n.s.
	Luc	$Y = 7.2 - 1.6 (0.87^{SI})$	0.74	0.36	***	*
ME intake, kJ/kg MW.day	Wht, Sor, Luc	Y = 371.7 + 35.3 LWG	0.68	72.4	***	n.s.
Energy retention, kJ/kg MW.day	Wht, Sor, Luc	Y = -1018.7 + 3.1 MEI	0.67	277	***	n.s.
K_g	Wht	$Y = 0.58 - 0.33 (0.95^{SI})$	0.93	0.02	***	*
	Sor	Y = 0.26 + 0.01 SI	0.79	0.03	***	n.s.
	Luc	$Y = 0.31 - 0.07 (0.88^{SI})$	0.75	0.01	***	*

[1]SI, supplement intake, g DM/kg LW.day

[2]LW, liveweight; MW, metabolic weight = $LW^{0.75}$; K_g, efficiency of use of metabolizable energy for LWG.

[3]*P*-values are given for the linear (Lin.) and quadratic (Quad.) coefficients in the regression equations; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$, n.s., non-significant; RSE, residual standard error; R^2, adjusted R-square.

Table 13. Effect of supplement intake (SI[1]) on liveweight gain (LWG), dry matter (DM), ash-free neutral detergent fibre (NDF), digestible organic matter (DOM) and metabolizable energy (ME) intake, nutrient digestibility, and energy utilisation of entire male Rangeland goats fed Mitchell grass hay alone or supplemented with increasing amounts of starch-based pellets (Experiment 3a)[2,3].

Y	Equation	R^2	RSE	Lin.	Quad.
LWG, g/day	Y = -30.32 + 7.12 SI	0.83	27.8	***	n.s.
LWG, g/kg MW.day	Y = -2.72 + 0.58 SI	0.85	2.09	***	n.s.
Mitchell grass intake, g DM/kg LW.day	Y = 18.4 - 0.4 SI	0.69	2.30	***	n.s.
Total intake, g DM/kg LW.day	Y = 18.4 + 0.6 SI	0.83	2.32	***	n.s.
DM digestibility, %	Y = 46.8 + 1.0 SI	0.89	2.97	***	n.s.
NDF digestibility, %	Y = 57.2 - 0.4 SI	0.20	6.28	*	n.s.
Starch digestibility, %	Y = 99.7 – 17.8 (0.64^{SI})	0.95	1.74	***	***
DOM intake, g DM/kg LW.day	Y = 8.6 + 0.5 SI	0.73	6.51	***	n.s.
ME, MJ/kg DM	Y = 6.44 + 0.17 SI	0.88	0.53	***	n.s.
ME intake, kJ/kg MW.day	Y = 371.7 + 35.2 LWG	0.89	64.4	***	n.s.
Energy retention, kJ/kg MW.day	Y = -1515.22 + 4.88 MEI	0.78	572	***	n.s.
K_g	Y = 0.28 + 0.01 SI	0.88	0.02	***	n.s.

[1]SI, supplement intake, g DM/kg LW.day

[2]LW, liveweight; MW, metabolic weight = $LW^{0.75}$; K_g, efficiency of use of metabolizable energy for LWG.

[3]*P*-values are given for the linear (Lin.) and quadratic (Quad.) coefficients in the regression equations; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$, n.s., non-significant; RSE, residual standard error; R^2, adjusted R-square.

10.2 Appendix 2. Review of literature

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Introduction

Goats together with sheep, cattle and many other foreign animals were introduced to the Australian landscape shortly after colonisation in the early nineteenth century. The goats that escaped from domestication formed small herds mostly in the more arid areas of New South Wales and Queensland and to a lesser extent in the other States. Their value as a source of commercially valuable meat and fibre has only been recognised since the early 1980's, when significant research was begun on their economic potential (Restall et al. 1982, McGregor 1982, Norton and Ash 1985). By 2010, Australia had become the largest exporter of goat products in the world, with 1.6 million goats being slaughtered for export that year (Pople and Froese, 2012). Recent surveys conducted by Meat and Livestock Australia (MLA) have shownthat since then, there has been a further rise in the number of goats slaughtered and in goat carcasses exported (MLA Industry Insights, 2018). A survey in 2016 estimated that there were 5.8 million goats in central and western New South Wales (MLA, 2017), this number fell to 3.5 million in 2017 (NSW Department of Primary Industries, 2018). The total value of Australian goat exports in 2017 was estimated at $257.19 million from the slaughter of 2.071 million goats. The majority of Rangeland goats are found in western New South Wales and south-western Queensland, their survival in these arid areas being secured behind the dingo fence which runs from the Darling Downs in Queensland to the Eyre Peninsula in South Australia. The majority of goats slaughtered come from Rangeland harvesting, with less than 10% coming from domesticated herds. It has been estimated that the above harvest rates of goats (30 to 40%) are sustainable in these environments despite the highly variable annual rainfall and pasture conditions.

A survey of the domesticated goat meat industries in New South Wales and Queensland in 2013 found that almost all goat producers in the pastoral zones (less than 500 mm rainfall) were involved in "opportunistic harvesting" whilst those in the higher rainfall zones (only 3% of all goats and small property sizes) were designated as "seedstock" producers, usually breeding Boer goats and their crossbreds (Nogueira et al. 2016a). The issues limiting productivity in the pastoral zoneswere low pregnancy and kidding rates, early age at first mating (6 months), high mortality rates, low liveweight gain and the performance of Boer bucks when compared with those in the higher rainfall zones (Nogueira et al. 2016b). This profile is likely associated with a lack of closer management on these large land holdings where goats are simply harvested for culling each year. Those of marketable weight (more than 30 kg liveweight [LW]) are drafted off, herd numbers and composition recorded and then returned to the paddock until next year's muster. The distance of many of these enterprises to abattoirs and markets makes the cost of transport expensive, lowering profit margins, thereby providing little incentive to improve goat productivity in these areas. Few producers in the pastoral zones provide supplements for goats,while those in higher rainfall areas favour supplementation at strategic points of the production cycle (Nogueira at al. 2016b). It was also noted in the NSW DPI General Position Paper (NSW DPI, 2018) that while New South Wales had the largest population of Rangeland goats, Victoria was the largest exporter of goat carcasses, mostly coming from New South Wales. This has prompted the New South Wales government to propose building an abattoir in Bourke by 2019 to slaughter local goats which are currently processed in Victoria, South Australia and Queensland. This development should lower the cost of transport and perhaps encourage goat producers in those areas to consider a more intensive management system (pasture improvement, selective breeding and supplements).

Although there appears to already be a significant body of published research on the nutrition, reproduction and carcass quality of Australian goats, recent reviews have suggested that therestill remains doubt and confusion about the effects of environment (cold, heat, photoperiod), genotype (dairy, fibre or meat) and nutrition (quality, quantity) on the productivity of Australian Rangeland goats (McGregor 1998, McGregor 2005, Jolly 2013). While these excellent and comprehensive reviews have searched the global literature for answers to the above questions, they have generally recommended that more research is needed to justify the application of this global knowledge to the energy, protein and dietary fibre requirements of Australian Rangeland goats. This cautious approach is justified given that add on costs of climate (temperature, wind, rain), possible effects of photoperiod, genotype differences and theenergy costs of grazing sparse pastures are usually quantified by applying some arbitrary "activity" factor to the basal energy requirements for maintenance. This practice often inflates estimates of energy requirements by up to 50% of basal requirements. A more rigorous approach is needed for these estimates of requirements to provide a reliable and realistic guideto the feeding of Rangeland goats in the Australian environment.

The current MLA funded project (B.GOA.127) aims to provide accurate information on the protein and energy requirements of young Rangeland goats by firstly critically reviewing the current recommendations for post-weaning growth in goats, and to decide what information is directly relevant to Australian Rangeland goats. These recommendations will then be tested by feeding a range of supplements (protein and energy) to young (male 15 to 20 kg LW) and older (males 30 to 35 kg LW) goats to generate responses to varying levels of intake (on a % LW basis). This information will then be used to construct an easy-to-use excel-based calculator available for download by goat producers and advisors to assist them make decisions regarding the relative returnon cost of a range of different supplements that might be fed to Rangeland goats to increase LWG. It is expected that the recommendations generated will be tested on properties where improvements in LW and turn-off rates are desired.

The first project activity is to review existing published and unpublished information on the nutrient requirements of goats with an emphasis on all classes of Rangeland goats or similar genotypes. The review will specifically focus on the following topics:

- Protein and energy requirements of Rangeland goats
- Dietary fibre requirements of Rangeland goats
- Information on supplementary and lot-feeding of Rangeland goats
- There is also a need to review additional factors which might affect these requirements and hence productivity of Rangeland goats, factors such as climate (temperature, rain, wind), cost of grazing (walking, eating), effects of photoperiod and genotype of goat.

Energy and protein requirements of goats

There is now an extensive global literature on the nutrient requirements of goats. This literature continues to be updated as more research is done. The latest nutrient requirements for goats have been published from the United Kingdom (AFRC, 1998; Sutton and Alderman, 2000), France (INRA, 2007), India (ICAR, 1998; Mandal et al. 2005), North America (Sahlu et al. 2004; NRC 2007), South America (Brazil; Fernandes et al. 2007) and Australia (NRDR, 2007) While it is not intended to review all these publications, it is important to distil from this literature the most salient facts that might relate to current recommendations for the nutrient requirements of Australian Rangeland goats. It was disappointing to find that the team who developed recommendations for Australian cattle and sheep (NRDR, 2007) could only find four references to goat nutrition despite the extensive published work that had been reported from Queensland, New South Wales and Victoria on the nutrition and feeding of Australian goats. One redeeming feature of this publication was a model which recognised a detailed partition of nutrients, particularly energy, of ruminants which will be presented later in this review.

The requirements for energy

The metabolisable energy (ME) requirements of ruminants has been defined by NRDR (2007) as follows:

$$MEI = NE_m/k_m + NE_g/k_g + NE_c/k_c + NE_l/k_l \qquad \textit{Equation 1}$$

where,

- MEI = metabolisable energy (ME) intake = (feed – (faecal + urine + methane) energy),
- NE_m = net energy for maintenance (fasting heat production, FHP),
- k_m = efficiencyof ME use for maintenance,
- NE_g = net energy stored in growth,
- k_g = efficiency with which ME is used for LW change (LWC),
- NE_c = net energy stored in the conceptus,
- k_c = efficiency with which ME is used for conceptus growth,
- NE_l = net energy stored as milk during lactation, and
- k_l = efficiency with which ME is stored as milk.

Since each of the above productive functions uses absorbed energy with different efficiencies, for growing, non-pregnant and non- lactating goats, the following equation describes their energy requirements for maintenance and growth:

$$MEI = NE_m/k_m + NE_g/k_g \qquad \textit{Equation 2}$$

When MEI is plotted against NEg (energy stored in growth), the resultant formula may be written:

$$MEI\ (MJ/day) = ME_m + NE_g/k_g \qquad \textit{Equation 3}$$

where,

- ME_m (NE_m/k_m) is a prediction of ME requirement (MJ/day)
  (i.e., where $NE_g = 0$),
- NE_g is energy stored in LWG (as protein and fat), and
- $1/k_g$ = regression co-efficient, and k_g = efficiency of ME use for LWC.

Throughout this review, LW (kg) raised to the power 0.75 will be used for comparisons of goats of different ages, LW and biotypes (breeds). Figure 32 provides a means of converting LWG expressed as g/kg $LW^{0.75}$.day to g/day if so desired.

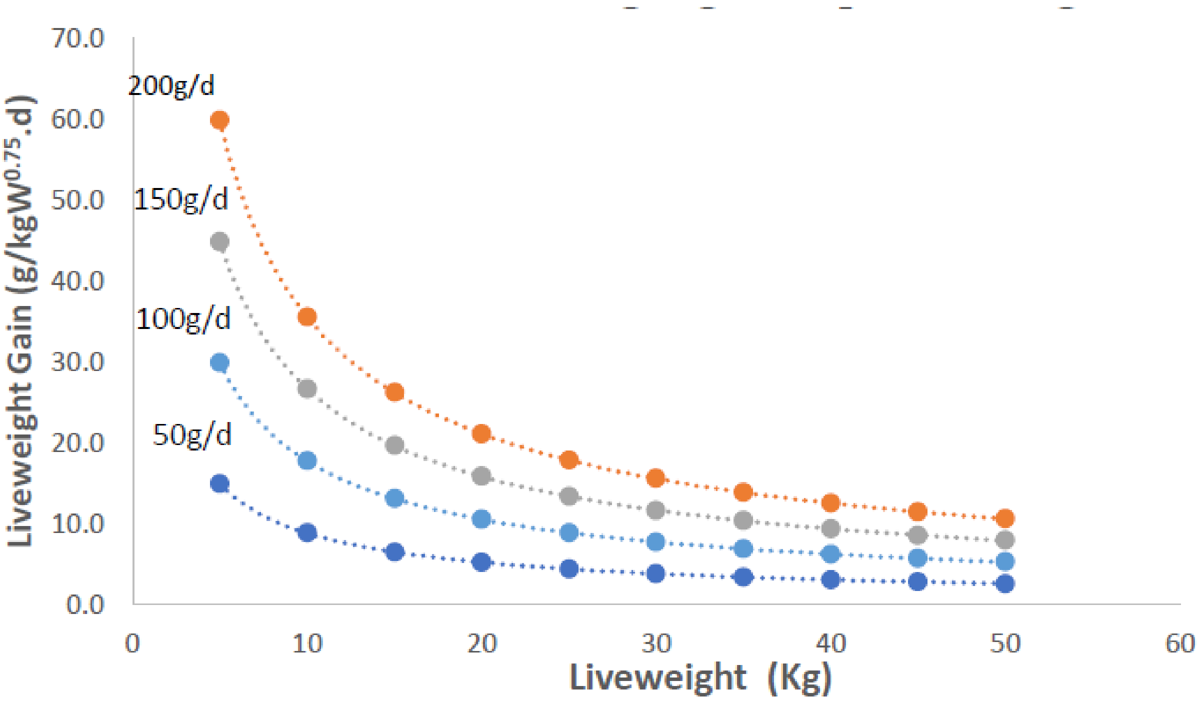

Figure 32. The relationship between the liveweight of goats and their liveweight gain (g/kg $W^{0.75}$.day) for different rates of liveweight gain (g/day).

The literature abounds with estimates and definitions of the maintenance requirements of goats. Maintenance has been variably described as the feed energy required to maintain body energy content (ME_m) or LW (ME_{mw}). The maintenance of body energy has been determined by calorimetric studies and defined as the feed energy required to replace the FHP. Slaughter analysis techniques measure body energy change (NE_g) with increasing ME intake. Plots of NE_g against MEI allows the prediction by regression of MEI where NE_g equals zero (Ash and Norton, 1987b). Similarly, a plot of LWC against MEI regressed to where LWC equals zero provides an estimate of the MEI required for LW maintenance (ME_{mw}). However, it should be noted that the energy intake (EI) for LW maintenance may not be the same as for energy maintenance. Animals may be gaining or losing fat or protein while maintaining LW, that is, storing energy while maintaining LW. In this case, the EI required for LW maintenance is usually greater than that found for energy balance.

The conditions under which maintenance requirements are measured will also have an effect on the MEI required. Studies conducted in indoor pens in thermo-neutral environments will yield lower maintenance requirements that those measured in grazing or group fed animals exposed to varying activities and climatic conditions. The extrapolation of the relationship between LW change and MEI in growing animals to zero LW change will also incur significant error in the prediction of the MEI required for LW maintenance. It has also been found that ME_m varies with age, sex, feeding level and genotype making generalisations about maintenance energy requirements without reference to the above variables spurious. It is also clear that there is variability associated with estimates of ME_m and ME_{mw}, and with values forthe energy content of the LWC. In many cases, the various estimates of these parameters may not be different if confidence limits are attached to each value.

This review of the literature found that there were three techniques used to establish the energy requirements for goats. Calorimetry was used by Holmes et al. (1981) to establish the energy requirement for body energy balance (NE_g = 0) and for LW maintenance (LWC = 0). In this case, they found for mature NZ Feral goats, body energy maintenance (ME_m) closely approximated LW maintenance (ME_{mw}). The comparative slaughter technique (SLT) was used to estimate both ME_m and $ME_{mw,}$ and the efficiency of ME use for net energy retention (kg) and the energy content of the LWG (Jagusch et al. 1983, Alam et al. 1983 and 1991, Ash and Norton 1987b, Pralomkarn et al. 1995, Fernandes et al. 2007). The other experiments cited used a meta-data approach, collecting together data from a large number of feeding trials with goats of different genotypes, and using regression analysisto predict ME_{mw} where LWG equals zero, the slope of these regressions predicting the ME content of the LWG (Norton and Banda 1992, Luo et al. 2004, Sahlu et al. 2004, Mandal et al. 2005). The variability in these estimates is partly a function of the techniqueused, but mainly associated with differences in age, sex, genotype and experimental environment (diet, cold and activity). The AFRC (1998) found that the mean and average standard error associated estimates of basal metabolic rate (BMR) in goats was 315 $\pm$ 21.4 kJ/kg $LW^{0.75}$.day (n=9) and for the maintenance of LW was 438 $\pm$ 10.9 kJ ME/ kg $LW^{0.75}$.day (n= 17). However, AFRC (1998) values for ME_{mw} ranged from 365 to 530 kJ ME/ kg $LW^{0.75}$.day, a range seen also in the data presented in Table 14. The following sections explore and seek to explain this variability with a view to establishing a logical estimate of the dietary ME required for maintenance and growth of Australian Rangeland goats.

