BEFORE INDEPENDENT HEARING COMMISIONERS

IN THE MATTER OF the Resource Management Act 1991

AND

IN THE MATTER OF Proposed Waikato Regional Plan Change 1: Waikato and Waipa River Catchment

---

STATEMENT OF PRIMARY EVIDENCE OF DR. CHRIS ROGERS
FOR NEW ZEALAND THROUGHBRED BREEDERS ASSOCIATION & ORS
DATE 23 APRIL 2019
SUBMITTERS 72503, 73067, 73095, 82030, 81968, 81978, 81976

NZTBA NEW ZEALAND THOROUGHBRED BREEDERS

New Zealand Thoroughbred Breeders' Association
9 Anzac Street
Cambridge 3434
New Zealand

Introduction

1. My full name is Associate Professor Christopher William Warnock Rogers.

2. I hold a MAgrSci (hons) in Animals Science and a PhD in Anatomy and Physiology from Massey University.

3. I am currently appointed as the Associate Professor in Equine Production and the co-group leader of the Animal Health and Production group within the Massey University Veterinary School. I also have a co-appointment within the Animal Science group, School of Agriculture and Environment (Massey University) and the University of Edinburgh (UK). My research interest / speciality is equine production. In this field to date I have published over 120 peer reviewed articles, 3 book chapters and more than 120 conference abstracts.

4. International recognition of my research is reflected in my membership of the International Surfaces Research Group, recognition by the European Union as an expert in equine production, and reviewer of equine research proposals within the European Union Seventh Framework Programme.

5. I hold Associate Editor or Editorial board positions with five prominent journals within my field (Animals, Animal Production Science, Equine Veterinary Journal, Journal of Equine Veterinary Science, and PlosOne).

Scope of Evidence

6. I have been asked by Sally Linton, consultant to New Zealand Thoroughbred Breeders Association and Others, to provide expert evidence on;

   a) Equine specific data on potential N loss from horses, as Overseer currently assumes N loss from horses based on a ruminant of similar bodyweight to a horse;
   b) The need to describe the different equine production systems and the inherent the complexity of the different equine production systems due to seasonal changes in stock numbers and stocking density; and
   c) Also provided as supporting evidence is a review article focusing on the on-farm production data available describing the commercial equine farm systems in New Zealand.

Expert witness code of conduct

7. I have read the Code of Conduct for Expert Witnesses in the Environment Court Practice Note 2014. This evidence has been prepared in accordance with it and I agree to comply with it. I confirm that the opinions I have expressed represent my true and complete professional opinions. The matters addressed by my evidence are within my field of professional expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

Papers to support this Evidence

8. My evidence is supported by the following papers;

a) ***"Deterministic modelling of nitrogen utilisation by horses managed under pasture based, intensive and semi-intensive systems with different levels of pasture intake"*** YY Chin, PJ Back, EK Gee, CW Rogers. *School of Agriculture and Environment, Massey University; School of Veterinary Science, Massey University.* (Appendix 1, page 6)

b) ***"Livestock and pasture management on commercial Thoroughbred breeding farms: Implications for estimating nitrogen loss"*** YY Chin, PJ Back, EK Gee, CW Rogers. *School of Agriculture and Environment, Massey University; School of Veterinary Science, Massey University* (Appendix 2, page 22)

c) ***"Growth and development of the equine athlete"*** Chris W. Rogers, C, Erica K. Gee, Charlotte F. Bolwell and Sarah M. Rosanowski *Massey Equine, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, New Zealand. Veterinary Epidemiology, Economics and Public Health, Royal Veterinary College, The Royal Veterinary College.*(Appendix 3, page 37)

9. These papers represent the finding of deterministic modelling of protein turnover in different classes of equine livestock and the impact of these on different equine farm systems. The first two papers have undergone peer review and will be published in the New Zealand Journal of Animal Science and Production. The third article is a review focusing on the on-farm production data available describing the commercial equine farm systems in New Zealand.

Executive Summary of Evidence

10. During the last 20 years there has been a contraction in the New Zealand Thoroughbred industry and to a lesser extent within the Standardbred industry. These changes have seen an increasing proportion of the market associated with fewer larger commercial farms.

