Deer seasonal growth pathways

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Abstract

Red deer are seasonal and generally experience a period of low growth in winter. Previous research has demonstrated that individuals vary in the degree of their seasonality. Mechanisms that drive the differences in seasonality are not well understood. Six sires paired by 12-month weight estimated Breeding Value (eBV) but with contrasting seasonality were used to generate progeny to investigate the mechanisms that influence seasonal growth. Progeny were fed *ad-lib* on pasture year-round to allow expression of genetic potential with liveweight monitored fortnightly. Feed intake and efficiency were estimated during a 10-day period in each season. Analysis of seasonal liveweight gains indicated that predicted seasonal growth rates were repeatable within sire lines. Significant differences within paired sire lines in growth rates were expressed during winter for the two lower 12-month weight eBV paired groupings. Winter intakes were estimated to be lower than spring intakes although absolute values were considerably higher than expected. Variations in estimated feed efficiency between sire-line pairings were significant in all seasons apart from summer however, more research is required to correlate this estimation technique against actual feed efficiency. This research demonstrated that variation in the degree of seasonality between sires does exist and could be exploited for management decisions.

Keywords: red deer; *Cervus elaphus*; seasonality; growth; feed intake; feed efficiency

Introduction

The seasonality of food intake and growth of red deer has long been an underlying principle driving feeding strategies for farmed deer (Stevens et al. 2003). While seasonal growth in red deer has been historically considered as inflexible, recent analysis of detailed stud deer liveweight records collected over 4 years has determined that there are significant genetic influences on variations in the autumn, winter and spring growth of weaner deer (Ward et al. 2021). The New Zealand deer herd is a composite herd (Archer et al. 2007) that is an admixture of many sub-species of red deer from across the European continent that may provide the source in seasonal growth variation. This variation provides an opportunity to select for deer that have growth rates that better match the feed supply of different farm systems or environments. For example, deer that grow faster in winter may better suit regions with a mild climate that have active winter pasture growth, while deer that grow slower in winter and faster in spring may be better suited to environments where pasture growth is more seasonal.

It is currently unknown if the differences in seasonal growth are linked to differences in feed intake/appetite regulation, animal feed type preferences (e.g. crops vs pasture), metabolic processes (i.e. feed efficiency) or behavioural differences. Understanding the processes driving differences in seasonal growth are critical to applying this knowledge in a farming context. If increased seasonal growth is a result of an up- or down-regulation of feed intake, then animals could be selected to align with different environments and feed supply profiles. If differences in growth between seasons is due to animal behaviour then farm management practices need to be considered for their effect on behaviour expression.

The potential impacts of choosing deer of different seasonal growth pathways (SGP) on the overall productivity and profitability of a farm system will only be determined once underlying physiological and behavioural mechanisms are understood. Further value may be realised if deer with different seasonal growth pathways have differences in digestion and feed conversion efficiency.

A trial was set up to investigate the expression of seasonal growth rates under the same nutritional conditions and to test the hypothesis that seasonal growth rate was a result of the regulation of feed intake or alternatively changes in feed conversion efficiency.

Materials and methods

All animal manipulations were approved by the Invermay Animal Ethics committee in accordance with the provisions of the New Zealand Animal Welfare Act 1999, and the New Zealand Codes of Welfare developed under sections 68-79 of the Act.

Progeny generation

Artificial insemination (AI) was used to generate progeny from 6 red-deer sires paired by their 12-month weight estimated breeding value (W12eBV), henceforth known as sire pairing. Each sire within each sire pairing represented a differing growth profile or pathway to 12-months of age (Table 1). The sires were selected based on the growth of their male progeny from previous research experiments based at the AgResearch Invermay Agricultural Research Centre, Mosgiel, New Zealand. Progeny growth rates over the autumn (post-weaning), winter and spring periods were assessed on a proportional growth rate of start of period liveweight. Final sire selection for each sire pair was primarily based on their similar W12eBV and contrasting male progeny winter growth rates representing a slower winter growth, (S) or faster winter growth, (F). However, due to limited availability of low W12eBV sires or semen, selecting sires with contrasting winter

Table 1 Sires used to generate progeny for seasonal growth pathways experiment, where W12 = 12-month, WWT = weaning, AWT = autumn and MWT = hind mature liveweight estimated breeding values (eBV) in kg. Sire pairing of stags based on weight 12 estimated breeding value and considered to be low, medium or high within this cohort and WinterSGP is the abbreviation given to explain the sires relative growth during winter compared to its sire pair and is considered to be either fast or slow.