Table 14. Data selected from the literature showing estimates of the metabolisable energy (ME) requirements of growing goats for maintenance of body energy and liveweight, and for the efficiencies of energy used for these processes in Australian Rangeland and other indigenous goats and crossbred goats.

Biotype/Breed	Liveweight range kg	Ave. age	Diet	Sex and parity	Maintenance kJ/kg LW $^{0.75}$.day		Efficiency of ME use kJ/gain		References
					ME_m	ME_{mw}	Energy gain kJ	Liveweight gain MJ/kg	
Pre-weaning goats									
Australian Feral	2 - 14	7 wks	Cow Milk	M, F ,S, T		440		13.10	Norton & Banda (1992) (Pens)
Saanen (SA)	3 - 8	1.5 wks	Goat milk	M	458/392[&]	483	0.45	11.68	Jagusch et al. (1983) (Pens)
Granadina (Spain)	3 - 8	2 wks	Goat milk	Not Stated	444	362	0.73	16.12	Sampelayo et al. (1988)
Granadina (Spain)	3 - 4	2 wks	Milk Replacer	Not Stated	413	362	0.58	17.91	Sampelayo et al. (1988)
Meat, IN[$]	3 - 22	11 wks	Unknown	M, F, S, T		485		13.37	Luo et al. (2004)
Growing meat and indigenous goats									
NZ Feral (NZF)	15 - 26	2 - 6 yrs	Lucerne	C	391	389	-	-	Holmes & Moore. (1981) (Pens)
Granadina (Spain)	26 - 33	2 - 3 yrs	Mixed diet	C	443				Prieto et al. (1990)
NZFxSA	13 - 21	4 mths	Hay	C	312	393	-	-	Alam et al. (1983) (Pens)
Australian Feral	18 - 21	4 mths	Concentrate	M, F, S	272	376	0.32	24.8	Ash and Norton (1987b) (Pens)
NZFxAN, NZFxAG	12 - 18	4 mths	Hay	C	440		0.28		Alam et al. (1991) (Pens)
ThaiNative x AN	14 - 24	3 mths	Concentrate	M	-	376	-	25.9	Pralomkarm et al. (1995) (Pens)
¾ Boer x SA[#]	21 - 35	6 mths	Concentrate	M		357		28.1	Fernandes et al. (2007)
All Indian Breeds	5 - 24	2 mths	Various	M, F, S, T	-	455	-	24.3	Mandal et al. (2005)
Meat, IN	6 - 52	6 mths	Various	M, F, S, T		489		19.8 - 23.1	Sahlu et al. (2004)
Mature Meat, IN	43 - 56	2 yrs	Various	M, F, S, T		423		28.5	Sahlu et al. (2004)
International recommendations for growing goats									
UK goats	Mostly Dairy	6 mths	M/D = 11	M, F, S, T	438		0.70	23.9	AFRC (1998)
French goats	Dairy	6 mths	M/D = 11	M, F, S, T	434			26.3	INRA (1988)
USA goats	Meat, IN	1.5 yrs		M, F, S, T		489*		23.1	NRC (2007)
USA goats	Meat, IN	1.5 yrs		M, F, S, T		462		28.5	NRC (2007)

From - # Brazil, South America; $ North America. & Different methods of calculation. M = Male, F = Female, S = Single, T = Twin, C = male castrates, IN = indigenous; ME_{me} = metabolisable energy for maintenance of body energy, ME_{mw} = metabolisable energy for maintenance of liveweight, *Average of Males 527, Females and Castrates 452.

Requirements for energy balance (ME_m) and liveweight maintenance (ME_{mw})

Some clarification is needed when presenting the maintenance requirements for goats. The maintenance of body energy content does not necessarily imply the maintenance of LW. The maintenance of body energy content can only be determined by either calorimetry (where heat production equals ME intake) or by slaughter analysis techniques (measured change in body energy content (fat and protein) with increasing ME intakes above that required for maintenance. In most cases, the ME requirement for energy balance is less than that for LW maintenance, and where this was found, LW (and sometimes energy) maintenance was associated with a gain in fat, and a loss of protein (and water). Differences between these estimates may also be associated with the range of data used, as in some cases goats were fed to just maintain LW, while in other cases, data from growing goats was projected by regression back to zero LWG or energy gain to obtain estimates of maintenance requirements. This latter predictive technique significantly increases the error of the estimate.

Effects of body weight, age and sex on maintenance requirements

Basal metabolic rate (BMR) or FHP measures the loss of energy required for the maintenance of gut wall and liver function, skin, kidneys, nervous tissue and basic muscle activity. It follows that variation in the level of activity of these tissuesdue to genotype, age, physiological state, level of feeding and environmental conditions will modify BMR and hence the maintenance energy requirement of the animal (NRDR 2007). The BMR in sheep has been shown to decline with age at about 8% per year and is moderated by the previous level of feeding and LWC (Graham et al. 1974). This decline continues until about 6 years of age (0.84 of initial BMR) when mature LW is reached. Liveweightincreases in an exponential manner with age, and it is now commonly accepted that the appropriate scalar factor for comparison of animals of different LW is LW raised to the power 0.75 (kg $LW^{0.75}$). It has also been estimated by Graham (1967) that the BMR of males is approximately 19% higher in rams (268 kJ/kg $LW^{0.75}$.day) than in ewes and wethers (226 kJ/kg $LW^{0.75}$.day), indicating that scaling for LW did not eliminate an age difference. A figure of 15% has been used by NRDR (2007) when predicting requirements for sheep and cattle in Australia. While AFRC (1998) do not appear to make any additional allowances for goat gender, NRC (2007), using the data of Sahlu et al. (2004), have also recommended a 15% difference between males and females/castrates but applied factors of 0.927 and 1.075 to average standard ME_{mw} requirements for pre-weaning and growing female and castrates/males respectively. Graham (1967) found that at all ages, males had a 20% higher BMR than females and castrates but accepted 15% as the appropriate correction factor. However, Norton and Banda (1992) could find no differences in ME_{mw} between male and female Rangeland kids offered a reconstituted cow's milk diet up to 14 weeks of age. It seems likely that gender differences in requirements will only arise after weaning and be associated with the onset of sexual maturity in males.

The ME intake required for maintenance is calculated as BMR/k_m, where k_m is the efficiency of dietary ME energy use for maintenance. However, k_m has also been shown to vary with dietquality, and NRDR (2007) recommended the following equation:

$$k_m = 0.02M/D + 0.5 \qquad \textit{Equation 4}$$

where the k_m value for suckling kids was estimated at 0.85

Table 15. Variations in k_m with changes in dry matter digestibility and M/D of the diet.

Measure	Feeds and Forages				Milk
DMD, %	50	60	70	80	95
M/D, MJ/kg DM	6.89	8.61	10.33	12.05	17
k_m	0.64	0.67	0.71	0.74	0.85

Given that BMR and hence the ME requirements for maintenance varies with age, LW,sex and prior feeding and LWC, it is not surprising that the values shown in Table 14 vary considerably. However, it is recognised that the maintenance requirements of pre-weaninggoats decrease to post-weaning, and as the animal proceeds to maturity. There is perhaps a need to recognise these trends when proposing a model which adequately describes how all the above factors interact to determine the ME requirement for maintenance of the goat. The NRDR (2007) have proposed such a model based largely on data from cattle and sheep. The following formula may be used to calculate MEI when animal performance is to be predicted.

$$ME_m \text{ (MJ/day)} = K.S.M.(0.28LW^{0.75} \exp(-0.03A)/k_m) \qquad \textit{Equation 5}$$

where,

- K = 1.0 for sheep and goats, or 1.2 for *B. indicus*, or 1.4 for *B. Taurus*, or intermediate values for crosses between these cattle types,
- S = 1.0 for females, castrates and males before puberty, 1.15 for mature entire males,
- M = 1 + (0.23 x proportion of DE from milk) for suckling goats, equals 1 for weaned goats. Where the proportion of milk in the diet is not known, M = 1 + (0.26 – Ba), with B = 0.015 for suckled kid goats and a is week of life. The minimum value of M is 1.0,
- LW = liveweight (kg), excluding conceptus and fleece (hair, mohair, cashmere),
- A = age in years, with a maximum value of 6.0, when exp (–0.03A) = 0.84, and
- k_m = net efficiency of ME use for maintenance (km = 0.02M/D+ 0.5), 0.85 suckling goats, when M/D = ME (MJ)/kg DM in feed where ME = Gross Energy (GE) feed*GE Digestibility (GED) (as proportion of GE)*0.81 (proportion of GED available for tissue use).

This formula from NRDR (2007) recognises that BMR and hence ME_m declines with age at a rate of 3% per year, that milk fed kids have a high efficiency of energy use (k_m = 0.85), that males have higher requirements post-puberty and that feed quality affects the amount of energy required for maintenance. It is perhaps relevant to predict the requirements for goats of different ages and LW given, say, a standard diet (M/D = 10 MJ/kg DM).

In *Equation 5* above, the constant K is varied according to the species and body type. The values of K shown in Figure 33 below are 1.0 for sheep (female and castrate), and tested value K = 1.1 for both females and castrates and for males (1.075 female value). This latter test assumed that perhaps goats are more like cattle than sheep. The scatter of values from the literature fits only loosely to the NRDR model, partly due to the method of data collection andanalysis. The few values that fit the “sheep” model were mostly determined by slaughter analysis in pens. The values that fit the “goat” model, that is, K = 1.1, were mainly derived from prediction of growing goats of varying ages, sexes and breeds, and the “maintenance” requirement here probably includes varying levels of activity. With this analysis in mind, no definitive or reasonable recommendation can be made about the maintenance energy requirements of Australian Rangeland goats. The average value for all the estimates of ME required for LW maintenance in Table 14 was 423 kJ ME/kg $LW^{0.75}$.day, which given the variability, is little different to the value of 405 kJ ME/kg $LW^{0.75}$.day assumed by McGregor (2005) in his review of drought feeding of goats. It will be assumed that this latter value is the best estimate to date and should be used until a better value is found.

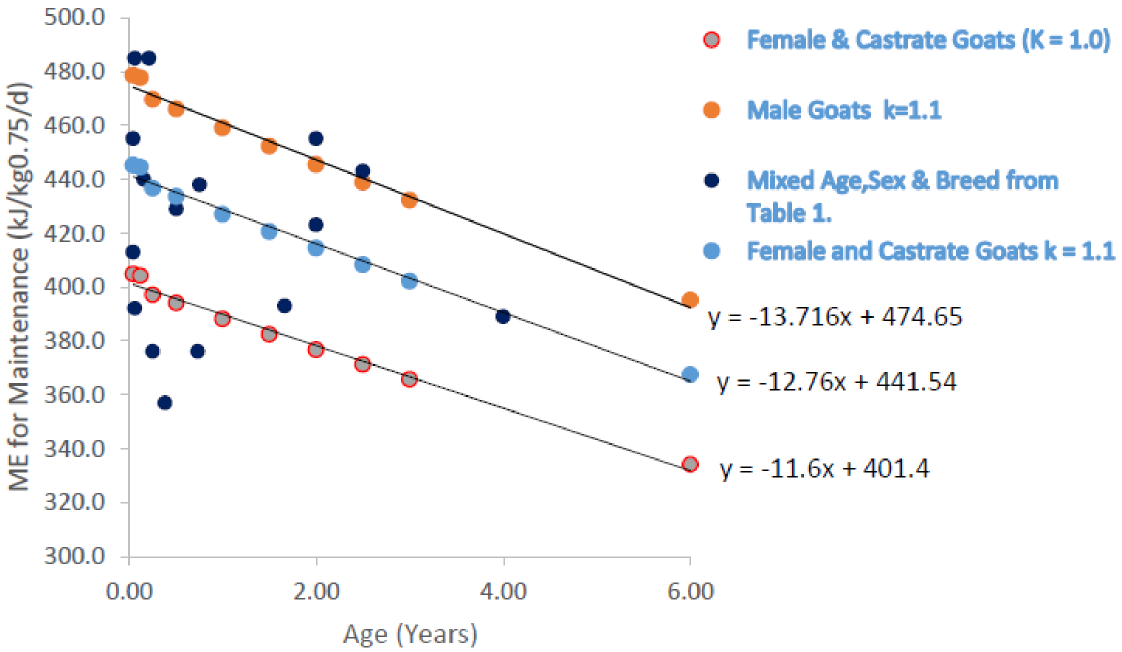

Figure 33. Effects of age on metabolizable energy requirements for liveweight maintenance in goats.

Effects of genotype

The Australian Rangeland goat is the product of the crossbreeding of goats from manydifferent global locations, particularly Europe, Africa, India and North Asia. These goats have self-selected for survival in the dry areas of Australia and cannot easily be defined as any one genotype or biotype. They share this mixed heritage with the indigenous goats of many old and new world countries, experiencing little selection for specific traits, except survival. Genotype differences in nutritional requirements are usually seen in highly selected populations, such as shown in the literature for Dairy and Angora goats. Sahlu et al. (2004) broadly categorised American goat genotypes as Meat (includes Boer and Boer crosses) and Indigenous (non-dairy goats introduced to the Americas, mainly from Europe). They found no significant differences in requirements for these genotypes and combine this data in making their final recommendations which were adopted by the NRC (2007).

The most comprehensive study of goat genotypes in Australia was conducted by Murray and colleagues at The University of Queensland (Gatton, QLD). They studied the effects of cross-breeding Australian Rangeland does with Boer, Saanan and Angora sires on birth and weaning weights, and the carcass weights and composition of entire males slaughtered at 16 kg (Capretto) and castrate males 30 kg (Chevon) LW (Dhanda et al.1999) All kids in the Capretto group were raised with their mothers at pasture until slaughteredat 90 ± 6 days of age. Chevon kids were castrated at weaning and raised at pasture with *ad libitum* access to concentrate pellets (18% CP, 12.3 M/D/kg) until slaughtered after weaning at 270 ± 10 days. Despite small differences in birth weights, there were no significant differences between the genotypes in the LW of the male kids at 90 days of age (range 15.1 to 16.4

kg). At 9 months of age, kids from does crossed to a Saanen buck were heavier (34.1 to 36.3 kg LW) than does crossed to Rangeland and Angora bucks (30.6 to 32.4 kg LW). Although there are no more specific details on the nutrition of these goats than mentioned above, it would seem that despite the possible expression of hybrid vigour in thesecrosses, there were few differences in the maintenance and growth requirements between the different genotypes. It is with this justification, and the conclusions of Sahlu et al. (2004), that it is assumed that there is one common energy requirement for LW maintenance and growth in Australian Rangeland goats up to approximately 30 kg LW.

Effects of activity

The energy requirements of goats for both maintenance and growth will be increased by the amount of energy needed in their search for and consumption of feed and water. Detailed measurements of the energy costs of standing, horizontal and vertical movement and position change in goats have been summarised by AFRC (1998), and further expanded by NRDR (2007) to include costs of eating and ruminating. The AFRC (1998) calculated that the maintenance energy requirements of goats grazing pasture or good quality range would be increased by 12 to 15%, and when grazing arid or mountainous range, requirements would be increased by up to 44%. This latter value assumed that goats walk about 20 km a day in search of feed in this environment. The NRC (1981) recommended an arbitrary 25, 50 and 75% increase in maintenanceenergy requirements. The NRC (2007) have suggested that the more recent evidence presented by Sahlu et al. (2004) is the best estimate for the activity of goats in relation to changes in feed quality (organic matter [OM] digestibility, %), time spent grazing and walking (h/day), distance walked (km/day) and steepness of terrain (scale 1 to 5). Sahlu et al. (2004) suggested that the activity costs associated with the minimum and maximum activities required an additional 4% to 73% increase in ME to meet these activities. The NRC (2007) provided a formula purportedly derived from Sahlu et al. (2004) which predicts a much wider range of extra requirements.

The problem with determining the energy requirements for activity is the diverse range of environments in which goats are found. It is generally agreed that no activity increment needsto be applied to housed or penned goats. It is possible that the higher values for ME_{mw} shown in Table 14 (e.g. from Sahlu et al. 2004) are associated with the inclusion of males, females andcastrates in their general equations as well as unknown levels of activity. The NRDR (2007) have proposed a more quantitative approach to the measurement of activity increment as described by the following equation:

$$ME_{graze} = [C.DMI.(0.9 - D) + 0.0026\ H]\ W/k_m \qquad \textit{Equation 6}$$

where,

- H (horizontal equivalent of the distance walked) (km),
- H = T [(min(1, SR/SD)/(0.057GF + 0.16) + M],
- C = 0.02 (sheep, goats) or 0.0025 (cattle),
- DMI = dry matter intake from pasture, kg/day, excluding supplementary DM;D = digestibility of the dry matter (decimal),
- GF = availability of green forage (t DM/ha when cut to ground level; if GF is < 0.1 T/ha, total weight of forage is used in place of GF),
- M = total distance walked each day from pasture to milking shed (km);
- SD = threshold for grazing density (animals/ha) of 40 for goats/sheep or 5 for cattle,
- SR = current grazing density (animals/ha), and
- T takes values that range from 1.0 to 2.0 as terrain varies from level to steep.