11. Many of these farms manage their own mares, and the mares and foals of a number of clients. This in turn has increased the similarity of the management of breeding and young stock within New Zealand. The temperate climate allows the majority of the management of breeding and young stock to be pasture based. The predominant pasture is ryegrass / clover mix which has been demonstrated to provide adequate nutrition for growth and development. The temperate climate also permits management of horses at pasture year round which is proposed to stimulate development of the musculoskeletal system.

12. Apart from a brief period during weaning, most youngstock remain at pasture from birth until the start of yearling preparation. Free access to pasture exercise provides the opportunity to stimulate the musculoskeletal system for the future challenges as a racehorse.

13. The export focus of many of the equine industries heavily influences the management decisions. Despite the availability of good quality pasture post weaning, many foals receive up to 50% of the daily DE requirement as concentrates, possibly reflecting the emphasis on early sales as yearlings and the drive to optimise growth. The observations of drench resistance of common internal parasites presents an emerging problem for pasture based production systems. A large proportion of the Thoroughbred foal crop are exported as yearlings or ready to run 2-year-olds. There is an increasing trend for Standardbreds to be sold as yearlings and this has resulted in changes in the management of Standardbred youngstock.

14. There are limited data on the average nitrogen (N) intake and N loss for the different classes of equine livestock, and the different equine production systems within New Zealand. Using a deterministic model, the total nitrogen excreted, and nitrogen partitioned into animal requirements, urine and faeces were estimated based on the crude protein requirement, digestible crude protein intake, and crude protein excreted in urine and faeces. Separate models were generated for five different livestock classes managed within three different production systems (commercial breeding farm, sport horse and racehorse).

15. Overall, the N in diet (%), the modelled daily N intake and N losses varied with the percentage of pasture in the diet. The faecal N loss remained consistent (20-25%) across diets and horse classes whereas urinary N loss increased with daily N intake and percentage of pasture in the diet. Total N loss per day was estimated to be 0.18, 0.28, and 0.48 g N/kg body weight in racehorse, sport horse and Thoroughbred mares respectively.

16. The N excretion per unit weight from young horses, racehorses and sport horses were substantially lower than that reported for ruminants of similar bodyweight. Therefore, horse-specific data should be used when modelling farm level nitrogen excretion.

17. Published data on livestock and pasture management on Thoroughbred breeding stud farms were collated to model and estimate farm level variables required to estimate nitrogen leaching. On commercial farms, stocking density doubled during the breeding season (August – December).

18. The effective stocking density increased with farm scale (number of resident mares) but decreased with farm size (total effective area). Therefore, farm nitrogen output fluctuates seasonally and is influenced by farm size and scale.

19. Farm size and scale independently affected the stocking and grazing management (i.e. paddock rotation interval) for the different equine stock classes (empty, pregnant, mares with foals). Stocking and grazing management influenced the pasture available and subsequently, the grazing behaviour as determined by the difference between the pasture mass of lawns (areas preferentially grazed) and roughs (latrine areas). The difference between pasture mass of lawns and roughs was reduced with increasing stocking density and decreasing pasture availability, and increased under conditions of high stocking density (>2 mares/ha) and low pasture availability (<400 kg DM/ha/horse). Modification in grazing behaviour could affect the nitrogen leaching potential by modifying the size of manure deposition area and the N-loading rate on urine and dung patches.

20. The complex relationship between farm, horse and management factors needs to be included when estimating nitrogen leached from equine properties.

Summary

21. As the N excretion per unit weight from young horses, racehorses and sport horses was shown to be substantially lower than that reported for ruminants of similar

bodyweight, it is my opinion that horse-specific data should be used when modelling farm level nitrogen loss.

22. The complex relationship between the farm and horse management factors needs to be included when estimating nitrogen leached from equine properties as well as in developing equine environmental Good Management Practices.