Sire name	W12eBV	WWTeBV	AWTeBV	MWTeBV	Sire Pairing	WinterSGP
Aramis	0.5	-1.2	0.7	-6.0	Low	Slow
Claudius	1.9	3.4	2.3	-4.7	Low	Fast
Charles	14.2	12.6	15.1	8.8	Medium	Slow
Jeff	14.6	6.4	10.7	13.3	Medium	Fast
Nadal	29.1	18.5	22.7	24.8	High	Slow
R290/10	23.7	14.4	17.4	19.2	High	Fast

seasonality from the existing dataset was not possible. One sire with slightly faster growing progeny during winter was nominally classed as a fast growth winter sire however, compared to other sire pairings both demonstrated slower winter growth rates.

Progeny were identified using DNA pedigree testing (Genomnz, AgResearch Invermay Agricultural Research Centre, Mosgiel, New Zealand) and assigned to two mixed sex groups at weaning (~3 months of age) balanced by sire and sex. Animals were managed on *ad libitum* pasture supplemented with pasture baleage when required to allow the expression of their genetic potential for growth.

Liveweight

All animals were weighed at ~60 days-of-age on the 22 January 2018. From weaning on 27 February 2018 (~100 days-of-age) animals were weighed fortnightly until the end of the trial (04 February 2019) to the nearest 0.5 kg.

Feed Intake

Feed intake was measured during a single period in each of the three seasons (autumn, winter, spring) representing ~5, ~8, and ~11 months of age for 90 individual progeny balanced by sex and sire. Summer (~14 months of age) feed intake was measured on the females only due to practical issues with handling the larger male progeny.

Two feed marker methods were used to estimate feed intake at pasture: the alkane dilution technique (Dove & Mayes 1991) and the use of titanium dioxide (TiO_2) following a similar technique to that of Titgemeyer et al. (2001). Markers were combined in a single capsule for dosing, using 2.5 g of TiO_2 and 101 mg each of Dotriacontane (C_{32}) and Hexatriacontane (C_{36}) alkane powders and were measured into size 12 Torpac lock ring gelatin capsules (Torpac Inc. USA.). Animals were yarded and dosed with one gelatin capsule per day for 6 continuous days to achieve an equilibrium of makers within the gastrointestinal tract. Faecal samples were collected (per rectum) on days 6 and 7. Pasture samples were collected pre- and post-grazing by selectively plucking pasture, mimicking animal grazing behaviour. Faecal and pasture samples were freeze-dried in a Martin Christ Gamma 1-16 freeze drier for 85 hours with a final pressure of 0.500 mbar, condenser temperature of -55°C, and a shelf temperature of 20°C. Faecal samples were ground and consolidated into a single sample for each sampling period for each individual, using the same weight of material from each sampling day. Dried material samples, both faecal and pasture, were sent to the Analytical Department, Lincoln University, for alkane concentration analysis of C_{31}, C_{32}, C_{33} and C_{35} following a modified technique of Mayes et al. (1986) by digesting samples in an oven at 90°C instead of using a heated block. Intake was calculated using the alkane dilution in faeces (Dove & Mayes 1991), as the mean of that calculated from C_{31}:C_{32} and C_{33}:C_{32} ratios. Apparent organic matter digestibility (OMD) was calculated following Dove & Mayes (1991) where:

$$OMD = 1 - (Alk_H / Alk_F), \quad (1)$$

Where Alk_H is herbage alkane C_{35} content and Alk_F is faecal alkane C_{35} content.