Given the somewhat arbitrary approach taken by AFRC (1998) and NRC (2007), the above equation could be just as reliably applied to goats in Australian grazing systems. The equation recognises that goats will travel seeking quality feed and expend more energy when competing under higher stocking rates and where they are in hilly or mountainous areas. In the following calculation it is assumed that 50 kg green feed is available per goat at M/D = 10 (67% digestibility), and that activity increments for goats at 1 goat/ha (pastoral zone) and 20 goats/ha(improved pastures) cover a range appropriate for Rangeland goats in Australia (Table 16). The AFRC (1998) have calculated for a 65 kg goat, increases in ME intake of 14% of its maintenance requirement should be allowed to account for goat walking 2 km a day, and thatand additional 67% allocated for goats walking 20 km/day in arid areas. While it is possible that such extreme conditions may exist, according to the above equation (NRDR 2007), goats grazing steep pastures at a high stocking rates only required a 30% increase in allowance to meet their maintenance requirements. McGregor (2005), using similar calculations, estimated that the maintenance energy requirement of a 35 kg doe was 404 kJ/kg $LW^{0.75}$.day and when grazing a hilly paddock this would increase by 20% to about 485 kJ/kg $LW^{0.75}$.day. It is of interest to note that, with the possible exception of pre-weaning goats, the values shown in Table 16 cover the range of maintenance requirements reported from the different sources (408 to 542 kJ/kg $LW^{0.75}$.day). It is proposed that the above approach is a more logical way to estimate the energy costs of activity, and that 30% is probably the highest allowance for activity increment needed for goats in the Australian Rangelands.

Table 16. Estimated metabolizable energy (ME) requirements to maintain liveweight of female or castrated goats of different liveweight under different inclines and stocking rates (SR) (values calculated from *Equation 6*).

Incline	Activity level	Liveweight (kg)					Increase in ME requirement (%)
		15	20	25	30	35	
		ME intake (kJ/kg $LW^{0.75}$.day)					
Penned	Maintenance	433.4	427.0	420.6	414.4	408.2	0
Level	SR = 1 goat/ha	440.4	435.5	430.7	425.8	421.1	2.4
	SR = 20 goats/ha	488.0	486.6	484.7	482.4	479.9	15.1
Steep	SR = 1 goat/ha	442.9	438.2	433.5	428.8	424.2	3.0
	SR = 20 goats/ha	538.0	540.4	541.6	542.0	541.7	28.5
	Average	468.5	465.5	462.2	458.7	455.0	

Effects of environment

It is well known that cold ambient temperatures, rainfall and wind may increase heat loss and hence the energy requirements of animals for maintenance and growth. High ambient temperatures, humidity and photoperiod are also known to affect animal productivity, mainly through effects on voluntary food intake and an increase in deep body heat production (increased maintenance).

Cold, rain and wind.

The NRDR (2007) have presented the following equation which expresses an animal's response to the above conditions. E_{cold} is the additional energy expenditure (MJ ME/day) when the ambient temperature is below the animal's lower critical temperature (additional ME is used with an efficiency of 1.0 in cold stress).

$$E_{cold} = A \times (T_{LC} - T_A)/(I_T + I_E)$$ *Equation 7*

where,

- A = the surface area of the animal (m^2) = 0.09 kg $LW^{0.66}$,
- T_{LC} = lower critical temperature of the animal (°C),
- T_A = ambient temperature (°C),
- I_T = tissue insulation
- I_E = external (hair, wool) insulation

Values of total insulation ($I_T + I_E$, °C m^2 day/MJ) for sheep with fleece lengths of 50 mm were estimated to vary from 7.83 under calm conditions to 3.83 in rainy and windy conditions. Similar values may be applied to goats, although their lower subcutaneous fat could decrease their effective insulation. Holmes and Moore (1981) found T_{LC} for adult feral goats in NZ to vary from 9 (coat length 57 mm) to 13°C. This information suggests that additional energy should be provided for adult goats when ambient temperatures fall below approximately 10°C. Newborn goats and newly shorn goats will be most at risk of cold stress (Holmes and Clarke, 1989). While temperatures below 10°C are often found at night for many Australian environments, goats usually seek warm and dry shelter on these occasions, and, with the exception of newborn and newly shorn goats, additional feed allowances for cold stress in goats are probably not needed for most Australian environments.

Heat and humidity

Temperatures greater than 39°C will cause a physiological response in animals, inducing sweating and panting to reduce the heat load. Thisstress is exacerbated by high humidity and leads to decreased feed intake and consequently a loss of productivity. This is especially important for milk production in the tropics. Fortunately, such conditions are seldom found in Australia, although the provision of shade in feedlots is now standard practice in the beef industry. As for cold, goats will seek relief from hot conditions where possible and heat stress is not likely to be significant problem with Rangeland goats in Australia (Holmes et al. 1986) but maybe more important in lactating does.

Photoperiod

It is now well documented that photoperiod causes seasonal effects in Australian Rangeland goats on reproduction (Walkden-Brown et al. 1994a), cashmere growth (Kloren et al. 1993), voluntary feed intake and LWG (Walkden- Brown et al. 1994b) and milk production in Australian Saanan and Saanan x British Alpine goats (Russo et al. 2013). However, there is no mention of these effects on the requirements forgoats as described by the AFRC (1998), NRC (2007) or NRDR (2007). Australian goat producers have observed a period of decreased growth by goats during the autumn and early winter (March to June), this is often called "winter growth stasis" and is attributed by these producers to "*a combination of endoparasite load, infection, nutritional deficiencies and low dry matter intake during cold wet weather alleviated to some extent by feeding out cereal hay ad libitum* (Jolly 2013). However, "winter growth stasis" has been found in parasite free goats grazing tropical pastures in Queensland and northern New South Wales (Norton and Ash 1985) where neither temperature nor rainfall was related to this "winter stasis". McCall et al. (1989) reported an autumn depression in the growth of NZ feral hogget goats irrespective of the quantity of pasture offered. Observations with pen fed Australian cashmere goats found similar autumn depressions in growth which were directly related to decreased voluntary feed intake (Table 17; Ash, 1986).

Table 17. The effects of month of year on dry matter (DM) intake, and digestibility of DM in diet (DMD) and liveweight (LW) change of weaner goats fed concentrate rations in southeast Queensland.

Month	Liveweight (kg)	Intake (g DM/kg $LW^{0.75}$.day) (g DM/kg LW.day)	DMD (%)	LW change (g/kg $LW^{0.75}$.day) (g/kg LW.day)	Feed Conversion Efficiency (kg DM/kg LW gain)
April to June	15.3	81.5 (41)	63.3	13.4 (6.8)	6.1
	17.6	70.0 (34)	59.6	5.4 (2.6)	11.9
	19.7	67.2 (32)	61.0	8.7 (4.1)	7.7
October to November	12.0	79.9 (43)	64.0	15.9 (8.5)	5.0
	15.1	93.3 (47)	64.2	17.0 (8.6)	5.5

The time of kidding is also important for determining the potential for sustained growth of kids following weaning (Figure 34). The depression in growth during the autumn period is clearly shown for kids born in August but has its worst effect on kids born in December. All kids grew at their greatest rate from July to December. However, these effects may be modified by diet. Ash and Norton (1987c) found that unsupplemented weaner goats (13.7 kg LW) grazing Pangola grass pastures between 6-April and 19-June lost 35 g/day (2.6 kg) over this period, while those supplemented with protein (60 g CP/day) meals (casein, cotton seed, sunflower) lost only 10 g/day (0.7kg) over the same period. Males lost more weight (33 g/day) than females (14 g/day) in this experiment. It may be concluded that during the period between the autumn equinox (21-March) and winter solstice (21-June) the growth potential of Australian Rangeland goats at pasture is limited by change in photoperiod. These effects will be exaggerated by significant endoparasite loads, poor nutrition, gender(males affected more than castrates and females), although alleviation of these stresses will still not turn a LW loss into a LW gain. The above evidence suggests that photoperiod, particularly day-length decline between the autumn equinox (greatest rate of decline) and winter solstice (shortest day), has a significant effect on LWC of both young and old Australian Rangeland goats. It was also noted that the principal effect was a decrease in DMI which was significantly correlated with decreasing LWC (Walkden-Brown 1994b). This observation indicates that photoperiod has its effect solely on voluntary DMI, without affecting the animal's maintenance energy requirement (or BMR). It is recommended that this matter deserves consideration when planning supplementary or lot-feeding of goats in the autumn period and requires some mention when describing the nutrient requirements for goats.

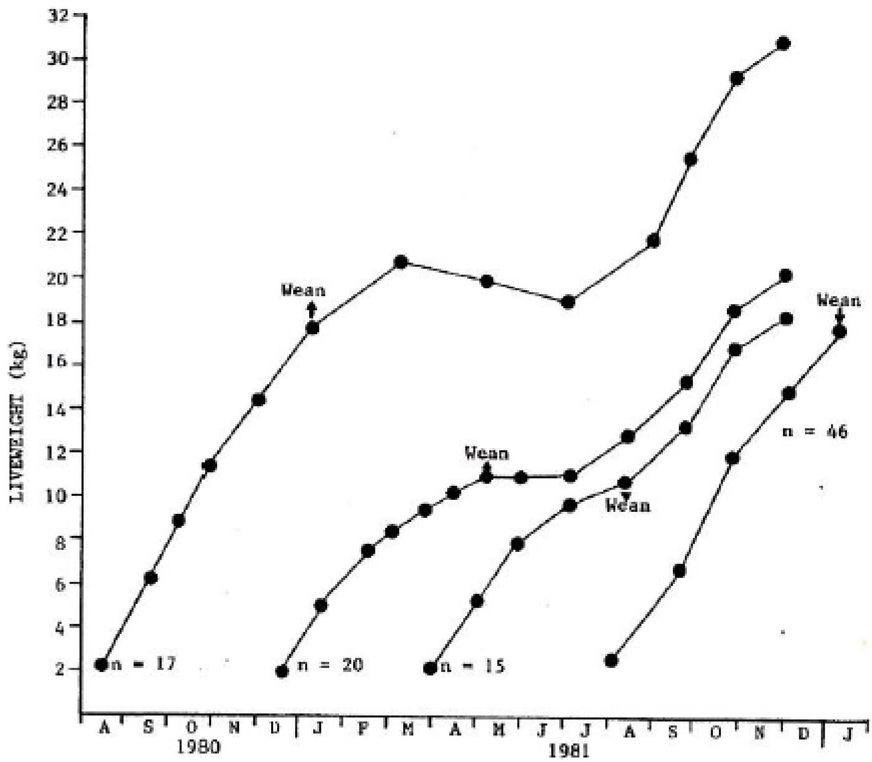

Figure 34. Effect of season of birth on growth rate of mixed-sex kids born in north eastern New South Wales.

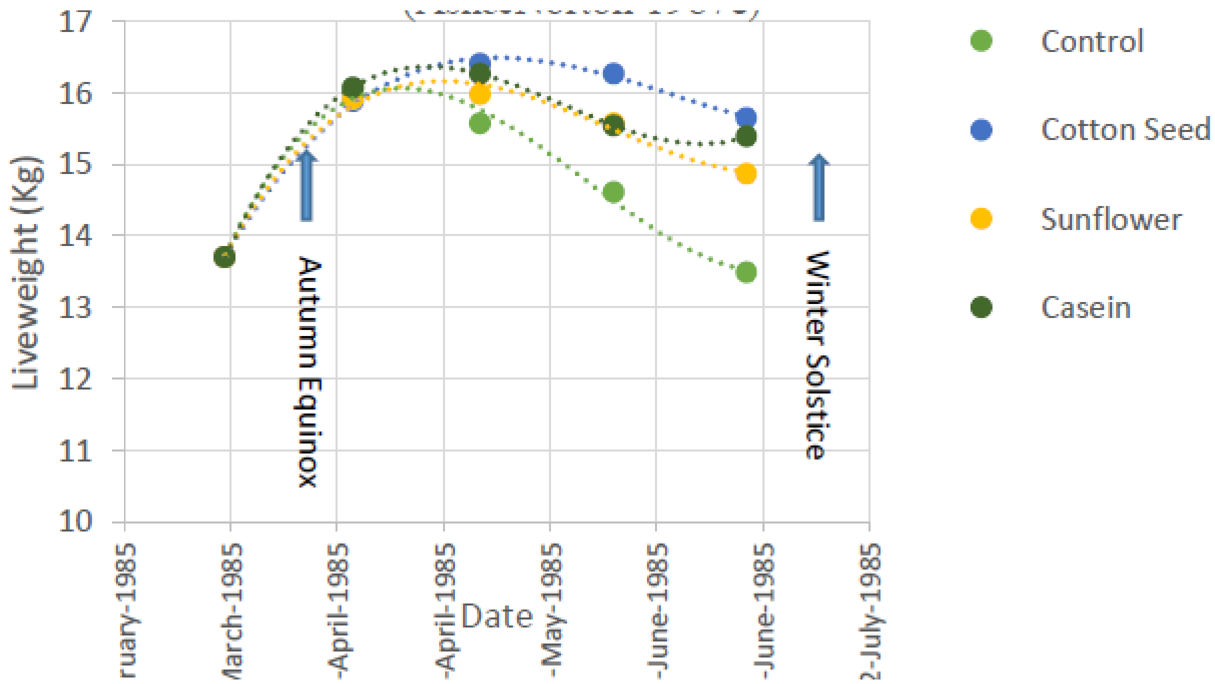

Figure 35. Liveweight changes of Rangeland goats supplemented with various protein sources between February and July in southeast Queensland (Ash and Norton, 1987c).

Effects of physiological state

Liveweight gain (fat, protein, water and ash deposition), reproductive state (placenta and conceptus growth), lactation and fibre growth (hair, wool, mohair, cashmere) all require additional sources of nutrients above maintenance in the productive farm animal. This reviewis only concerned with the growing non-pregnant, non-lactating Rangeland goat, and only theenergy and protein requirements for maintenance and growth were considered. Hair and cashmere growth in Rangeland goats could also be considered as a draw on nutrients but would only represent a small fraction of the energy and protein needs for maintenance and growth when compared with sheep and Angora goats.

Conclusions

The maintenance energy requirements of Australian Rangeland goats have been reviewed and compared with those from the international literature and, with the exception of dairy and Angora goats,the values found generally agree with those found for non-dairy indigenous goats. The general formulae used for the prediction of maintenance ME requirements recommended by NRDR (2007) was found to be a useful tool. This formula accounts for the main variables affecting requirements, liveweight, age, gender, feed quality, pre- and post-weaning stages of development and the efficiency with which dietary energy is used for maintenance (k_m). While a close fit to this model was not found for the data available, the principles guiding a decision about which model might be the best predictor were sound, i.e. FHP, age, sex, genotype, activity, environment and diet are all variables which might affect a final estimate ofthe maintenance ME requirement of any one goat. A pragmatic view was therefore taken that a generally accepted value (approximately 400 kJ ME/kg $LW^{0.75}$.day) be accepted until further information is available. The current project will contribute to this quest.

The energy requirements for liveweight growth in Rangeland goats

There is also an extensive literature on the energy requirements of goats for LWG. There is more agreement between studies for the energy requirements forLWG (or energy gain) than there is for the energy requirements for LW maintenance (Figure 36). It is recognised by most that in the earliest stages of growth, more protein (and water) is gained than fat and, consequently, the energy content of the gain is much lower than at later stages ofgrowth when more fat is being deposited than protein. Since protein deposition uses less energy(29 kJ/g or 81% efficiency) than that used to store fat (76 kJ/g fat or 52% efficiency) (Blaxter 1962, Norton et al. 1970, Jagusch et al. 1983) the energy cost of LWG in young animals is lower (11 to 18 kJ/g) than that for LWG in older animals (20 to 28 kJ/g) (e.g. Table 14). As the animal ages and increases in LW, the rate of protein deposition decreases while that of fat increases until maturity is reached. The logical expectation would be that with increasing fat deposition, the energy cost of tissue gain should increase (Figure 36). However, when this process is expressed as body energy gain (kJ of protein and fat) per unit of ME intake (kJ), the efficiency of energy retention (k_{g}/k_{f}) is usually found to be a constant. The AFRC (1998) have suggested that this value changes with M/D(q_m) of the diet, increasing from 0.318 to 0.552 as energy digestibility increases from 49 to 85%. The AFRC (1998) have also suggested that this value remains constant for pelleted diets (0.48) over the same range of q_m values. Ash and Norton (1987b) found a value of 0.32 for young Rangeland goats consuming pelleted diets of 65 to 68% organic matter (OM) digestibility (q_m = 0.53).