Further Research

23. Given the information provided in these papers and the lack of specific information for New Zealand equine systems I consider the following research would be valuable in getting a greater understanding of on farm pasture management and utilisation.
    (i) Examination of pasture utilisation and protein turnover in the horse when managed at pasture under typical New Zealand management conditions (horse level data).
    (ii) Examination of the impact of stocking density and grazing pressure on pasture utilisation and the impact the development of lawns and roughs (latrine areas) has on N concentration and loss.
    (iii) Quantifying the impact of the different (stud) farm systems on the seasonal fluctuations in stock numbers and the impact of these on pasture utilisation, and potential N loss.

APPENDIX 1

Deterministic modelling of nitrogen utilisation by horses managed under pasture based, intensive and semi-intensive systems with different levels of pasture intake.

Short Title: Modelling nitrogen utilisation of horses with a deterministic approach.

YY Chin[a*], PJ Back[ab], EK Gee[b], CW Rogers[ab]

[a]*School of Agriculture and Environment, Massey University, Private Bag 11-222, 4442, Palmerston North;* [b]*School of Veterinary Science, Massey University, Private Bag 11-222, 4442, Palmerston North*

**Corresponding author*. Email: Y.Chin@massey.ac.nz

Keywords:

Abstract

There are limited data on the average nitrogen (N) intake and N loss for the different classes of equine livestock, and the different equine production systems within New Zealand. Using a deterministic model, the total nitrogen excreted, and nitrogen partitioned into animal requirements, urine and faeces were estimated based on the crude protein requirement, digestible crude protein intake, and crude protein excreted in urine and faeces. Separate models were generated for five different livestock classes managed within three different production systems (commercial breeding farm, sport horse and racehorse). Overall, the N in diet (%), the modelled daily N intake and N losses varied with the percentage of pasture in the diet. The faecal N loss remained consistent (20-25%) across diets and horse classes whereas urinary N loss increased with daily N intake and percentage of pasture in the diet. Total N loss per day was estimated to be 0.18, 0.28, and 0.48 g N/kg body weight in racehorse, sport horse and Thoroughbred mares respectively. The N excretion per unit weight from young horses, racehorses and sport horses were substantially lower than that reported for ruminants. Therefore, horse-specific data should be used when modelling farm level nitrogen excretion.

Introduction

Farm animals consume and utilize nitrogen (N) from crop or grain protein for maintenance and production (e.g., milk, growth). Surplus or undigested N will be excreted in urine and faeces. Nitrogen that is not utilised by plants or is deposited on non-fertile surface (e.g., races, bedding) can be converted into reactive form (ammonia, nitric oxide, nitrous oxide, nitrate) which can be volatilised into the atmosphere (ammonia, nitric oxide, nitrous oxide) and leached (nitrate) into ground and surface water (Galloway et al. 2003). Nitrate leaching will negatively affect water quality, and human and ecosystem health (Hubbard et al. 2004).

To monitor N leaching losses, nutrient budget models such as the 'OVERSEER' program are designed to estimate the balance of nutrient inputs and outputs, farm-level N leaching losses, and appropriate amount of fertiliser input (available on www.overseer.org.nz) (Cameron et al. 2017). The model takes account of animal N excretion when estimating farm-level N leaching losses for animal farming systems (Watkins et al. 2015).

At present, this model assumes that horses are equivalent to ruminants when estimating animal-level N losses. As a mono-gastric hindgut fermenter, horses utilise N differently from ruminants. Significant digestion and absorption of protein in the form of amino acids occurs in the small intestine, where there is no evidence of ability to utilise microbial protein in the hindgut, so the recycling and utilisation of non-protein N within the animal are considered minimal (Santos et al. 2011; Trottier et al. 2016).

Compounding this, different equine sectors (Thoroughbred, sport horses, racing) have management systems that vary in intensity. On Thoroughbred stud farms, breeding mares are managed on pasture (pasture as predominant feed source) while young horses (weanlings, yearlings) are provided with a mixture of pasture and premix feed or grains (concentrates) (Rogers et al. 2017; Rogers et al. 2007; Stowers et al. 2009). Racehorses and sport horses are managed using intensive (little or no pasture access) or semi-intensive (~50% DE requirement from pasture) systems (Bolwell et al. 2017; Verhaar et al. 2014; Williamson et al. 2007). Different levels of forage and grains, and protein content in the diet can alter the estimates of protein turnover (Karlsson et al. 2000), and subsequently, the N utilisation, and hence, the implications for property level nitrogen leaching.