TiO2 analysis of faecal samples followed the technique outlined in Garrett et al. (2020) where samples were digested and then analysed for Ti concentration using an inductively coupled plasma optical emission spectrophotometer (ICP-OES; Varian 720 ICP-OES, Varian Australia Pty Ltd). Daily faecal output was calculated following Garrett et al. (2020) using a Ti concentration adjusted for faecal recovery of 94% as previously found in deer (unpublished data) which is similar to that of beef cattle (Titgemeyer et al. 2001). Organic matter intake (OMI) was then calculated using the OMD calculated in equation 1 with following equation:

$$OMI_{Ti}\left(\frac{kg}{DM}\right) = Faecal\ Output\ \left(kg\frac{OM}{d}\right)/(1 - OMD), \quad (2)$$

Feed efficiency

Feed efficiency was measured at the same time as the feed intake measurements on the same 90 individuals using nitrogen fractionation as an efficiency estimation following Wheadon et al. (2014). Nitrogen fractionation measures the differential fractionation of two stable isotopes of N (^{14}N and ^{15}N) and the ratio change from heavy to light isotopes is expressed as δ. If this ratio is greater than 1 the tissue is enriched and expressed as Δ. The difference between $d^{15}N$ for plasma and $d^{15}N$ for the diet is termed $D^{15}N$. Briefly, a 10 ml blood sample was collected via jugular venepuncture using sodium heparin vacutainers on the first day dosing with feed intake markers during each season. Blood samples were centrifuged, and plasma drawn off and frozen at –20°C until freeze drying with a Martin Christ Gamma

1-16 freeze dryer. Samples were dried for a 48-hour period with a final vacuum of 0.500 mbar, a condenser temperature of –55°C and a shelf temperature of 20°C. Pasture samples were also collected at the time of blood sampling and dried following the same procedure as the blood samples. Once dried, samples were sent to the Analytical Department, Lincoln University, New Zealand, for analysis of ^{15}N content by isotope-ratio mass spectrometry.

Statistical analysis

All liveweight, feed intake and feed efficiency data were imported into the package R (R Core Team 2019) for statistical analysis. Liveweight data were separated into seasonal periods to calculate seasonal growth rates for autumn (22 March-22 May), winter (22 May-14 August), spring (14 August-4 December) and summer (4 December -4 February).

Variables were analysed in a fixed effects linear model, which included Group, sex, initial liveweight (for the season) nested within sex, and sire group (or equivalently, eBV-WinterSGP combination). Initial models included a term for the interaction between sex and sire group, but this was dropped from final models as it was never significant (P>0.05). Predicted means were calculated using the predictmeans package.

Results

Two animals died due to illness during the trial and one animal was culled due to temperament issues, leaving a total of 161 animals for analysis spread across the 6 sires (Table 1).

Liveweight and growth rate

Progeny liveweight for combined sexes aligned with the predicted genetic merit (Fig. 1a) for all sires except for the High-F and Medium-S sires. Due to a large skewing of gender ratios at birth only 7 females were produced from the High-F sire, biasing the mixed sex liveweight profile (Fig. 1a). However, when looking at within sex liveweights (Figs. 1b and c) the High-F progeny were similar in liveweight or lighter than the High-S progeny and therefore matched their W12eBV. The Medium-S sires' progeny exhibited greater than normal sexual dimorphism, which altered the rankings when separated by sex with males ranking higher and females ranking lower (Figs. 1b and c).

Seasonal growth rates were (P<0.001) different between progeny from sires grouped by W12eBV for all seasons apart from summer, suggesting that summer growth rate was not influenced by sire pairing (Table 2). However, live weight at the start of summer, regardless of sire, was (P<0.001) correlated with summer growth

Figure 1 Live weight of progeny from six sires paired by 12-month weight estimated breeding value (High, Medium and Low) with contrasting winter growth rate within each pair (F = fast and S = slow) to 440 days of age for combined sex (a), male progeny only (b) and female progeny only (c).