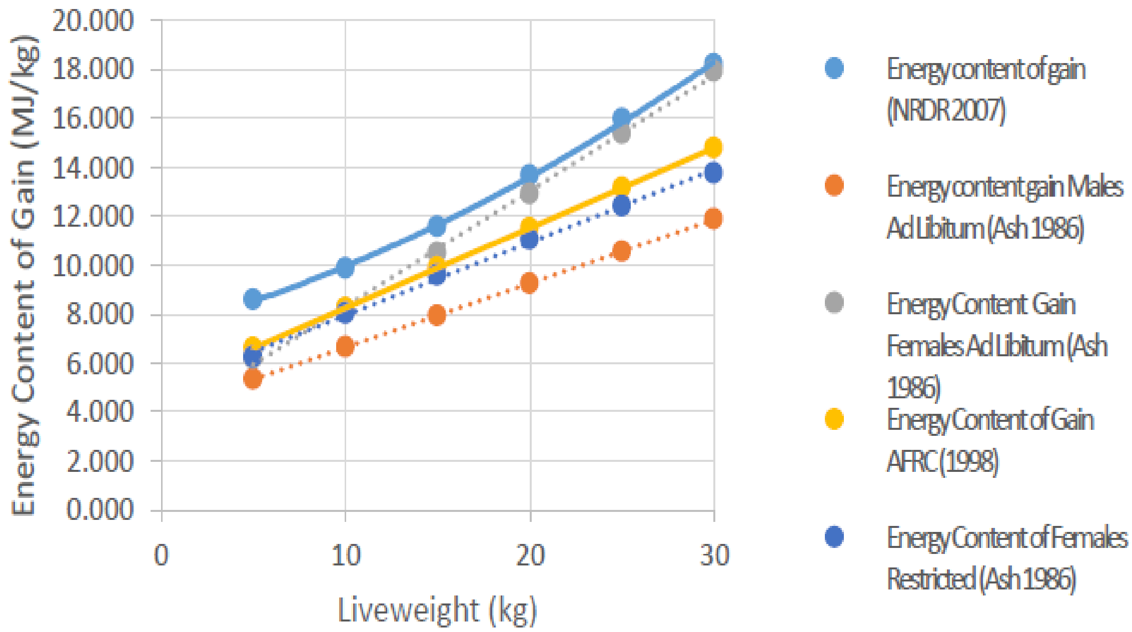

Figure 36. The relationship between energy content of the gain and liveweight of growing goats.

Calculation of the ME requirements for growth uses a value predicted at a particular LW for the energy content of the gain (MJ/kg), then multiplies this value by the amount of gain (g/d) and divides by the efficiency (k_g/k_f) with ME used for energy storage. The relationship between LW and the energy content of the gain for the predictions used by AFRC 1998 and NRDR 2007 were comparable of those reported by Ash and Norton (1987b) for males and female offered pelleted diets *ad libitum,* and for females offered a restricted (75% *ad libitum*) (Figure 36). It may been seen that the energy gain/kg determined by slaughter analysis was lower in males than females, and that females fed *ad libitum* had high energy gain than those fed restricted diets. The AFRC (1998) predict gains well for restricted females but not well for *ad libitum* fed males and females. It is clear that the use of the tables presented by AFRC (1998) will not accurately predict the energy requirements for LWG in Rangeland goats. The prediction equation used by NRDR (2007) developed from sheep will generally overestimate the energy gain predicted from LW, and therefore overestimate ME requirements for growth in Australian Rangeland goats. The variables that affect energy gain are the same as those which affect the maintenance requirement for energy. For any particular genotype, energy gain will be determined by the rates of protein and fat deposition as the animal grows to maturity. Where energy intake is restricted, the time to maturity is longer, and the rate of fat deposition decreased, and hence energy gain is decreased. Thiscircumstance can be seen for female goats on restricted diets (Figure 36). There is need for further study in this area with Rangeland goats grown to maturity at different rates by varying intakes. Such a study of body composition changes would provide information on how varying rates of gain affect protein and fat deposition, and hence allow a better estimate of the ME required for LWG. Until that time, there seems little point in presenting a table ofrequirements for growth developed from generalisations made by AFRC (1998), NRDR (2007)or NRC (2007), and shown for Australian goats in the recent reviews by McGregor (2005) and Jolly (2013).

The current project will provide information on the growth rates and energy intakes of Rangeland goats offered basic hay and supplement diets. Measurements of intake and digestibility will allow predictions of the relationship between ME intake and growth rates butwill not provide any information on the composition of the LWG. There is also a need to determine the growth potential of these goats given a good quality diet (pellets), and to determine the changing composition of the LWG as they grow to maturity. Such information would provide a baseline from which to judge the genetic potential in the average Rangeland goat.

The requirements of goats for dietary protein

The goat, as a ruminant animal, harvests and ingests plant material as its major source of nutrients. Plant proteins are found in both the cell content and the cell wall. The cellular proteins are released by cell rupture during mastication and digestion in the rumen and are usually rapidly fermented in the rumen. Some proteins may be rendered insoluble by complexing with other plant compounds (e.g. tannins) or by denaturation during processing to stored product (hay). Soluble protein, dietary non-protein N and recycled endogenous N (saliva, entry through rumen wall, cell sloughing) all contribute to the pool of amino and ammonia N used for microbial protein synthesis. Insoluble protein may pass to the duodenum and lowerdigestive tract where it is degraded and absorbed as amino acids for tissue use by the animal.

The protein requirements of goats for growth is therefore determined by the intake of dietary protein and non-protein N, the amount of this dietary N which escapes fermentation and provides amino acids for absorption, the amount of microbial protein synthesised in the rumen that enters to small intestine also providing amino acids for absorption, the balance of essential and non-essential amino acids absorbed and the efficiency with which these amino acids are utilized for the maintenance and growth of the animal. The AFRC (1998) have reviewed the literature and found that the publications of Alam et al. (1983) and Ash and Norton (1987b) are a major source of this information for goats. Where information is missing, they have used values for cattle and sheep.

The requirements for protein are determined by that needed for maintenance and that for production. Since the growth of weaner goats is the focus of this project, the production needs can be simplified as the protein needed for tissue synthesis, and presuming that fibre growth isa negligible draw on protein needs. The concept of using metabolisable protein (MP) to express protein requirements encompasses two processes, the extent to which the diet provides amino acids for tissue growth and the demand of the tissues for amino acids for different production processes. The AFRC (1998) and NRC (2007) have reviewed this information for goats and reported their findings in terms of MP required for maintenance and LWG of goats. Central to this calculation is the estimation of the protein content of the LWG, and the above authoritieshave presented different approaches to this estimation. The NRC (2007) have used the following equation from Sahlu et al. (2004) to predict the MP required for weight gains of meat goats,

$$\text{MP content of gain/MBW} = 0.404*\text{ADG/MBW} + 3.07 \qquad \textit{Equation 8}$$

where,

- MP = metabolisable protein,
- MBW = metabolic body weight (kg $LW^{0.75}$), and
- ADG =average daily gain (g/day)

Equation 8 indicates a maintenance requirement of 3.07 g MP/kg $LW^{0.75}$.day and 0.404 g MP/g ADG. Alternatively, the AFRC (1998) have proposed the following equation (Equation 9) for the composition of the LWG in growing goats (Panaretto and Till, 1963),

$$\text{Protein (g/kg)} = 157.22 - 0.694*\text{LW} \qquad \textit{Equation 9}$$

where,

- LW = liveweight.

The requirement for MP was then calculated by dividing with the efficiency with which absorbed amino acids are used for tissue protein synthesis (protein content of gain) by young growing goats (Figure 37, Table 18).

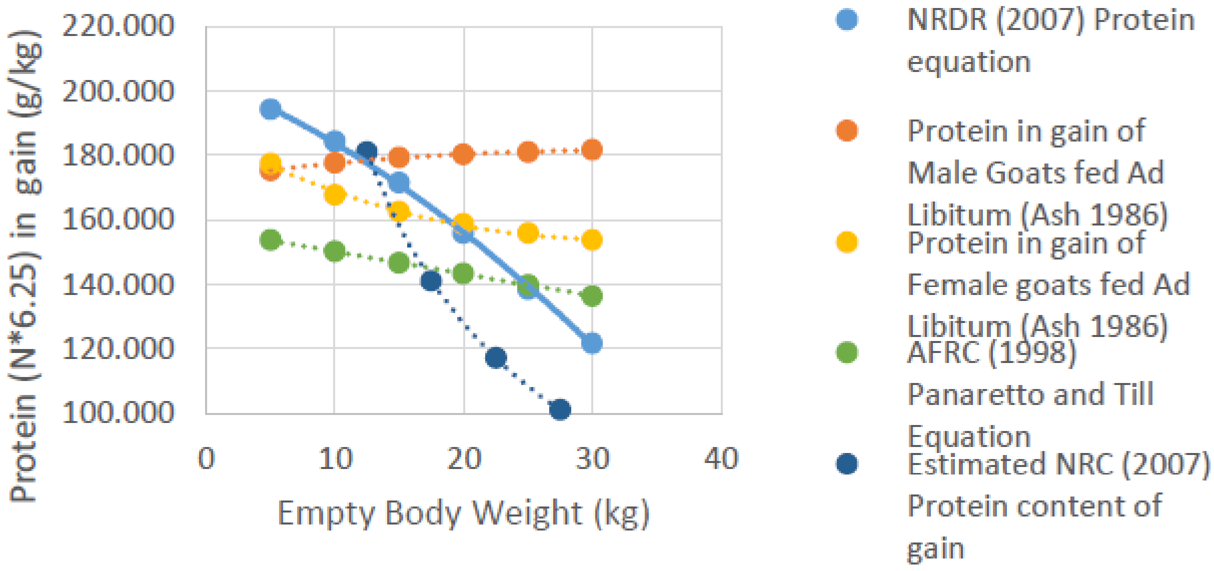

Figure 37. Changes in protein content of liveweight gain of Rangeland goats with increasing liveweight.

Table 18. Mean metabolisable protein (MP, g/day) requirements recommended by AFRC (1998) and NRC (2007) for the maintenance (M) and liveweight gain (LWG) of non-dairy goats of different liveweights.

Liveweight (kg)	AFRC (2007)			NRC (2007)		
	M	LWG 100 g/day	LWG 200 g/day	M	LWG 100 g/day	LWG 200 g/day
10	12.3	25.5	50.9	17 (25)	53 (70)	75 (107)
15	16.7	24.9	49.7	23 (33)	55 (74)	81 (116)
20	20.7	24.3	48.6	29 (41)	58 (82)	87 (124)
25	24.5	23.7	47.4	34 (49)	63 (90)	92 (131)
30	28.1	23.1	46.2	39 (56)	68 (97)	97 (138)

values in brackets are for crude protein intakes when assuming proteins are 60% degradable in the rumen.

As shown above, values used for prediction of the protein composition of the gain in goats varies between authorities. When compared with the data of Ash (1986) for Australian Rangeland goats, all underestimate the protein content of the gain and the rate at which it declines with age and weight. The lower protein content of the gain in females is related to a higher fat content of their gain. As a consequence, the predicted protein requirements shown below are probably underestimates of the true requirements. The simple conversion factor here is MP/0.70 to estimate CP intakes. It is clear that there are some major discrepancies where AFRC seems to underestimate both endogenous requirements and the protein needed for LWG (Table 18). It is perhaps relevant to recalculate the protein requirements of Australian goats from the data of Ash and Norton (1987b) and Alam et al. (1991). The second component of the equation needed to determine requirements for protein is the composition and fermentability of the rations used. The literature now abounds with values forthe protein and energy contents of feedstuffs, the degradability of proteins in the rumen, the microbial composition and yield arising from fermentation and the digestibility of the mixed plant and microbial fractions presented for absorption in the intestines. The predictability of the amounts of dietary protein being absorbed from the intestines is much higher than that of the composition of the weight gain likely to be found in Rangeland goats. There is a need for more intensive studies of diets of varying protein and energy content which will promote optimal/maximum gains in both Rangeland goats and their crossbreds.

The requirements of goats for dietary fibre

Ruminants, by nature, are grazing and browsing animals which rely on plants for their nutrition.The reticulo-rumen is an expanded forestomach, which makes possible the fermentation and digestion of plant matter, thereby providing sustaining nutrients for absorption in the intestines.The function of the rumen has been studied in great detail and the fibre content of plants is often the limiting component of the diet. Voluntary feed intakes are often limited in high fibrediets, with indigestible lignified plant cell walls being retained for long periods in the rumen and limiting voluntary intake. The fibrous component, once characterised as crude fibre, and now analysed as neutral detergent fibre (NDF), is an important component to measure in ruminant diets. The NDF is said to represent the plant cell wall, which is varyingly digestible. The soluble plant cell contents (proteins, sugars, minerals) are completely digestedin the rumen. The NDF consists of two factions, hemicellulose/pectin and lignified cellulose, the latter being measured as acid detergent fibre (ADF) It is thought that the hemicellulose fraction of the plant wall is extensively digested by colonising microorganisms (bacteria, protozoa, fungi) while the ADF fraction is variably digested depending on the extent to which lignin and tannins bind the cellulose fraction. Much of the difference between the digestibilitiesof temperate and tropical grasses and legumes can be accounted for by differences in the content and composition of the plant cell walls (Norton, 1982).

Goats have been found to digest dietary fibre better than sheep (Watson and Norton, 1982, Alam et al. 1983, Doyle et al. 1984) particularly when diet quality is poor (low digestibility). These workers could not find differences in voluntary feed intake between sheepand goats, and yet AFRC (1998) found significant differences in the voluntary feed intake of Saanen castrates and sheep (mostly Suffolk crossbreds) in England. The voluntary feed intake of DM by these goats was, on average, 27% higher than sheep. These differences are possibly explained by differences in BMR; BMR for adult sheep is around 257 kJ/kg $LW^{0.75}$.day (Graham et al. 1974) and for goats BMR has been estimated around 315 kJ/kg $LW^{0.75}$.day (AFRC 1998). It seems likely that the highervoluntary feed intake recorded above is related to the differences in BMR. Alam et al. (1985) showed that the difference between sheep and goat voluntary feed intake was greatest for diets of low quality, diets greater than 66% OMD were consumed by sheep and goats in equal amounts, while goats givenlow quality diets (50% OMD) consumed 27% more of this feed than sheep. Unfortunately, it was not recorded whether this greater intake resulted in increased LWG, although the extra energy available may simply be used to meet the goat's higher maintenance energy requirements.

While the evidence above does suggest that goats may digest low quality forages better than sheep, they still require a minimum level of dietary fibre to maintain effective rumen function. The question that needs to be asked is whether these differences in fibre digestion have value in terms of increased productivity. Where there is an increased digestion of fibre, this should lead to an increased absorption and availability of energy for maintenance and production. Where fresh, dried or ensiled forages are fed, the physical characteristics of the feed offered is also important, for example, the water content of fresh forage can limit intake, particle size may also limit (long fibre, fine particles affecting palatability) or increase (chopped particles) intake. A discussion of these effects is outside the scope of this review. However, where digestibility is limited by the lignified cellulose (ADF) content of the forage, it is well established that a minimum content of 200 g ADF/kg DM is required to maintain effective rumen function, and that a fine particle size (> 60% through 1.18 mm sieve) in total mixed rations can be tolerated by goats (Se Young Jang et al. 2017). It is also recognised thatdilution of concentrate feeds with forages will decrease M/D content of the total diet, so that effects of high fibre levels in concentrate feeds are confounded with decreasing M/D content.

In conclusion, digestible and indigestible fibre are essential for effective rumen function in all ruminants, including goats, and a minimum of about 200 g ADF/kg feed DM is required. The ADF is a variable fraction of the cell walls (NDF) depending on the plant species and its stage of maturity. The NDF of young grasses and legumes contains about 25% ADF, whereas mature grasses may have as much as 60% ADF in NDF. It is for this reason that ADF may be a better indicator of the “effective” fibre content than NDF.

Supplementary feeding trials with Australian Rangeland goats

Supplementary feeding is a management strategy used when pasture availability or quality is limiting animal production and may be used to offset the often negative effects of increasing stocking rate on animal production from pasture. Supplementary feeding has been shown to improve the LWG of goats at pasture but these responses are moderated by level, type and quality of supplement, age and genotype of goat, stocking rate, photoperiod, rainfall anddisease, particularly intestinal parasites. The effects of supplementary feeding of goats grazing tropical pastures have been reviewed by Norton (2004), McGregor (2005) for goats underdrought conditions in southern Australia, and Jolly (2013) forsupplementation of goats generally. The intent of the present review is to provide informationon regarding the supplementary feeding of Australian Rangeland goats only, other breeds and cross-breeds will only be discussed where comparisons are made with Australian Rangeland goats. It also seemsappropriate to present only information from peer refereed journals as this should ensure that reliable information is presented.

Supplementation is designed to optimise productivity where environmental conditions are limiting, and success is judged by the extent to which such regimes allow expression of the full genetic potential of the goat. Allan and Holst (1989) have presented information on the growth of domesticated Rangeland goats at Condobolin, New South Wales (Figure 38).