Currently, there is a lack of published data on N utilisation and excretion by horses. The objective of this study was to estimate and model the N utilisation and excretion of horses managed under different management systems within New Zealand.

Methods

A deterministic model was developed to assess protein intake and N output for horses managed under commercial conditions at pasture in New Zealand.

Management and diet

To simulate N excretion specific to management and dietary conditions of different horse classes, the management data and diets for Thoroughbred weanlings, yearlings, broodmares, sport-horses and racehorses were reviewed, collated and summarised in Table 1.

[Insert Table 1 here]

Model details

The calculations used to obtain the total N excreted are as described in Table 2. Briefly, crude protein intake (Equation 4) and crude protein digested (Equation 5) were calculated to obtain crude protein excreted in faeces (Equation 3). Crude protein digested was then deducted with crude protein requirements to obtain crude protein excreted in urine. Protein requirements for different horse classes were calculated using Equation 8-17. The nitrogen excreted in faeces and urine was calculated by dividing urinary and faecal protein excretion values with 6.25 (Equation 3 and 7). Finally, total nitrogen excreted is nitrogen excreted plus nitrogen excreted in urine.

The crude protein intake was calculated based on DMI and crude protein content of food (Equation 4). Total daily DMI of animal was estimated based on percentage body weight (BWT). Modelling assumptions for BWT and DMI are as listed in Table 3. For horse classes where diet consists of multiple feedstuffs, estimates of the amount fed for each feedstuff were obtained from the literature. The pasture DMI was then calculated by difference between total DMI and the known feed intake of other feeds consisted in the diet.

[Insert Table 2 here]

[Insert Table 3 here]

Results

The N percentage in the diet, modelled N intake (kg/day), N losses in urine and faeces (kg/day, percentage N intake), N loss (g) per kg BWT, and % of N intake utilised in young Thoroughbred horses (P_{100Y}) and broodmares receiving 100% pasture (P_{100m}), young

Thoroughbred horses (P_{50y}) and sport horses receiving 50% pasture (P_{50s}), and racehorses (P_{11}) receiving 11% pasture are presented in Table 4. Overall, the N in diet (%), the modelled daily N intake and N losses decreased with the percentage of pasture in the diet.

[Insert Table 4 here]

Nitrogen intake

The percentage of N in the diet was 2.2% in the P_{100} diets, 1.7-1.8% in P_{50y} diets, 1.6-1.8% in P_{50s} diets and 1.3% in P_{11} diet. The daily N intake of P_{50y} was 0.15 kg/day and 35% lower than P_{100Y} (0.23 kg N/day). The daily N intake of P_{100m} was 0.43 kg/day, and was 33% and 49% higher compared to P_{50s} (0.29 kg N/day) and P_{11} (0.22 kg N/day).

Total, urinary, and faecal nitrogen losses

In P_{100Y}, 57% (0.13 kg N/day) of daily N intake was excreted where 33% (0.07 kg N/day) was lost in urine and 24% (0.05 kg N/day) lost in faeces. These N loss values are higher than those modelled for P_{50y} where 34% (0.05 kg N/day) of daily N were excreted, with 14% (0.02 kg N/day) lost in urine and 21% (0.03 kg N/day) lost in faeces. For adult horses, the N loss in P_{100m} was 69% (0.27 kg N/day) where 43% (0.17 kg N/day) was lost in urine and 25% (0.1 kg N/day) lost in faeces. Fifty percent of daily N intake was excreted by P_{50s}. The urinary loss was 28% (0.08 kg N/day) and the faecal loss was 22% (0.06 kg N/day). P_{11} receiving lowest proportion of pasture in the diet (11%) had lowest N loss (41%, 0.09kg N/day) with 21% (0.046 kg N/day) urinary loss and 20% faecal loss (0.046 kg N/day). The faecal N loss remained consistent (20-25%) across diets and stock classes whereas urinary N loss increased with daily N intake and percentage of pasture in the diet. The N loss in grams per kg BWT showed a similar trend in response to changes in N intake and percentage of pasture in the diet (0.18g/kg BWT (P_{11}); 0.28g/kg BWT (P_{50s}); 0.48g/kg BWT (P_{100m}); 0.17g/kg BWT (P_{50y}); 0.40g/kg BWT (P_{100y}).