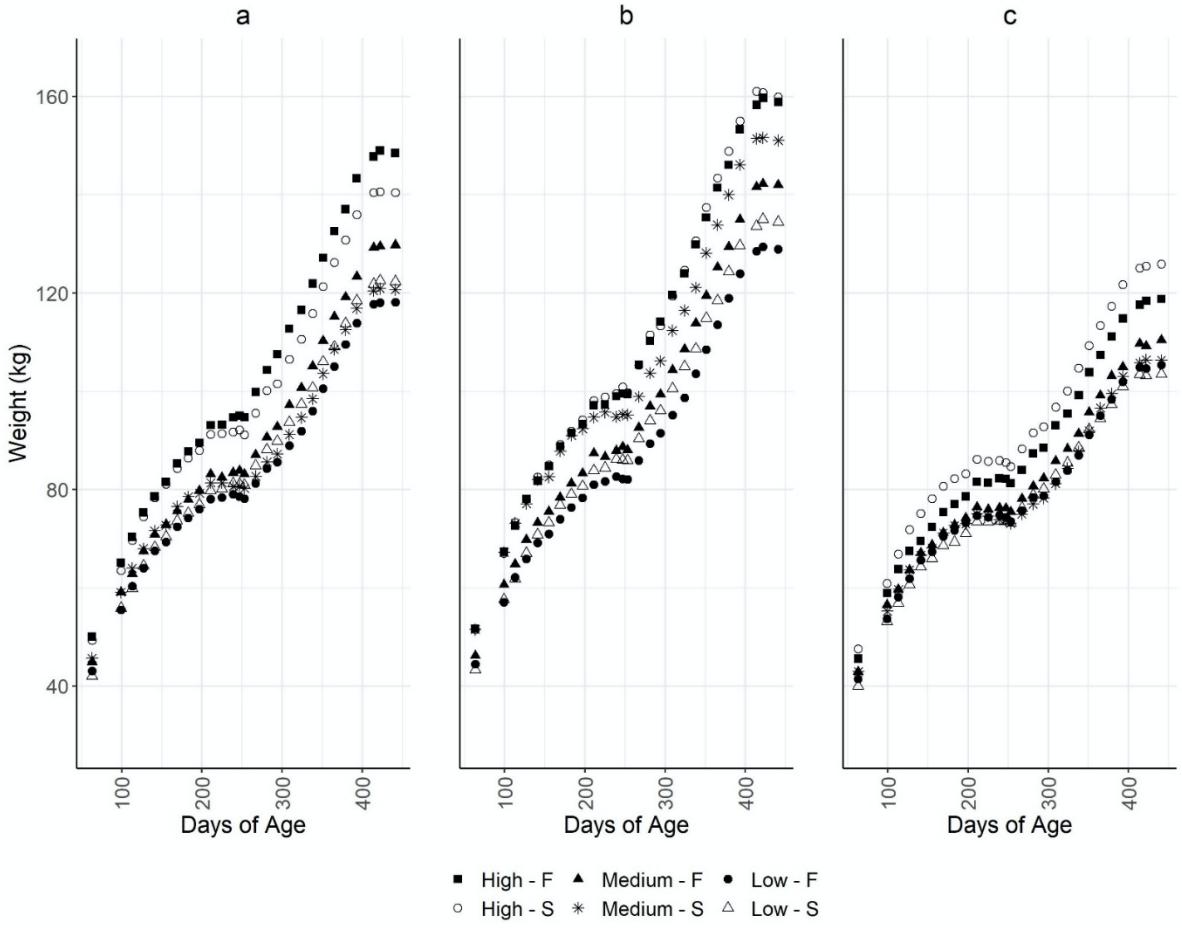

Table 2 Number and sex, average daily growth (g/d), Alkane and TiO2 marker estimated feed intake (kg DM/d) and Δ15N predicted feed efficiency for progeny from six different sires paired by W12eBV (Sire Pairing) and selected for divergent seasonal growth pathways to 12 months of age where Winter SGP is the relative winter growth rate within each sire pairing.