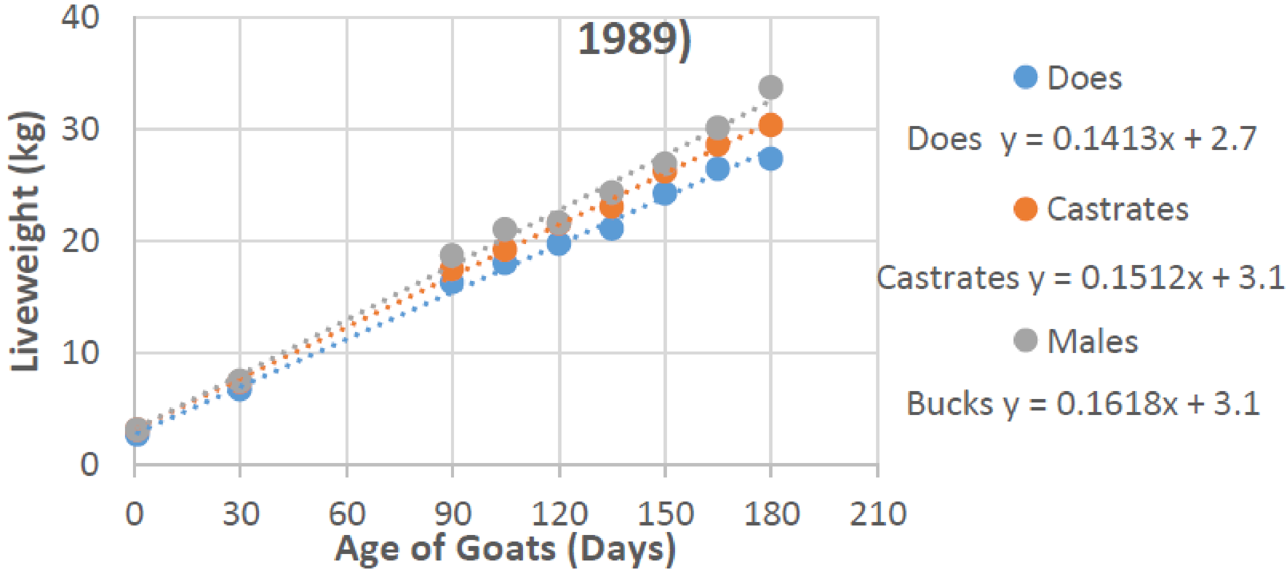

Figure 38. The growth of female, castrate and entire male Rangeland goats at Condobolin, New South Wales (Allan and Holst, 1989).

These goats were born in August (late winter) and held on native pastures for the duration of the study. Apart from a slight decrease in LWG after weaning, these goats grew at a steady rate until February (late summer). Entire males grew faster than castrates (161 vs 151 g/day) which in turn grew faster than does (141 g/day). It is clear from this report that youngRangeland goats in this environment are capable of growing to a marketable weight (35 kg)by 6 months of age and before the autumn equinox (21-March). Bajhau and Kennedy (1990) reported that when pasture conditions in the same area were poor during the summer the weaning weights of kids decreased from 17.0 to 14.6 kg, and cross-bred (Rangeland x Anglo-Nubian) kids (16.3 kg) had higher weaning weights than Rangeland kids (15.3 kg). They also observed that kids with the highest birth weight (single males) had the highest growth ratesto weaning, and while heavier does produced more milk that lighter does, there was no significant effect of litter size (single, twin or triplet) on milk production. This result suggests that the poor growth rates of twin and triplets is mostly the result of limited milk availability. Norton and Banda (1992) also found no difference in the growth rates of male and female twin and single kids offered artificial milk *ad libitum*.

It would seem that optimising the growth of young goats to market weight requires attention toall levels of management, that is, maximizing doe milk production for optimum kid growth toweaning, providing strategies to minimise weight losses after weaning and post weaning supplementary feeding of weaner goats to maximise growth rates to slaughter weight.

Maximising kid growth and survival to weaning

Goodwin and Norton (2006) found that supplementing domesticated Rangeland pregnant does grazing Pangola grass pastures with 360 g supplement (50% kibbled sorghum, 50% cotton seed meal) 2 weeks before kidding (early September) significantly reduced the immediate (16 days after kidding) post-natal mortality of kids from 18% to 3% of kids born. There appeared to be little benefit extending this supplementary period to 4 weeks after kidding, with all classes (males, females, singles, twins) benefitting from doe supplementation. This effect was most likely related to increased colostrum production as found in sheep by Milton et al. (2002)

Supplementary feeding of cashmere does (of Rangeland background) one month before and one month after kidding has been shown to significantly increase milk production (901 vs1708 mL/day) in the first

3 weeks after kidding, with supplements of high protein (20 vs 12%) offered *ad libitum* further increasing milk production in this period (Norton et al. 1984). However, this increased production did not persist past this period. These does were held on Kikuyu grass pastures at Wollongbar, northern New South Wales. Contrary to popular opinion, pre-kiddingsupplementation only (120 to 150 days post conception) did not increase milk production or kid birth weights (single or twins), nor did any supplementation regime improve overall kid growth rates to weaning (Parry 1986). Average weaning weight of all kids in this environment was only 12.0 kg at 105 days of age (February), much lower than that reported by Allan and Holst (1989). As found by others, both sex and birth type affected liveweights at weaning: single males 15.3 kg, twin males 11.3 kg, single females 13.2 kg, twin females 10.3 kg. These goats were next weighed at shearing in September (301 days of age) and only modest LWG had been made post-weaning. At this time, single males weighed 18.6 kg (17 g/day),male twins weighed 15.7 kg (23 g/day), single females weighed 17.2 kg (21 g/day) and twin femalesweighed only 13.3 kg (15 g/day) The poor growth of single males (17 g/day) is possibly related to effects of photoperiod in the April-June period after weaning.

The above results suggest that supplementing the pregnant doe is only effective in improving the immediate survival of their kids (Goodwin and Norton, 2006), although continued feeding of the doe throughout lactation may improve kid growth rates. Lambert et al. (1996) proposed an alternative strategy for improving pre-weaning kid growth (Figure 39). In this study, grazing does and their kids, 6 weeks after kidding, were offered a loose concentrate supplement (77% kibbled sorghum, 20% cotton seed, 3% limestone, 13 MJ ME/kg DM) in covered troughs and in a creep feeder only accessible to kids. The kids were weaned at 10 weeks, and LWG measured until 14 weeks of age. The supplements were offered from 6 to 16 weeks, or from 10 to 16 weeks, with the control group being offered no supplement over this period. Whilst supplementary feeding prior to and after weaning improved both the pre- and post-weaning growth of young kids, the high levels of supplementconsumed (> 300 g/day) may not be economical. The practice of weaning goats onto improved pastures at low stocking rates is still probably the best nutritional strategy for managing the post-weaning depression in growth (Mugeni, 1992).

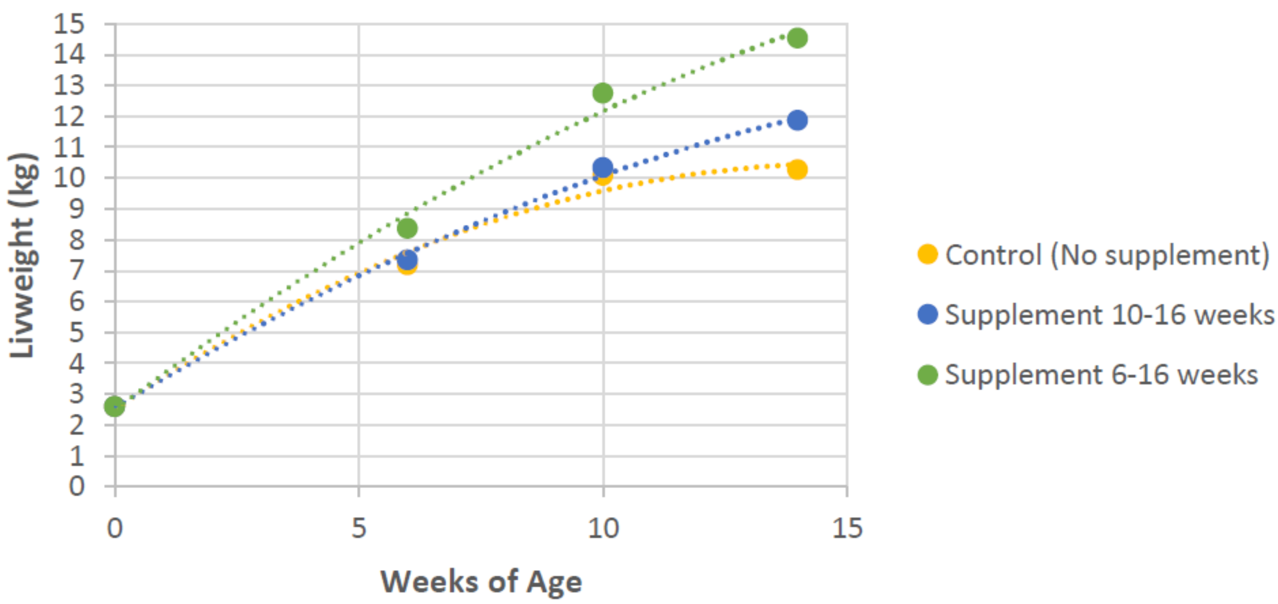

Figure 39. Effect of pre-weaning supplementation on kid weights at weaning (10 weeks) and 4 weeks post-weaning (Lambert et al. 1996).

Supplementary feeding of weaner goats

Studies at The University of Queensland investigated the use of concentrate and fodder tree supplements for weaner goats grazing tropical grass and legumes pastures as well as studies of the responses of weaner goats to various concentrate mixes, commercial goat pellets,lucerne pellets, copra meal, sorghum and molasses in pens. Where the aim is to produce kid LW greater than 35 kg for slaughter it is essential to start with well grown kid weaners free of parasites and disease, to know the genetic potential for growth of these kids, to providesupplements capable of providing an economic return and, as discussed earlier, avoiding any time of year when LWG responses might be limited by photoperiod. The weaning LW of Rangeland goats will vary with the management and pasture systems available, and the extent to which they have been cross-bred with exotic sires. Nogueira et al. (2016b) foundthat goats raised in the pastoral zones of NSW and Queensland had lower birth weights (2.3 kg), were weaned at 18 to 20 weeks at 19.6 kg LW (128 g/day since birth). Those raised in the high rainfall zone were mainly Boer cross-breds with higher birth weights (3.5 kg) and were weaned earlier (14 weeks) at a higher LW (22.2 kg, 191 g/day since birth). The growth of kids in the pastoral zones is similar to that found for domesticated Rangeland goats at Condobolin (Allan and Holst 1989), with average weaning weights at 14 weeks of about 20 kg. However, this contrasts strongly with the results found for domesticated Rangeland goats grazing in the sub-tropics (southeast Queensland and northeast New South Wales) where average weaning weights seldom exceeded 15 kg. It was also clear from an extensive review of the Australian literature that Rangeland goat growth rates seldom exceed 200 g/day irrespective of age, gender, LW or feeding regime. This observation should put into perspective any expectations of growers about the potential of these goats for LWG, and even for modest growth rates of 150 g/day (1 kg/week) it would take at least 6 months for a weaner goat to reach marketable weight (35 kg).

Liveweight gain decreases with increasing stocking rate, irrespective of the pasture type or supplement fed, and LWG in the January to June period were poor when compared with those of goats grazing oats/rye grass pastures in the latter half of the year (Table 19). The growth rates have been expressed in relation to metabolic LW so that comparisons can be made independent of size. The maximum growth rates for females and castrates(15 kg LW) on these pastures was low (8 to 10 g/kg $LW^{0.75}$.day, or 68 g/day) and not much better thanthat for 15 kg male goats (11 g/kg $LW^{0.75}$.day, or 84 g/day) grazing oats. It is not known whether this is an expression of the genetic potential of these goats for growth or a limitation posed by the environment (pasture quality, photoperiod). Comparable values for the post-weaning growth of the Rangeland goats (average LW from Condobolin were 14.0, 14.2 and 14.5 g/kg $LW^{0.75}$.day for females, castrates and entire males respectively (Allan and Holst 1989)).

Table 19. Summary of effects of pasture type, stocking rate, supplementation and time of year on the liveweight (LW) gain (g/kg LW$^{0.75}$/day) of weaner Rangeland goats in southeast Queensland.

Pasture type	Type of stock	Initial LW (kg)	Stocking rate (no/ha)				Grazing period
			20	40	60	80	
Oats-Rye grass	wether sheep	26.5	11.9	10.0	8.1		Jun-Sep$
	male goats	19.0	10.6	8.4	6.1		
PG+Nitrogen	female goats	16.1	4.4	3.6	2.7		Jan-May@
PG+TLegume		16.1	5.9	3.7	1.5		
PG+Nitrogen	male and female goats	13.3	5.9	4.4	-	3.0	Mar-July*
PG+TLegume		11.8	9.9	7.6	-	5.3	
PG+CLegume	female goats	11.8	3.4 3.9 3.4		-	-	Jan-Oct*
PG+TLegume			5.0 3.8 3.4			-	
PG+Nitrogen	castrate and female goats	12.4	-	7.9	-	3.6	Jan-May#
PG+Copra meal		12.4	-	7.4	-	6.6	

PG = Pangola grass, TLegume = Tropical legumes, CLegume = Temperate legumes.

*Mugeni, 1992. #Galgal, 1990. $Norton et al. 1990b, @Norton et al. 1990a.

Values for daily LWG in this Table vary from 138 g (26.5 kg wether sheep gaining 11.9 g/kg LW$^{0.75}$.day) to 12 g (16.1 kg doe gaining 1.5 g/kg LW$^{0.75}$.day)

Supplementation of grazing goats

When goats are drafted from unmanaged Rangeland herds, the immediate problem is to ensure that all goats consume the rations offered in a timely manner. This issue has become particularly important where live goats are to be shipped overseas or introduced to feedlots. There are usually a significant number of goats which will not feed, even after long periods ofadaption (Gherardi and Johnson, 1994, 1995). These issues have been resolved by suggesting that Rangeland goats need a significant period of domestication before entering feedlots, that only male goats may be exported and that a maximum shipload should not exceed 1500 goats (Hawkins, 1995). These difficulties of adaptation to feedlot conditions have also been shown in the publications of McGregor (1994) and Flint and Murray (2001) where high levels of inanition and digestive disorders were encountered. Post-weaning supplementation may take the form of access to good quality pastures, providing supplements of hay, concentrates or minerals in the paddock or by feed-lotting groups in pens. The responses obtained will dependon breed and sex of goat, on the quality and quantity of the diet provided, and on the amounts of supplement eaten (voluntary intake). Jolly (2013) has presented a review of supplementary feeding of goats, but of the 17 papers listed, only four were on Australian Rangeland goats, one being the MLA publication “Going Into Goats”. There is an urgent need to know what supplements have been used and how effective they are in increasing LWG of weaner goats under Australian farming conditions.

McGregor (1988), in Victoria, fed Rangeland goat males, castrates and females 400 g barley/lupin supplement with hay from January to April. Intakes were not reported, but LWG were as follows: entire males 9.1, castrates 8.3 and females 7.3 g/kg LW$^{0.75}$.day. McGregor (2005) in his excellent report on drought feeding for goats provides information on how, when and what to feed goats in a drought but relied on published tables of requirements (NRC 2007) to describe how much should be fed. There is no mention of experiments where Rangeland goats were fed under drought conditions. In a recent MLA report (B.GOA 0122), Rangeland goats (15 to 17 kg) from Queensland (Dirranbandi, Eudlo, Kingaroy, Warwick) were fed supplements of goat pellets and lupins (1 to 2% liveweight) from July to the following February in successive years. Goats offered pellets gained 92 g/day (9.4 g/kg $LW^{0.75}$.day) over the period while those unsupplemented gained 81 g/day (8.6 g/kg $LW^{0.75}$.day). Those supplemented with lupins in a drought year gained 70 g/day (6.9 g/kg $LW^{0.75}$.day) compared with unsupplemented goats grazing droughted pastures gaining 32 g/day (3.5 g/kg $LW^{0.75}$.day). There was no significant response to goat pellets offered in the first year, but there was a response to lupins during a drought in the second year. This latter responsewas claimed to be provide better Gross Margin returns than not supplementing during drought.

Supplementation with browse

The experiments proposed below plan to investigate the use of browse as an alternative source of supplement for growing goats in western Queensland and New South Wales. The effects of browse for goats in the sub-tropics has been extensively studied as supplements to grazing goats(Bint and Norton, 1982 (Pigeon pea); Kochpakdee, 1991 (tropical fodder trees)) and as supplements to low quality hays (Norton, 1994 (tropical and temperate tree legumes). A summary of the responses obtained with the various legumes tested is presented in Figure 40.

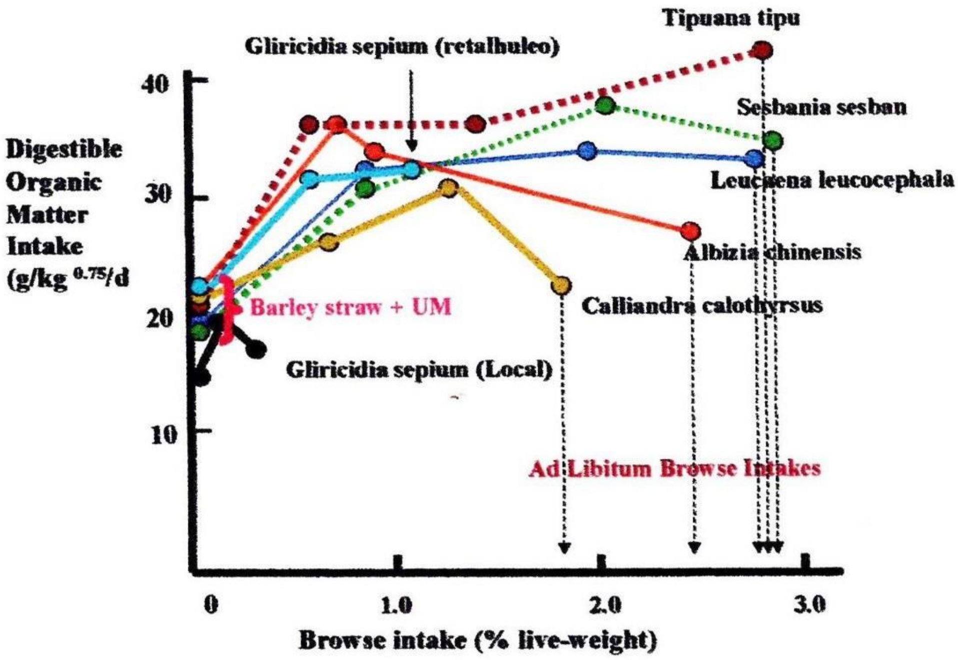

Figure 40. Intake of different legumes by goats.