Discussion

To date, this is the first deterministic equine model for N utilisation. The DMI, crude protein content of feed, and crude protein digestibility used in this model were based on a limited number of available reports (Table 2 and 3). Feeding levels did not affect digestibility of crude protein in horses (Martin-Rosset et al. 1987). However, it could still affect the N intake modelled.

In diets consisting multiple types of feed, the pasture DMI were calculated by difference based on the reported amounts of supplements (grains, concentrate, conserved forages) fed to horses. This assumption has been previously used when estimating the relative contribution of different feed sources to total DE (Verhaar et al. 2014). These values do not represent the actual amount consumed. The substitution of supplement for pasture and its effect on DMI in horses has not been well described in the literature and may vary due to pasture quality and quantity on offer. Therefore, this model assumes that animals will consume food to their recommended total daily DMI.

Studies in ponies showed that protein from hay of different quality affected the relative, small and large intestine protein digestion and affected the N utilisation. High protein alfalfa hay had a greater pre-caecal digestibility compared to other types of hay and promoted more efficient N utilisation (Gibbs et al. 1988). In this model, the crude protein digested is calculated based on apparent digestibility and assumed to be bioavailable. Assuming microbial protein is not available to the horse (Santos et al. 2011) and non-protein N absorbed from hindgut is utilised less efficiently than is dietary protein (Reitnour et al. 1972), then the N available (protein digested) thus the modelled N balance (N excreted in urine) can be overestimated. However, there are few reports on pre-caecal and caecal-colon digestion of different equine feedstuffs. The extent of non-protein N utilisation is currently unclear due to lack of understanding for nitrogen metabolism in horses (Santos et al. 2011). Hence, these factors cannot be included for modelling until the nitrogen metabolism in the equine is fully elucidated.

There are few reports on N excretion in horses. N excretion in horses reported from different sources to be 0.12 kg N/day (Bouwman et al. 1997) and 0.095 (Smil 1999) (values calculated from annual N excretion values). Values reported by Bouwman et al. (1997) were calculated by difference (N intake – N requirements, maintenance requirements are proportionate to metabolic BWT) and assumed nitrogen excretion of horses is similar to that of buffalo. The data presented by Smil (1999) only accounted for faecal N and the values were estimated for a 400 kg horse using amount of faeces produced per day and assumed faeces contained 3% nitrogen. The estimation from Smil (1999) agrees with the faecal N loss modelled for mature horse in this study whereas Bouwman et al. (1997) reported a lower total N excretion rate than the modelled results, possibly due to differences in protein requirements per unit metabolic BWT, protein intake and digestive systems difference (mono-gastric vs ruminant) between buffalo and horses (Illius et al. 1992; Kurar et al. 1981).

In this model, the crude protein percentage of pasture (22%) is higher than that of supplement feeds (13%). Hence, reduction in the percentage of pasture offered in the diet reduced N percentage of the diet, and the daily N intake. The faecal N losses decreased with level of pasture in the diet because crude protein digestibility of pasture (76%) was lower than that in the supplement feeds (80%). Therefore, in the mixed diets modelled, the urinary losses decreased with lower N intake along with greater amount of crude protein digested. In a study that measured N excretion in Standardbred geldings through urine collections, increase in proportion of hay which had lower crude protein content (6.5%) compared to oats (13%) led to lower daily N intake and urinary N loss (Karlsson et al. 2000). The lower urinary N loss observed, however, did not occur with increased digestibility in the diet as the crude protein digestibility of diets decreased with forage content. In contrast, increased crude protein digestibility reduced the urinary N loss (39.5 g/day vs 52.7 g/day) in ponies even when N intake increased (59.6 g/day vs 71.4 g/day) (Gibbs et al. 1988). Modelling results from this study, and those reported by other studies, show that the feeding management influences the dietary variables (N intake and digestibility) and will affect the N balance based on N requirement of different horse classes. Protein turnover varied greatly among studies due to differences in diet composition, protein quality, age and activity levels (Freeman et al. 1988; Gibbs et al. 1988; Glade et al. 1986; Karlsson et al. 2000). Therefore, the modelled results can only be applied to the specific equine stock classes and feeding systems referred in this study.