Sire Pair	High		Medium		Low		P value		
Winter SGP	Faster	Slower	Faster	Slower	Faster	Slower	W12eBV	Winter SGP	Interaction
Progeny #									
Male	20	12	19	9	13	14			
Female	7	16	12	19	11	9			
Daily gain, g/d									
Autumn	249.3^{b}	268.9^{a}	221.7^{c}	238.8^{bc}	226.8^{c}	231.6^{bc}	<0.001	0.010	0.524
Winter	116.5^{a}	108.5^{a}	97.9^{ab}	54.2^{c}	81.2^{b}	105.4^{a}	<0.001	0.080	<0.001
Spring	290.7^{b}	308.7^{a}	280.9^{b}	293.8^{ab}	262.8^{c}	256.3^{c}	<0.001	0.133	0.130
Summer	180.4^{ab}	169.6^{ab}	185.4^{a}	164.9^{ab}	165.0^{ab}	157.1^{b}	0.301	0.039	0.697
Alkane estimated feed intake, kg DM/d									
Autumn	5.48	5.37	4.29	5.10	3.20	4.09	0.095	0.381	0.732
Winter	3.90^{a}	3.07^{b}	3.37^{ab}	3.56^{ab}	2.75^{b}	3.97^{a}	0.816	0.322	0.003
Spring	7.93	7.09	6.53	7.43	5.47	8.03	0.700	0.196	0.089
Summer	4.31	4.15	4.22	4.63	3.62	3.84	0.188	0.641	0.751
TiO_2 estimated feed intake, kg DM/d									
Autumn	5.36	5.51	4.97	5.67	4.43	4.82	0.111	0.171	0.726
Winter	4.87^{ab}	4.20^{bc}	4.83^{ab}	5.58^{a}	3.68^{c}	4.50^{abc}	0.014	0.305	0.107
Spring	9.95	9.79	9.44	10.64	7.98	9.52	0.221	0.157	0.413
Summer	6.58	7.52	6.31	6.44	5.04	6.00	0.166	0.194	0.754
Feed efficiency, Δ15N									
Autumn	4.81^{abc}	4.68^{c}	4.91^{ab}	4.79^{bc}	4.90^{ab}	4.95^{a}	0.019	0.135	0.177
Winter	5.35^{ab}	5.28^{abc}	5.43^{a}	5.24^{bc}	5.06^{d}	5.16^{cd}	0.001	0.200	0.036
Spring	5.70^{b}	5.74^{b}	5.82^{ab}	5.73^{b}	5.82^{ab}	5.92^{a}	0.010	0.691	0.100
Summer	5.97^{ab}	5.92^{ab}	5.98^{a}	5.86^{ab}	5.79^{b}	5.77^{b}	0.083	0.142	0.713

^{ab}Means within rows with different superscripts are different (P<0.05)

rate with the heaviest animals growing the fastest. During autumn, the High-F progeny grew slower (P<0.05) than the High-S progeny (Table 2). During the winter period the Medium-F and Low-S progeny grew faster (P<0.05) than progeny from their paired sire progeny (Table 2), The growth of the Medium-S progeny during winter was almost half that of the Medium-F progeny and was (P<0.05) slower than all other progeny groups. The two sires selected for the low pair were not considered to have divergent winter growth rates based on previous data. In the winter, Low-S progeny grew (P<0.05) faster than the progeny of the sire assigned as Low-F (Table 2). Winter growth rate did not differ within sires that had a high EBV for 12-month-old weight (Table 2).

Spring growth rate was significantly different (P<0.05) within the high sire pairing with the High-S progeny growing 15 g/day faster than the High-F progeny (Table 2). The low sire pairings were significantly slower (P<0.001) at growing during spring than the other two pairings but did not differ from each other.

Feed intake

Estimated feed intakes measured by alkane and TiO_2 (Table 2) were higher than expected. The highest predicted feed intakes occurred in spring as measured by both techniques with the lowest intakes during the winter. The alkane analysis indicated that the High-F progeny had a higher intake (P<0.05) than the High-S progeny during winter despite there being no difference detected in growth rate during the same period. Utilising the alkane methodology, the Low-S progeny had a greater intake than the Low-F progeny and this was also demonstrated with increased growth rates during the same period (Table 2).

The TiO2 analysis indicated that the medium sire pair had significantly (P<0.01) higher intake rates in winter than the low sire pair. No other significant differences were seen between or within sire pairings.

Feed efficiency

Nitrogen isotopic fractionation was (P=0.005) different in autumn on average between the high and low sire pairing with the high sire progeny having the lowest D15N and the low sire progeny the highest D15N. In spring the low sire pairing on average had significantly higher D15N than the high sire pairing (P=0.01) and medium sire pairing (P<0.05). The only significant difference within sire pairing was for the medium sire pairing during winter where the Medium-F progeny were significantly higher (P<0.05) than the slow growth progeny.