The barley straw used in the above experiments was of low digestibility (50%), and the addition of most legumes significantly increased digestible OM intake. However, themaximum responses (75% increase in digestible OM intake) were found when about 1% of liveweight (or about 30% of the diet DM) was provided as fodder tree leaf dry matter. Further additions of browse did not increase total digestible OM intakes. However, the proposed experiments for the current project involves goats from arid zone areas, where there are few native fodder trees suitable as supplements. Mulga leaves are of low quality and may be little better as supplements than the native grass hay on offer. There are however other species native to these areas (e.g. Brachychiton *spp*, Sesbania *spp*, Atriplex *spp*) which might be useful as supplements, or introduced species such as tagasaste which might be grown in the wet season. As mentioned later, the type of fodder tree/forage which might be used in these experiments will be the topic of further discussion with goat producers and graziers.

Pen and lot feeding of Rangeland goats

The genetic potential for the growth of Rangeland goats is best measured in thermo-neutral and disease-free conditions where goats are offered high quality feeds *ad libitum.* Ash and Norton(1987a) fed a range of diets to domesticated Rangeland male and female goats in individual pens under natural light from March until kids in each treatment had gained 10 kg (84 to 226 days). At the beginning of the experiment, males weighed 14.3 kg and females 12.5 kg. The pelleted ration was formulated (g/kg) as follows: 300 g barley straw, sorghum grain (585 to 260), cottonseed meal (100 to 430) and limestone (10 to 15) to generate six different rations (Table 20). The values shown are averages for the whole period of the study, and as shown in Table 17, there was decline in intake between April and June, and higher intakes and growth rates were found in the last quarter of the year. Nevertheless, it is clearly shown that males consume more and grow faster than females when offered unrestricted intakes, and that increasing concentrations of protein in the ration promotes better intake and LWG of both sexes offered both diets. Maximum intakes were found to be about 83 g DM/kg $LW^{0.75}$.day (785g DM/day) with maximum LWG in males of 15 g/kg $LW^{0.75}$.day (142 g/day). Later in the year, intakes had reached 93 g DM/kg $LW^{0.75}$.day (880 g DM/day) with LWG reaching 17 g/kg $LW^{0.75}$.day (161 g/day). The energy content of the above ration was about 10 MJ/kg DM, and it is possible that higher intakes and LWG could have been achieved with higher quality rations. It is therefore estimated that the potential for intake and LWG in Australian Rangeland goats may be around 110 g DM/kg $LW^{0.75}$.day (1040 g DM/day) and 20 g/kg $LW^{0.75}$.day (190 g/day) respectively.

Table 20. The effects of rations of different protein and energy contents on the dry matter intakes and liveweight gains of Rangeland kids growing from 15 to 25 kg liveweight (LW).

Dietary treatment	Dry matter intake (g/kg $LW^{0.75}$.day)		LW gain (g/kg $LW^{0.75}$.day)	
	Males	Females	Males	Females
HE:LP	68.4	59.7	9.6	6.5
HE:MP	72.1	57.8	9.9	6.9
HE:HP	82.6	82.7	15.0	8.9
Mean	74.4	66.8	11.5	7.4
LE:LP	44.4	42.6	6.6	3.8
LE:MP	55.0	46.7	7.1	6.8
LE:HP	61.4	58.6	8.3	6.8
Mean	53.6	49.3	7.3	5.8

HE = high energy (*ad libitum*), LE = low energy (73% *ad libitum*), LP = low protein (11.2% in DM), MP = medium protein (15.6% in DM), HP = high protein (21.3% in DM)

The present review suggests that while the genetic potential of Rangeland goats for post-weaning growth maybe high (20 g/kg $LW^{0.75}$.day) there have been no confirmed reports that this potential is being realised in the field. Goats at Condobolin (Allan and Holst, 1989) showed the best potential for LWG when grazing native pastures (approximately 14 g/kg $LW^{0.75}$.day, 150 g/day), while pen fed goats fed concentrate rations (during November) reached a LWG of 17 g/kg $LW^{0.75}$.day (181 g/day) (Ash and Norton, 1987a). The recommendations that follow from these observations include:

- it is possible for Rangeland goats born in winter (July to August) to grow to a slaughter LW of more than 30 kg by the following March,
- where feed quantity or quality is limiting after weaning (southern Australia), lot feedingof weaners until March could produce 30 kg goats, and
- early weaning and supplementary feeding from weaning to March may produce 30 kg goats from singleton males and castrates but not twins or females.

Expectations from the current feeding trials

The basic plan of the current MLA project (B.GOA 0127) is to conduct experiments with Rangeland goats at different stages of maturity fed a low quality basal diet with increasing amounts of protein and energy to generate LW and intake responses for each supplement. Liveweight and intake response data will be used to generate a least cost supplement calculator available to producers. This will assist with supplementation decisions based on the likely response of goats to supplementation and the cost of each supplement to achieve this response. The expectation is that supplements will increase LWG by 100 to 150 g/day, thereby allowing an earlier turnoff of goats of higher LW for slaughter. The following experiments have been proposed for this project.

Experiment 1. Response of entire male Rangeland goats to protein supplements

Response of entire male Rangeland goats (18 to 20 kg LW) to increasing amounts of cottonseed meal, whole cottonseed, lucerne (0.3. 0.6. 0.9 and 1.2% LW) and urea (0.1, 0.2, 0.3 and 0.4% LW) at an equivalent amount of rumen degradable nitrogen to that of the protein supplements) when fed a basal diet of Mitchell grass hay (n=54 goats). This experiment will be run from October to December and provide supplement type specific data on the LW response of Rangelands goats to increasing amounts of a range of sources of nitrogen in the diet.

Experiment 2. Response of entire male Rangeland goats to energy supplements

Response of entire male Rangeland goats (18 to 20 kg LW) to increasing amounts of lupins, barley, sorghum grain and sorghum grain with urea at 0, 0.5, 1.0, 1.5 and 2.0% of LW intake when fed a basal diet of Mitchell grass hay (n=54 goats). This experiment will be run from July to September and provide supplement type specific data on the LW response of Rangelands goats to increasing amounts of a range of sources of energy in the diet.

Experiment 3. Response of young female and entire male and mature entire male Rangeland goats to protein and energy supplements

Young (18 to 20 kg LW) and mature (30 to 35 kg LW) entire male and young female (18 to 20 kg LW) Rangeland goats will be used in the experiment. Each class (young and mature) and sex will be fed increasing amounts of best-bet supplements from Experiment 1 (protein) and Experiment 2 (energy) when fed a basal diet of Mitchell grass hay (n=90 goats; 30 young does, 30 young bucks, 30 mature bucks). This experiment will be run in October to December and answers a question about how different classes of Rangelands goats respond protein and energy supplements.

Experiment 4. Effect of proportion browse in the diet on the response of entire male Rangeland goats to protein and energy supplements

Response of entire male Rangeland goats (18 to 20 kg LW) to increasing amounts of best-bet supplements from Experiment 1 (protein) and Experiment 2 (energy) above when fed a basal diet that contains either 30 or 60% browse (n=54 goats + n=6 goats fed the same basal control diet as in other experiments). While Mulga is known as a common source of browse in western pastoral areas, even as a full feed, it only supports maintenance in sheep (Norton et al. 1972, Norton et al. 1995). Its value as a drought feed may be improved byadding molasses or inorganic sulphur (Hoey et al. 1976) or polyethlene glycol to reducethe effects of tannins (Pritchard et al. 1988). Further discussion on the level of browse and type of browse will be required prior to commencement. This experiment answers a practical question around response to supplementation when the diet contains various levels of browse.

Mature Mitchell grass (Astrebla *spp*) is of low quality for both cattle and sheep. When fed to sheep, low digestibility (49.3% OMD) and intakes were not sufficient to support LW maintenance (Norton et al. 1978). If similar values apply to goats, the expectation is that they will maintain or lose a little LW depending on their intakes. For a 20 kg goat, with maintenance requirements of 400 kJ/kg $LW^{0.75}$.day (3.78 MJ ME/day), it may be calculated that this goat would need to consume about 500 g DM or 2.5% LW to maintain LW. Supplements of cottonseed meal (9.8 MJ ME/kg DM, 37% CP), whole cottonseed (13.1 MJ ME/kg DM, 30% CP) and lucerne chaff (8.8 MJ ME/kg DM, 25% CP) provided at 1.2% liveweight would provide an additional 2.35, 3.14 and 2.11 MJ ME/day respectively, and 89, 50 and 60 g of additional CP to the diet. Where lupins (10.1 MJ ME/kg DM, 30% CP), barley (11.3 MJ ME/kg DM, 12% CP), and sorghum (10.6 MJ ME/kg DM, 10% CP) are provided at the same rate (1.2% liveweight) they would contributean additional 2.42, 2.71 and 2,54 MJ ME/day respectively, and an additional 72, 29 and 24 g CP to the diet. This experimental plan will provide goats with a range of protein (0 to 90 g/day) and energy (0 to 2.54 MJ ME/day) supplements allowing LWG response curves to be described and used to predict the optimum requirements for LWG in these goats.

Conclusions

This review was selective, considering only results from Australian and New Zealand goats derived from Rangeland and feral herds respectively. Information on the productivity of crossbred (Boer, Angora, Dairy) goats could be the topic of another review. There was a wide variation found in international estimates of the energy requirements for maintenance in growth, and some of the variation was related to the method of prediction, and meta-data analysis adds further variability by includingdifferent ages, breeds, sexes and levels of activity. Australian and NZ goats appear to have a sensitivity to photoperiod, with LWG depressed between the months of April and June. It is suggested that this period should be avoided when supplementary feeding is planned. The genetic potential of Rangeland goats was explored, with maximum values for LWG being about 14 g/kg $LW^{0.75}$.day (160 g/day) under pastoral conditions in New South Wales, and about 20 g/kg $LW^{0.75}$.day (190 g/day) when fed good quality (M/D = 11) pelleted concentrate diets during the spring growth period. It was concluded that no national or international authority (i.e. AFRC 1998, NRDR 2007, NRC 2007) have accurately predicted the composition of LWG of Australian Rangeland goats, and that some reappraisal of these requirements may be needed. The experiments proposed in the current project will contribute significantly to answering some of these questions.

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10.3 Appendix 3. Feeding goats in outdoor pens

Introduction

At the commencement of this project goats less than 25 kg LW were of NCV to producers. At the end of each experiment undertaken within the current project a portion of the goats remained under 25 kg; this was an expected result of the supplement dose-response where goats offered no or low supplement allowances were expected to have low LWG. Therefore, the project was faced with the same issue as industry; how to convert these low LW goats of NCV to a heavier goat that was a commercially valuable product. As a result, goats were grown out in smaller group pens at the end of each experiment, with slight modifications to the feeding and management approach on each occasion.

Materials and methods

After the completion of Experiments 1 and 2, and concurrent with Experiments 3a and 3b (utilising spare goats from these experiments) goats were held in group pens with *ad libitum* access to high quality diets. After Experiments 1 and 2, the intention was to increase LW of goats to above 25 kg for subsequent sale and slaughter. Concurrent with Experiments 3a and 3b the intention was to maintain goats on the maximum possible growth trajectory for subsequent sale and slaughter when the planned experiments were concluded. These recovery periods (referred to as Phase 2 of all experiments) were not part of the original project and were not implemented in such a way that would allow for statistical analysis of intake data (i.e. no individual replication of intake). As such, the results below must be viewed with caution. Nevertheless, the results provide some insights into potential growth rates of Rangeland goats under confinement feeding conditions and identify some of the opportunities and challenges associated with a more intensive feeding management system for entire male Rangeland goats. Approval was obtained from The University of Queensland Animal Ethics Committee to maintain and grow-out the goats as described below.

Experiment 1

After completion of Experiment 1, goats were allocated to a diet of either lucerne hay and Mitchell grass hay *ad libitum* (Lucerne) or a starch based commercial pellet (Ridley Agri-products; 11.7 MJ ME, 135 g CP, 225 g crude fibre, 11 g crude fat, 7.3 g Ca, 2.8 g P, 1.7 g S, 2.8 g Mg/kg DM with 28 mg monensin/kg included in the form of Rumensin100) and Mitchell grass hay *ad libitum* (Pellet). The Mitchell grass was the same as that used during Phase 1 of this experiment. Goats (19.7 ± 2.5 kg LW) were allocated to either of these treatments based on LW ranking, allocation block and dietary treatment during Phase 1. This resulted in approximately equal representation of goats from each of the three LW blocks (light, medium, heavy) and Phase 1 dietary treatments in each of the Lucerne and Pellet treatment groups (n=27/group). Goats were adapted to their respective treatment diets for 5- to 7-days in the individual pens before relocation to outdoor group pens (1 pen/treatment) adjacent to the shed where the Phase 1 period of the experiment was conducted with natural shade (Figure 41) and *ad libitum* access to water. Hay was provided in racks and pellets in a self-feeder; hay and pellets were added as required and water was available to each group at all times. Goats were weighed at the same time of day approximately every 14-days over a 64-day period.

Experiment 2

Concurrent with Experiment 2, omitted goats were divided into two groups (n=13/group) based on LW and placed in two adjacent outdoor pens. Both groups of goats had access to Mitchell grass hay and water *ad libitum* and the same rolled-wheat fed in the main experiment offered at either 18 g DM/kg LW.day (18) or *ad libitum* (AL). Goats were weighed every 7-days. Rolled-wheat was available at all times in a self-feeder (Advantage Feeders) for AL goats or offered in approximately equal portions in the morning and afternoon in open feed troughs with approximately 1 m trough spacing per goat in the 18 group. For goats in the 18 group, rolled-wheat allowances were calculated based on the total LW of the group at each weighing with daily allowances prepared for the next 7-days and adjusted at each weighing. Whilst no statistical comparison between these two groups or the experimental goats are possible, this was established to give some indication of the effect of individual indoor vs group based outdoor feeding, and differences between a high rolled-wheat supplement intake (18) vs *ad libitum* rolled-wheat intake.

After completion of Experiment 2, experimental goats and omitted (outdoor) goats were separated into Heavy (n=40; 26.9 ± 2.8 kg LW) and Light (n=40; 19.7 ± 1.9 kg LW) groups to avoid some of the bullying issues observed with goats fed pellets during Phase 2 of Experiment 1. Both groups of goats were fed the same starch-based commercial pellet and Mitchell grass hay as used in Phase 2 of Experiment 1 above. Mitchell grass hay was available *ad libitum* throughout this period, while goats were adapted to the pellet over 21-days prior to *ad libitum* feeding for an additional 21-days. Hay was provided in suspended hay nets and pellets were provided in self-feeders; hay and pellets were added as required and water was available to each group at all times. Both groups had abundant artificial shade with timber sleepers, plastic drums and exercise balls provided for additional enrichment (Figure 42). Goats were weighed at the same time on days 1, 21, 31 and 42 of the 42-day period.

Experiments 3a and 3b

Goats that were omitted from Experiments 3a and 3b (due to outlying LW, feeding behaviour, sex) were separated into Heavy (n=8; 30.1 ± 1.7 kg LW) and Light (n=11; 19.9 ± 3.1 kg LW) groups. Both groups of goats were fed the same starch based commercial pellet used in Phase 2 of Experiments 1 and 2 with *ad libitum* access to barley straw (920 g OM, 39 g CP, 61 g NDF, 2.1 g Ca and 0.5 g P/kg DM) as a roughage source. The goats were adapted to a starch based commercial pellet (Barastoc goat pellet, Ridley Agri-products) for 21-days prior to the commencement of this period, as a result no additional adaptation period was required. Barley straw was provided in hay feeders and pellets were provided in self-feeders; hay and pellets were added as required and water was available to each group at all times. Both groups had abundant artificial shade with enrichment provided as described for Experiment 2. Goats were weighed at the same time every 7-days over the 64-day period. Body condition score and number of milk teeth were recorded at the completion of this period. A number of castrated goats were within this group (n=1 and n=2 in the Heavy and Light groups respectively) and these were excluded from the results presented below.

a.

b.

Figure 41. Goats introduced to pellets (a) and lucerne hay (b) with Mitchell grass hay available during Phase 2 of Experiment 1.

a.

b.

Figure 42. Goats held in outdoor groups pens with access to Mitchell grass hay in suspended nets (a.) and with additional enrichment provided (b.).

a.