Based on a report from the Ministry of Primary Industry for nitrous oxide inventory development (Luo et al. 2014), the total N excreted in dairy cattle, beef cattle, and sheep were 0.31, 0.202, and 0.04 kg N/animal/day, respectively. Assuming an average BWT of adult cattle, beef and sheep are 600 kg, 500 kg, and 65 kg respectively, the N excreted would be 0.52 g/kg BWT, 0.40 g/kg BWT and 0.62 g/ kg BWT, compared to 0.18, 0.28, and 0.48 g N/kg BWT in racehorse, sport horse and Thoroughbred mares respectively. The N excreted per kg BWT for growing-finishing beef cattle (calculated with finishing weight), growing dairy cattle, and lambs were around 0.33, 0.43, 0.50 g N/kg BWT (Grenet 1983; Guo et al. 2005; Phillips et al. 1995; Zanton et al. 2009), compared to 0.17 g N/kg BWT in young Thoroughbred horses (fed mixture of concentrate and pasture) (P_{50Y}). The modelled N excretion per unit BWT in Thoroughbred mares were similar to values in beef cows and dairy cattle and was lower than those of sheep. The N excretion per unit weight from racehorses, sport horses and young Thoroughbred horses were substantially lower than that for ruminants. Therefore, horse specific values should be used when estimating N excretion.

The lower N excretion/kg body weight can be due to higher N utilisation in horses. The percentage of N intake excreted were reported to be 73.2% (dairy cattle), 65.9% (beef cattle and sheep), 76% (growing cattle), 86% (growing sheep) hence translating to N utilisation of 26.8% (cattle), 34.1% (sheep), 24% (growing cattle), 14% (growing sheep) (Grenet 1983; Luo et al. 2014; Zanton et al. 2009). These values are much lower than the N utilisation estimated by this model in Thoroughbred mares, sport horses, racehorses, and young Thoroughbred horses (32%, 51%, 59%, 44%(P_{100Y}), 66% (P_{50Y}), respectively). This higher utilisation in horses was due to lower urinary N loss and a similar faecal N loss compared to ruminants. The supplementation of pasture in the diet with conserved forage and concentrates increased the disparity between the ruminant data and the horse data.

Conclusion

Based on the comparison between the modelled results and ruminant values, the N utilisation in horses were generally higher than that of ruminants. Our model showed that the different feeding systems alter the quantity and proportion of pasture and other feedstuffs (concentrates and conserved forages) which in turn affect the nitrogen content and digestibility. The different stock classes varied in physiological demands for nitrogen. Together, they influenced N utilisation in the horses. Therefore, modelling N excretion of horses needs to correspond to the feeding management and stock class. This model estimates N output at animal level and does not reflect farm-level N output and leaching potential. To estimate the farm-level N leaching, information on stocking density, pasture, grazing and manure management on equine farms is required. At present, there are limited reports on these farm variables for equine properties and no studies have been done to investigate their impact on N leaching in soil.

References

Bishop LM. 2013. Growth, voluntary feed intake and digestibility in thoroughbred weanlings [Masters]. Palmerston North, New Zealand: Massey University.

Bolwell CF, Rogers CW, Firth EC, French NP. 2010. Management and exercise of Thoroughbred yearlings during preparation for yearling sales in the North Island of New Zealand. Proceedings of the New Zealand Society of Animal Production; June; Palmerston North.

Bolwell CF, Rogers CW, Gee EK, Rosanowski SM. 2017. Commercial equine production in New Zealand. 3. The racing and sport industries. Animal Production Science. 10.1071/AN16753.

Bouwman A, Lee D, Asman W, Dentener F, Van Der Hoek K, Olivier J. 1997. A global high-resolution emission inventory for ammonia. Global Biogeochemical Cycles. 11(4):561-587.