Discussion

The objective of this research was to investigate the consistency of seasonal growth rate changes from previous research and to explore the mechanisms by which this may be achieved. This research has reinforced the findings of Ward et al. (2021) that variation exists in seasonal growth

rates of some sire lines. The lack of difference in winter growth rate for the high W12eBV pairing may reflect that the progeny could not meet their genetic potential for growth due to nutritional limitations on a pasture only diet. It may also indicate that there is a biological limitation to winter growth rate regardless of W12eBV or that both sire lines represent aseasonal animals which may be a necessary growth pathway to reach the higher 12-month liveweights that they achieve. The faster growth rate of the Medium-F and Low-S progeny during the winter period suggest that these individuals show a genetic propensity for less seasonal change in growth.

The identification of a sire that has larger than normal sexual dimorphism has the potential to be very beneficial to breeding/finishing systems where finishing males quickly is important but maintaining or reducing hind mature size is desirable. Generally female mature weight correlates highly with W12 (Ward & Meenken 2018), so when selecting for faster growing progeny, hind mature liveweight also increases as a consequence. Excessive hind mature liveweight may have detrimental effects on farm profitability, as higher maintenance costs are required year-round to support the heavier hind herd. Some of the increased maintenance cost can be offset by faster weaner finishing but reducing hind mature weight while maintaining this faster weaner finishing increases the potential profitability of the farming enterprise (Ward & Thompson 2017; Ward & Meenken 2018).

Feed intake

As previously stated, the estimated feed intakes measured during this trial are significantly higher than would be expected for animals of this age and weight. Using the deer feed app (Stevens & Casey 2014) to estimate intake rates based on actual average liveweight (mixed sex) from the end of each season resulted in predicted male intake rates of 2.9, 2.6, 3.8 and 3.6 kg DM/d for autumn, winter, spring and summer seasons respectively. These values are 30% lower on average than the intakes estimated by the alkane technique and 50% lower than the estimated intake using the TiO_2 technique. The absolute values predicted by either technique are therefore considered to be inaccurate but a conclusion on why these estimated intakes are considerably higher than expected has not been found despite extensive investigation. The alkane technique has been used extensively in the past and produced sensible results from research in deer on the Invermay farm using the same protocol used in this trial (Stevens et al. 2014; Stevens et al. 2017). Due to increased cost related to the alkane methodology, TiO_2 was investigated as an alternative solution as promising results have been found in other livestock species (de Souza et al. 2015; Glindemann et al. 2009; Titgemeyer et al. 2001). A concurrent study completed at Lincoln University, New Zealand (Garrett et al. 2020) investigated the use of alkanes and TiO_2 as markers of feed intake alongside actual intake data from animals fed indoors using cut-and-carry methods. The work by Garrett et al. (2020) suggested that the TiO_2 methodology provided the best alternative to measure actual feed intake with no statistical differences between actual intake and estimated intake ($P>0.05$).

The analysis of estimated intake rates does not explain differences recorded in actual liveweight gain for any of the seasonal periods measured however, due to the uncertainty surrounding the estimated feed intake results definitive conclusions cannot be made.

Feed efficiency

Negative correlations between D15N and feed conversion efficiency (FCE) have been shown in sheep (Cheng et al. 2015) and beef cattle (Wheadon et al. 2014), where the lower the D15N the more efficient the animal is at converting feed into growth. To the authors' knowledge feed conversion efficiency regression equations based on D15N have not been developed for any deer species. Analysis of this data set utilising the cattle regression equations (Wheadon et al. 2014) do not hold as they result in negative FCE values. More research is needed in this area to investigate whether this is a phenotype worth exploring further.

There were no consistent relationships between sire pairings, and seasonal growth pathways with Δ15N across seasons.

In conclusion, this research has demonstrated that differences in seasonality of growth do exist between sire lines which achieve similar 12-month liveweight and could be utilised in the future as a phenotype to better align animals with feed supplies. We acknowledge that this research tested a small number of sires but believe that this warrants further investigation. While the feed intake methodologies did not appear to accurately estimate actual feed intake in this instance, relativities did indicate that there was a difference in seasonal intakes. Feed efficiency estimations using N15 needs further research to correlate with actual intake data but could be of use in the future.

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