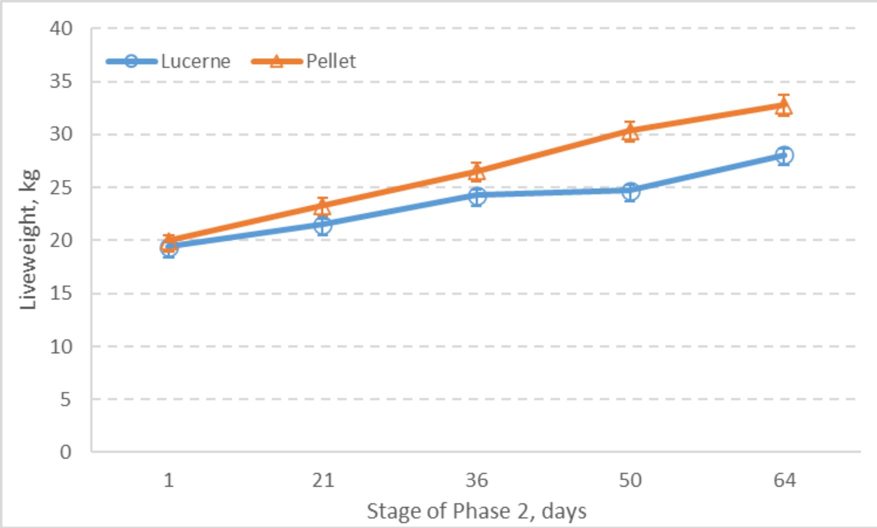
b.

Figure 43. Light goats with *ad libitum* access to pellets (a.) and heavy goats with enrichment and artificial shade (b.).

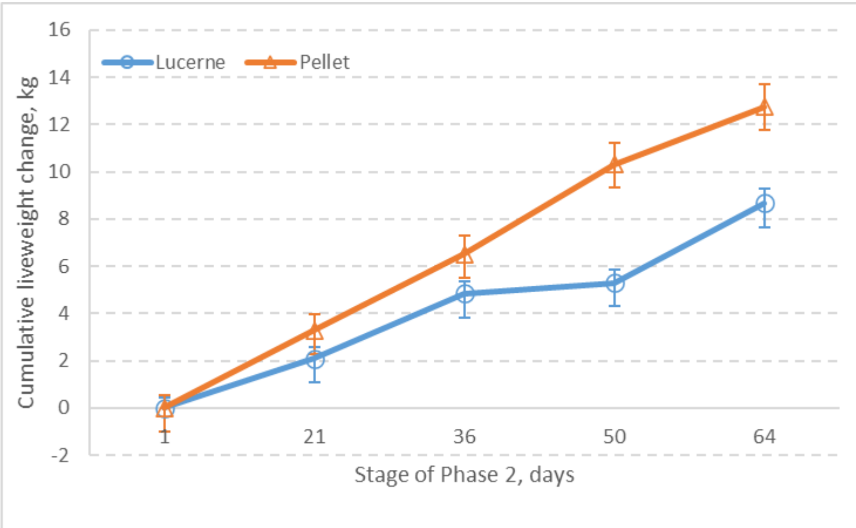
Results

Experiment 1

During Phase 2 of Experiment 1, goats offered pellets had an average LWG of 209 ± 11 g/day (range 99 to 318 g/day) while goats offered lucerne hay during the same period had an average LWG of 132 ± 7 g/day (range 64 to 205 g/day) (Figure 44). The results demonstrate the significant animal to animal variation in responses to diets which is unsurprising given the likely genetic diversity amongst Rangeland goats. Despite the wide variation in LW at the commencement of Phase 2 there was no evidence that LW *per se* affected the LWG response to diets during Phase 2 (Figure 45) within the LW range of goats included in the measurement period. The average hot carcass weight was 14.4 ± 0.3 kg (range 11.2 to 20.4 kg) with an overall dressing percentage of 45. While it was not possible to accurately quantify hay (Mitchell or lucerne) intake during this period, both groups consumed progressively less of the Mitchell grass hay available across the phase, with almost no Mitchell grass hay consumed over the final four weeks by either group. It was estimated that mean pellet intake was 0.95 kg/goat.day over the period which would equate to a feed conversion efficiency of approximately 5 kg pellets (as fed)/kg LWG.



a.



b.

Figure 44. Liveweight (a.) and cumulative liveweight change (b.) of entire male Rangeland goats fed lucerne hay or commercial starch-based pellets in group pens for 64-days after Experiment 1.

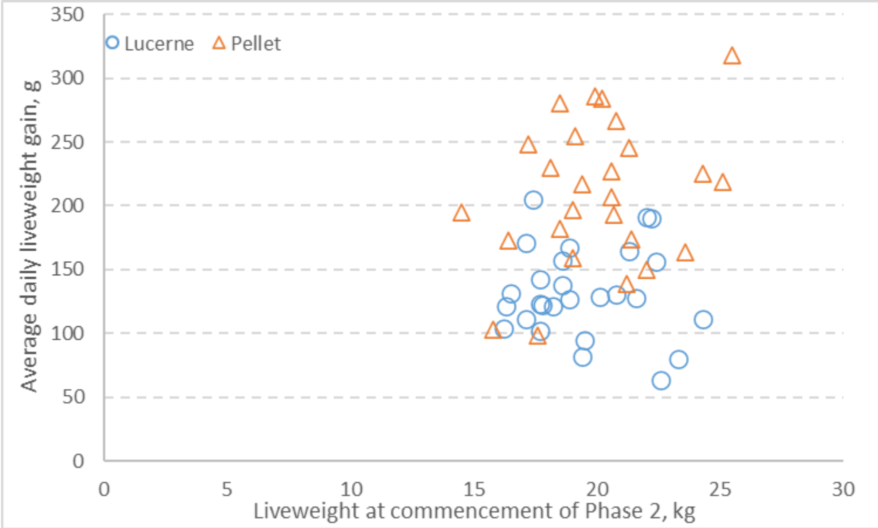
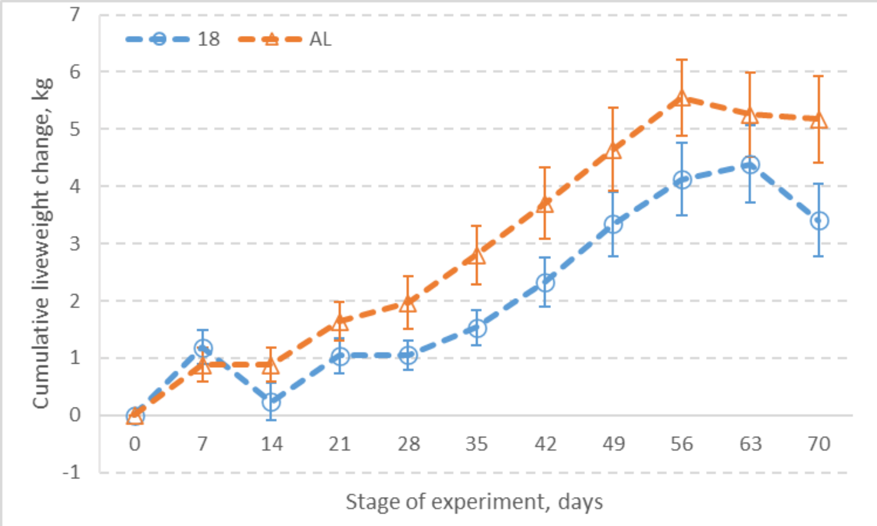


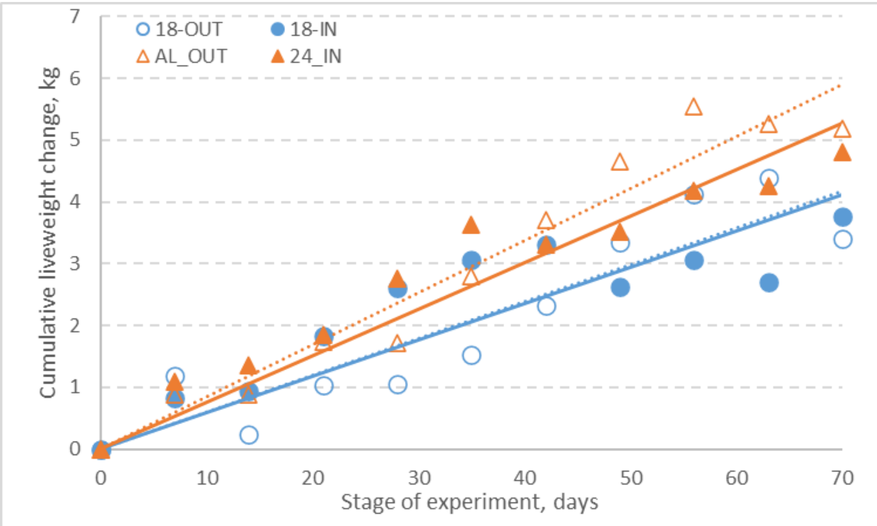
Figure 45. Relationship between liveweight at the commencement of Phase 2 and liveweight gain of entire male Rangeland goats fed lucerne hay or commercial starch-based pellets for 64-days after Experiment 1.

Experiment 2

Goats fed rolled-wheat at 18 g DM/kg LW.day consumed the full allocation of wheat at each morning and afternoon feeding and had an average LWG of 62 ± 10 g/day over the 70-day measurement period. Goats with *ad libitum* access to the rolled-wheat consumed the equivalent of 22 g DM/kg LW.day and had an average LWG of 84 ± 13 g/day over the 70-day measurement period (Figure 46). This equated to a rolled-wheat (DM) intake to LW conversion of approximately 7 for the *ad libitum* group. The intake of Mitchell grass hay was unable to be measured in these group pens. There was high variability in LWG in both groups, at least in part due to social and behavioural issues with bullying apparent, particularly in the 18 group. Goats were removed from this group at various stages (and data is omitted from the above results and figure below) and managed as a separate smaller group. It was observed that the restricted feeding often resulted in very rapid consumption of the rolled-wheat, with less dominant goats having less opportunity to consume the rolled-wheat, whilst goats that consumed the rolled-wheat too rapidly developed mild digestive upsets typically observed as loose faeces for a short period of time. The reduced LWG of goats in the final two weeks was associated with the start of a period of increased rainfall and there was a noticeable reduction in intake of rolled-wheat by both groups of goats. The LWG of goats in the outdoor pens were comparable to that measured for goats held in individual indoor pens fed approximately equivalent diets (WHT18 and WHT24) and would suggest that individual indoor penning of goats had little impact on intake or LWG when fed high amounts of a rolled-grain supplement within the conditions of the current experiment.



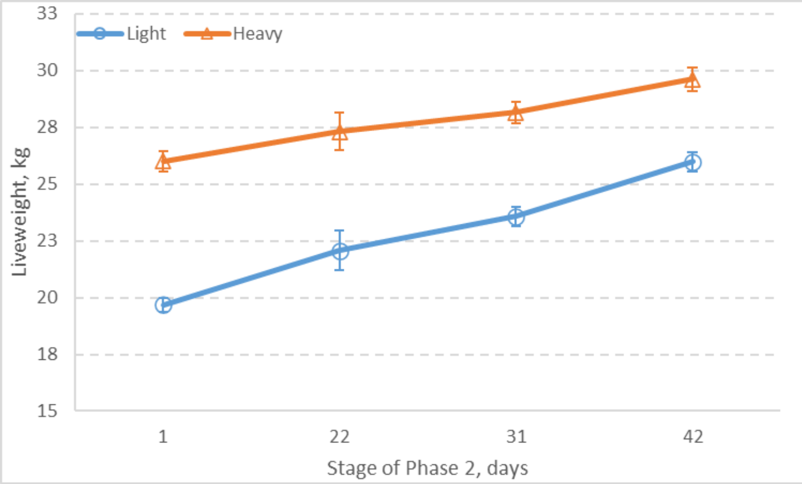
a.



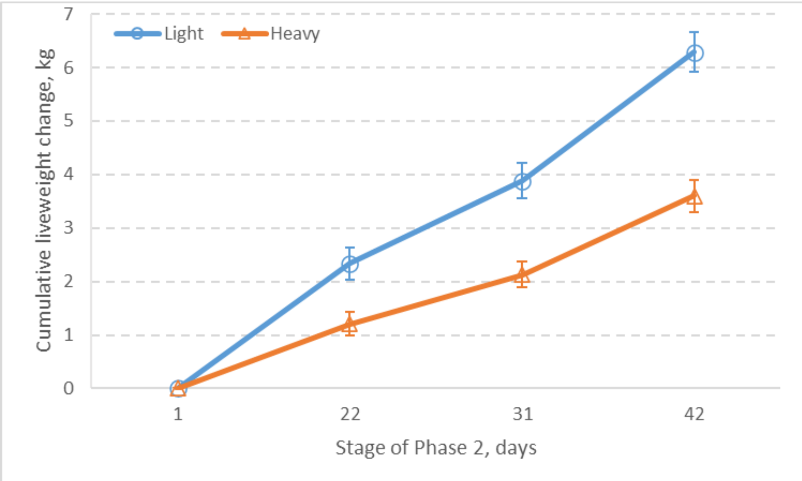
b.

Figure 46. Cumulative liveweight (LW) change of entire male Rangeland goats fed rolled-wheat at 18 g DM/kg LW.day (18) or *ad libitum* (AL), with *ad libitum* access to Mitchell grass hay and water in outdoor pens (a.) and the comparison of cumulative LW change of goats fed approximately equivalent amounts of rolled-wheat in outdoor group pens (dotted lines) and individual indoor pens (solid lines) (b.).

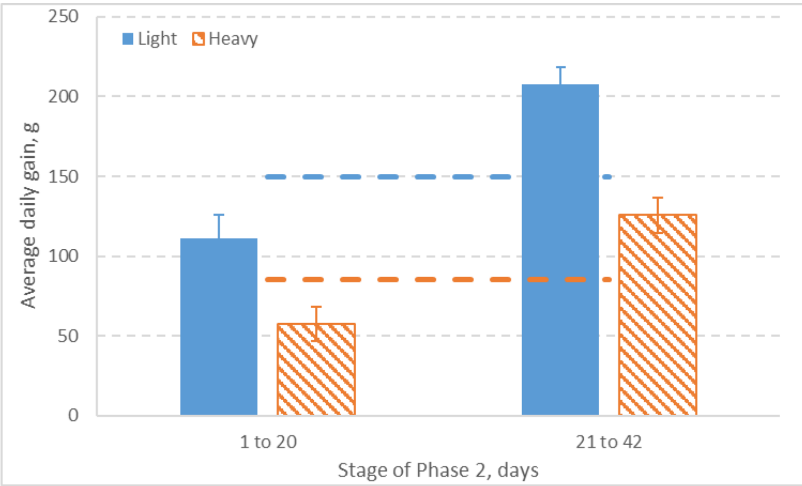
During Phase 2 of Experiment 2, Heavy goats had lower LWG than Light goats (85 ± 7 and 150 ± 9 g/day) over the entire 42-day period, and this difference in LWG between Light and Heavy goats was similar (although LWG for both was quantitatively higher) during the second 21-day period during which goats were fully adapted to the pellets and were provided *ad libitum* access (121 ± 12 and 209 ± 11 g/day) (Figure 47). The results demonstrate that high LWG (200 g/day) is achievable for young entire male Rangeland goats once adapted to a high ME diet but that wide variation in LWG exists between individual goats (-20 to 350 g/day). In contrast to Experiment 1, a negative relationship appeared to exist between LW at the commencement of Phase 2 and LWG over the 42-day period (Figure 48). The average hot carcass weight was 13.0 ± 0.3 kg (range 9.1 to 18.5 kg) with an overall dressing percentage of 46.



a.



b.



c.

Figure 47. Liveweight (a.), cumulative liveweight change (b.) and average daily liveweight gain (c.) of entire male Rangeland goats fed commercial starch-based pellets in group pens for 42-days after Experiment 2. Goats were classified as Light (19.7 ± 1.9 kg) or Heavy (26.9 ± 2.8 kg) based on their liveweight at the commencement of the Phase 2 period.