Cameron KC, Hedley M, Clark H, Di HJ. 2017. Chapter 19, Impact of pasture and supplement feeding on the environement. In: Rattray PV, Brookes IM, Nicol AM, editors. Pasture and supplement for grazing animals. New Zealand: New Zealand Society of Animal Production; p. 317-339.

Csapó J, Salamon S, Lóki K, Csapó-Kiss Z. 2009. Composition of mare's colostrum and milk II. Protein content, amino acid composition and contents of macro-and micro-elements. Acta Univ Sapientiae Alimentaria. 2(1):133-148.

Fernandes KA, Rogers CW, Gee EK, Bolwell CF, Thomas DG. 2015. Body condition and morphometric measures of adiposity in a cohort of Pony Club horses and ponies in New Zealand. Proceedings of the New Zealand Society of Animal Production; 07/2015; Dunedin.

Freeman D, Potter G, Schelling G, Kreider J. 1988. Nitrogen metabolism in mature horses at varying levels of work. Journal Of Animal Science. 66(2):407-412.

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB, Cosby BJ. 2003. The Nitrogen Cascade. BioScience. 53(4):341-356.

Gibbs P, Potter G, Schelling G, Kreider J, Boyd C. 1988. Digestion of hay protein in different segments of the equine digestive tract. Journal Of Animal Science. 66(2):400-406.

Glade M, Biesik L. 1986. Enhanced nitrogen retention in yearling horses supplemented with yeast culture. Journal Of Animal Science. 62(6):1635-1640.

Grace ND, Gee EK, Firth EC, Shaw HL. 2002. Digestible energy intake, dry matter digestibility and mineral status of grazing New Zealand Thoroughbred yearlings. New Zealand Veterinary Journal. 50(2):63-69.

Grace ND, Rogers CW, Firth EC, Faram TL, Shaw HL. 2003. Digestible energy intake, dry matter digestibility and effect of increased calcium intake on bone parameters of grazing thoroughbred weanlings in New Zealand. New Zealand Veterinary Journal. 51(4):165-173.

Grace ND, Shaw HL, Gee EK, Firth EC. 2002. Determination of the digestible energy intake and apparent absorption of macroelements in pasture-fed lactating Thoroughbred mares. New Zealand Veterinary Journal. 50(5):182-185.

Grenet E. 1983. Utilization of grass-silage nitrogen by growing sheep. The Journal of Agricultural Science. 100(1):43-62.

Guo K, Zoccarato I. 2005. A dynamic model to predict the nitrogen excretion in growing-finishing cattle. Ecological Modelling. 187(2):219-231.

Hirst RL. 2011. Seasonal variation of pasture quality on commercial equine farms in New Zealand [Masters]. Palmerston North, New Zealand: Massey University.

Hubbard R, Newton G, Hill G. 2004. Water quality and the grazing animal. Journal Of Animal Science. 82(Suppl):E255-E263.

Illius A, Gordon I. 1992. Modelling the nutritional ecology of ungulate herbivores: evolution of body size and competitive interactions. Oecologia. 89(3):428-434.

Karlsson CP, Lindberg J, Rundgren M. 2000. Associative effects on total tract digestibility in horses fed different ratios of grass hay and whole oats. Livestock Production Science. 65(1):143-153.

Kienzle E, Fehrle S, Opitz B. 2002. Interactions between the apparent energy and nutrient digestibilities of a concentrate mixture and roughages in horses. The Journal Of Nutrition. 132(6):1778S-1780S.

Kurar C, Mudgal V. 1981. Maintenance requirements for protein in buffaloes. Indian Journal of Animal Science. 51(9):817-824.

Luo JF, Kelliher F. 2014. Partitioning of animal excreta N into urine and dung and developing the N2O inventory (MAF POL 0910-11528, 09-03). New Zealand: Ministry for Primary Industries.

Malacarne M, Martuzzi F, Summer A, Mariani P. 2002. Protein and fat composition of mare's milk: some nutritional remarks with reference to human and cow's milk. International Dairy Journal. 12(11):869-877.