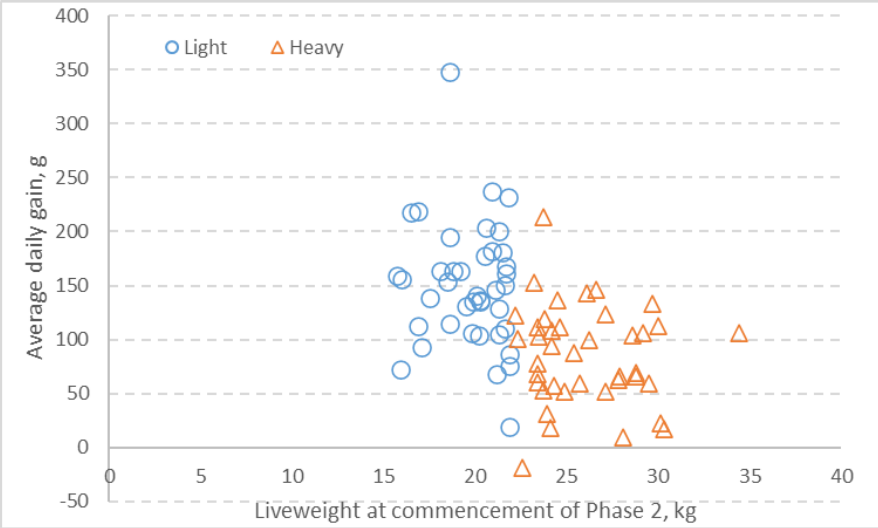
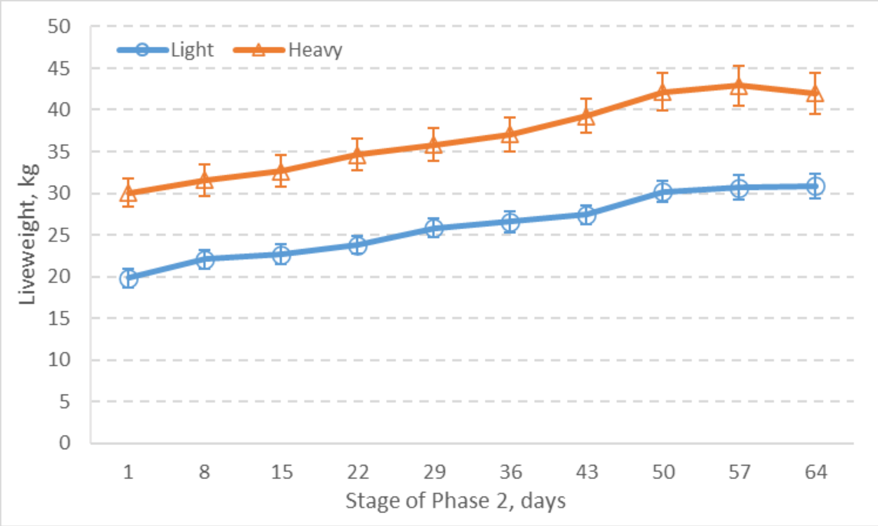


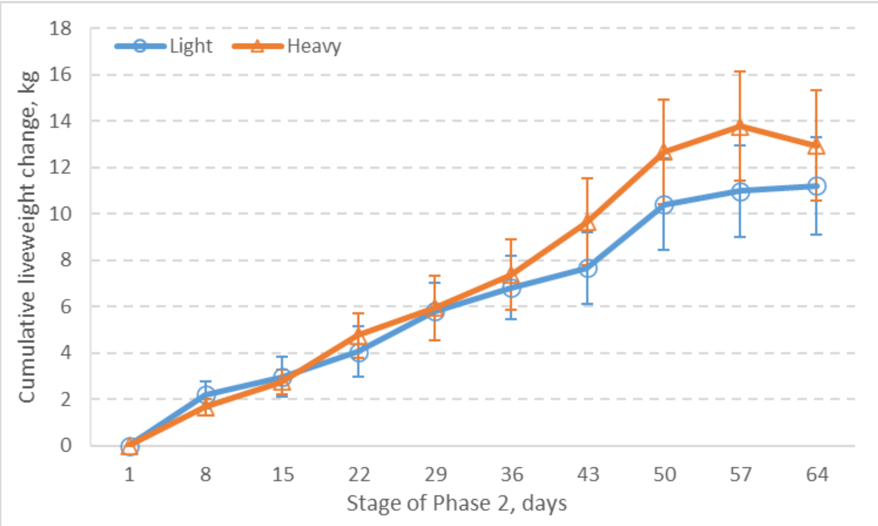
Figure 48. Relationship between liveweight at the commencement of Phase 2 and liveweight gain of entire male Rangeland goats fed commercial starch-based pellets for 42-days after Experiment 2.

Experiments 3a and 3b

In contrast to Phase 2 of Experiment 2, Heavy goats had higher LWG than Light goats (237 ± 44 and 181 ± 32 g/day; castrates excluded) over the 64-day period during Phase 2 of Experiments 3a and 3b. It was estimated that Heavy goats had a lower feed conversion efficiency than Light goats (6.1 vs 4.9 kg pellets (as fed)/kg LWG). It should be noted that hay intake could not be measured but was assumed to be minimal (~10 to 15% of total intake) and similar between the two groups based on visual estimates. There was little evidence that the Heavy goats (43.9 ± 6.1 kg LW) were approaching a mature liveweight or that Light goats (30.6 ± 4.4 kg LW) were undergoing compensatory gain at the end of the Phase 2 period given that growth rates appeared to be continuing in a linear and parallel fashion for both groups (Figure 49) and there was no relationship between starting LW and LWG over the 64-day period (Figure 50). The results again demonstrate that LWG of ~200 g/day are achievable for entire male Rangeland goats fed in group pens but that a wide variation (70 to 370 g/day) exists in this response independent of LW at the start of the feeding period, within the goats, diets and timeframe of this Phase 2 period (Figure 50). The average hot carcass weight was 13.4 ± 0.3 kg (range 8.2 to 21.8 kg; dressing percentage could not be calculated for these goats due to COVID-19 workplace restrictions at the time of transportation). It was estimated that mean pellet intake was approximately 0.88 and 1.28 kg/goat.day (Light and Heavy goats respectively) over the period which would equate to a feed conversion efficiency of approximately 5 and 6 kg pellets (as fed)/kg LWG for Light and Heavy entire male Rangeland goats respectively.



a.



b.

Figure 49. Liveweight (a.) and cumulative liveweight change (b.) of entire male Rangeland goats fed a commercial starch-based pellet in group pens for 64-days concurrent to Experiments 3a and 3b. Goats were classified as Light (< 25 kg) or Heavy (> 25 kg) based on their liveweight at the commencement of the Phase 2 period.

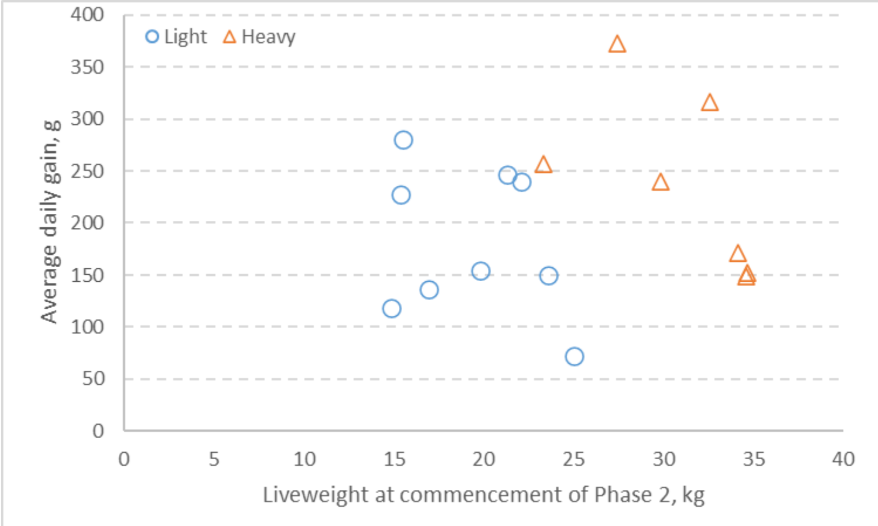


Figure 50. Relationship between liveweight at commencement of Phase 2 and average daily liveweight gain during Phase 2 of entire male Rangeland goats fed a commercial starch-based pellet in group pens for 64-days concurrent to Experiments 3a and 3b.

Discussion

Across all three experiments the average LWG of entire male Rangeland goats fed the same commercially available starch-based pellet was approximately 200 g/day with an estimated feed conversion efficiency of between 5 and 6 kg pellets (as fed)/kg LWG. The response was generally unaffected by LW at the start of each feeding period, suggesting that goats were in a similar part of the growth path over the range of LW tested (~19 to 30 kg mean LW at start of each period), and there was little evidence of compensatory LWG by lighter goats (except potentially in Phase 2 of Experiment 2). It is therefore concluded that a LWG of 150 to 200 g/day (1 to 1.4 kg/week) is achievable for young entire male Rangeland goats with *ad libitum* access to a high-quality ration and a source of roughage to maintain rumen function, in a confinement feeding system with enrichment. This is significantly higher than the maximum of 0.45 kg/week reported for castrated BoerxFeral goats in an enriched feedlot environment (Flint and Murray, 2001).

The LWG reported here (150 to 200 g/day) are amongst the highest in the literature for this class of Rangeland goat. Associated with this project, and in addition to the review undertaken by Norton (Appendix 2), growth rate data was collated from the literature for Rangeland goats (with the search term expanded to include Feral, Bush and Australian Cashmere goats). McGregor (2005) also collated growth rate data on Feral, Cashmere, Angora, Boer and dairy breed goats in Australia and concluded that the highest growth rates in the literature were for kids prior to weaning when does are grazing spring pastures in southern Australia (135 g/day). McGregor identified 52 treatment responses in total for feral goats that were not cross-bred with other pure-bred goats; this included kids, weaners, and more mature does, bucks, wethers raised under a range of conditions (individual and group pens, grazing pastures and crops with and without supplementation). The collation undertaken within the current project attempted to capture descriptive data on the experimental animal (pre-weaning, weaner, mature; doe, buck, wether, or mixed), the time of year the experiment was conducted (month range), initial liveweight and nutritional management (or treatments); Boer-Rangeland and Angora-Rangeland goats were excluded from the data-set, however Cashmere-Rangeland goats were retained. The data-set resulted in some 102 LWG measures for goats after weaning, although the description of the experimental model from which the data was derived was not always complete (i.e. month, initial liveweight, sex, any even nutritional management may have been incompletely described). The LWG of weaned Rangeland goats ranged from -32 to 162 g/day with an overall mean of 61 g/day. The lowest LWG were associated with studies conducted during periods of decreasing daylength (incorporating March to July); a surprisingly large number of studies were undertaken during these months when it is assumed a declining photoperiod mediates a suppression of intake, and hence, reduces LWG. The highest LWG (162 g/day) was for mixed sex weaners grazing native grass and lucerne pastures at Condobolin (Allan and Holst, 1989) was assumed to be the Condobolin selection line described by Holst et al. 1982, 1984. Across the entire data-set, where treatment means were specifically described by sex, bucks gained more LW than does (61 v 44 g/day). Across the entire data-set there was insufficient description of the nutritional content of the diets to make any conclusions around the nutritional requirements of Rangeland goats; in studies where the CP content of the diet was reported it was never below 100 g/kg DM.

Across all experiments in the current project there was a large range in average LWG between individual entire male Rangeland goats fed high quality diets (predominately starch-based pellets) in group pens (-20 to 370 g/day). Whilst undoubtedly behavioural factors (e.g. bullying, shy/dominant feeders) and, potentially, carry-over factors (e.g. compensatory gain) influenced this variation, it is also plausible that genetic factors may have also contributed to this variation. Holst, Pym (1977, 1982, 1985) reported an approximately 10% increase in LW (birth, weaning and 5 months of age) of male Rangeland goats when selected on LW at 5 months of age, and adjusted for litter size and dam age, with a heritability of 0.35. Within a breed, goats reportedly have greater genetic diversity than within sheep and cattle breeds, with Rangeland goats having higher genetic diversity than Cashmere or Boer goats in Australia (Kijas et al. 2013). The variation in individual LWG measured here, coupled with the high genetic diversity, would suggest that rapid gains in productivity could be made if selection was applied on the basis of increased LW at a specific age or time of year. The extensive nature of the Rangeland goat production systems makes intensive measurements to inform the selection of superior genotypes within the existing population a challenge. The development of genomic tools (e.g. single nucleotide polymorphism (SNP) chips, high throughput sequencing, high capacity bioinformatic processing) that are increasing in portability and decreasing in cost, may provide the tools to facilitate in-field genomic selection in the future.

Assuming a mean LW of 25 kg (11.2 kg $LW^{0.75}$), a LWG of 200 g/day (17.6 g ADG/kg $LW^{0.75}$), a total DM intake of 940 g/day (90% pellet DM intake + 10% hay DM intake) and a total ME intake of 10.5 MJ/day (assuming 11.7 MJ ME/kg pellet DM and 5.6 MJ ME (43% DMD)/kg hay DM) or 420 kJ/kg LW.day (37.5 kJ/kg $LW^{0.75}$.day) which is higher (less efficient use of ME for LWG) than that determined by Ash and Norton (1987) and Luo et al. (2004) but comparable to that determined in the pen studies conducted within this project.

During the Phase 2 periods of each of the experiments reported here, after a two- to three-week period of adaptation to the starch-based pellets goats had *ad libitum* access to the pellets from self-feeders, hay from racks or nets and clean drinking water; self-feeders were fully open once *ad libitum* feeding commenced. No incidences of acidosis or bloat were observed, although a low coccidia burden was detected for goats fed lucerne hay in Experiment 1, which was attributed to goats contaminating the hay. This was resolved through a physical barrier in Experiment 1, the use of hay nets in Experiment 2 and the placement of 100 x 100 mm weldmesh over hay feeders in Experiments 3a and 3b. The physical barriers also reduced the risk of goats getting trapped within hay feeders and reduced wastage of roughage. Whilst no incidences of acidosis occurred during the Phase 2 periods, several incidences did occur with goats transitioned from individual pens to group pens at the end of Experiments 3a and 3b. On this occasion, even though the goats were adapted to the pellets and had been fed prior to entry to the self-feeders several Light goats gorged themselves when pellets became available *ad libitum*, as opposed to the set feeding schedule when in the individual pens. It is considered that feeding starch-based pellets is relatively safe for goats after a three-week adaptation period providing the pellets (concentrate) and hay (roughage) are available at all times so that goats have the potential to self-regulate their intake of both concentrate and roughage.

Refinement of standard feeding infrastructure may also be required for goats when fed in group pens, particularly to restrict access of goats to roughages to minimise wastage and faecal contamination of feeds (Figure 51). Ring barking of tree's was also observed (Figure 52) and this issue should also be considered when identifying sites for confinement feeding of goats. Behavioural issues such as dominance, shy feeding and mounting were all observed in the group feeding conditions (Figure 53). Segregation of goats on a LW basis and the provision of additional enrichment in Phase 2 of Experiments 2 and 3a and 3b resolved this issue to some extent, but assertive dominant behaviours were still observed. It is difficult to see how this could be completely overcome in a group feeding situation where social interaction and attempts for dominance in the social structure are likely to always occur, particularly with entire males.

Whilst the activities described here were not designed in a way that would allow for statistical analysis of data, they do demonstrate the potential LWG of entire male Rangeland goats under confinement feeding. The results raise additional questions that may warrant further investigation with specific reference to the approach of confinement feeding to finish goats (or to achieve critical mating LW in young does prior to their first or second mating). Some of the questions that may warrant further investigation have been incorporated into the recommendations for future research described in Section 7 of the main report.

a.

b.

c.

d.

e.

f.

Figure 51. Modifications to roughage feeding infrastructure employed across the experiments to minimise wastage, contamination and access inside the feeders through an additional cover (a. and b.), use of hay nets (c. and d.) and weld-mesh (e. and f.).

Figure 52. Ring barking of tree's by young entire male Rangeland goats in confinement feeding.

Figure 53. Behavioural issues displayed by young entire male Rangeland goats in confinement feeding.

Conclusions

These activities demonstrated that growth rates of 1 to 1.4 kg/day are attainable for young entire male Rangeland goats fed a starch-based ration under confinement feeding conditions. In addition, the results demonstrate significant variation in LWG under these conditions and suggest that opportunity may exist for selection of genotypes for higher growth potential whilst maintaining the hardiness traits that allow Rangeland goats to survive under semi-arid and arid conditions. There were no major differences in intake or LWG between goats held in individual indoor pens compared with small group outdoor pens, providing some confidence in the experimental approach taken. It is concluded that short-term confinement feeding of high-quality diets may be a feasible feeding and finishing strategy to increase growth rates and carcass weights and reduce turn-off age of young entire male Rangeland goats, whilst reducing grazing pressure on the Rangelands. Further research is recommended on a range of issues identified above regarding the establishment, economics and associated benefits (Rangeland condition, life-cycle assessment of greenhouse gas inventories) of confinement feeding of Rangeland (and other genotypes of goats).

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10.4 Appendix 4. Collation of commercially available goat rations

Table 21. Nutritive value of a range of commercially available goat pellets and the commercial pellet[1] fed to goats in Phase 2 of Experiments 1, 2 and 3.

Product description	Pellet[1]	Goat Pellet	All Breed Goat Meal	Fattening Goat Pellet	Goat Nut	Lactating Goat Pellet	Grower Goat Pellet	Goat Pellet	Goat Pellet
Dry matter basis[2]	Yes	Yes	N/D	N/D	N/D	N/D	N/D	Yes	N/D
Total crude protein, %	13.5	15.7	15	16	14	16	14	18.0	14.2
Urea, %	0.9	0.0	0	1	1			0	
Crude fat, %	1.1	2.2	3	4	4				
Crude Fibre, %	22.5	13.5	10	9	9	10	8	9.6	19
Salt, %	0.56	0.6	2	0.34	1	0.5	0.5	1	
ME MJ/kg DM	11.7	11.8		12	12.5	10.7	11	11.7	11.6
Ca, %	0.73	1.0	2.4	1		1.5	0.8	2.24	0.11
P, %	0.28	0.6	0.45	0.55		0.6	0.4	0.78	0.62
S, %	0.17		0.15	0.25	0.02				0.14
Mg, %	0.28		0.35	0.25	0.007				0.019
Cu, mg/kg	11.2	22	10	10	10	12	12		30
Se, mg/kg	0.11	0.2	0.15	0.15	0.15	0.1	0.1		
Zn, mg/kg	44	90	25	40	25	40	40		
Mn, mg/kg	33.7	67	25	30	25	40	40		130
Mo, mg/kg	0.34	0.7							
Co, mg/kg	0.17	0.3	0.11	0.2	0.2	0.5	0.5		
I, mg/kg	0.34	0.7	0.3	0.3	0.3	0.5	0.5		
Fe, mg/kg			30	25	25	50	50		370
Vit A, IU/kg	3932	7865	4000		4000	10050	6700		
Vit D, IU/kg	393	787	400		400	1200	800		
Vit E, mg/kg	34	67	15		10	37.5	25		
Monenesin, mg/kg	28	0.0	0	0	0	0	25		

[2]Description on product specification reported on a dry matter basis – Yes, No, N/D (not determined); information collated from various online sources, May-2020.