Mariani P, Summer A, Martuzzi F, Formaggioni P, Sabbioni A, Catalano AL. 2001. Physicochemical properties, gross composition, energy value and nitrogen fractions of Haflinger nursing mare milk throughout 6 lactation months. Animal Research. 50(5):415-425.

Martin-Rosset W, Dulphy J. 1987. Digestibility interactions between forages and concentrates in horses: influence of feeding level-comparison with sheep. Livestock Production Science. 17:263-276.

Morel P, Bokor A, Rogers C, Firth E. 2007. Growth curves from birth to weaning for Thoroughbred foals raised on pasture. New Zealand Veterinary Journal. 55(6):319-325.

NRC. 2007. Nutrient requirement of horses. 6th ed. Wahington, DC: The National Academy Press.

Oftedal OT, Hintz HF, Schryver HF. 1983. Lactation in the horse: milk composition and intake by foals. Journal of Nutrition. 113:2196-2206.

Pagan JD. 1998. Nutrient digestibility in horses. Advances in Equine Nutrition.77-83.

Pagan JD, Brown-Douglas CG, Caddel S. 2006. Body weight and condition of Kentucky Thoroughbred mares and their foals as influenced by month of foaling, season, and gender. European Association for Animal Production. 120:245.

Phillips W, Horn G, Smith M. 1995. Effect of protein supplementation on forage intake and nitrogen balance of lambs fed freshly harvested wheat forage. Journal Of Animal Science. 73(9):2687-2693.

Reitnour C, Salsbury R. 1972. Digestion and utilization of cecally infused protein by the equine. Journal Of Animal Science. 35(6):1190-1193.

Rogers CW, Gee EK, Bolwell CF, Rosanowski SM. 2017. Commercial equine production in New Zealand. 2. Growth and development of the equine athlete. Animal Production Science. 10.1071/AN16752.

Rogers CW, Gee EK, Firth EC. 2007. A cross-sectional survey of Thoroughbred stud farm management in the North Island of New Zealand. New Zealand Veterinary Journal. 55(6):302-307.

Santos A, Rodrigues M, Bessa R, Ferreira L, Martin-Rosset W. 2011. Understanding the equine cecum-colon ecosystem: current knowledge and future perspectives. Animal. 5(01):48-56.

Smil V. 1999. Nitrogen in crop production: An account of global flows. Global Biogeochemical Cycles. 13(2):647-662.

Southwood LL, Evans DL, Bryden WL, Rose RJ. 1993. Nutrient intake of horses in Thoroughbred and Standardbred stables. Australian Veterinary Journal. 70(5):164-168.

Stowers NL, Rogers CW, Hoskin SO. 2009. Management of weanlings on commercial Thoroughbred studs farms in the North Island of New Zealand. Proceedings of New Zealand Society of Animal Production; Christchurch.

Suagee JK, Burk AO, Quinn RW, Petersen ED, Hartsock TG, Douglass LW. 2008. Effects of Diet and Weight Gain on Body Condition Scoring in Thoroughbred Geldings. Journal of Equine Veterinary Science. 28(3):156-166.

Trottier NL, Bott RC, Woodward A, Greene EA, Williams CA, Westendorf ML, Swinker AM, Mastellar SL, Martinson K. 2016. Gastrointestinal nitrogen metabolism of equids and impact on protein requirement. Journal of Equine Veterinary Science. 45:78-86.

Verhaar N, Rogers CW, Gee EK, Bolwell CF, Rosanowski SM. 2014. The feeding practices and estimated workload in a cohort of New Zealand competition horses. Journal of Equine Veterinary Science. 34(11–12):1257-1262.

Watkins N, Selbie D. 2015. Technical description of OVERSEER for regional councils. New Zealand: AgResearch Ltd.https://www.overseer.org.nz/overseer-explained/technical-description-of-overseer.

Williamson A, Rogers C, Firth E. 2007. A survey of feeding, management and faecal pH of Thoroughbred racehorses in the North Island of New Zealand. New Zealand Veterinary Journal. 55(6):337-341.

Zanton G, Heinrichs A. 2009. Digestion and nitrogen utilization in dairy heifers limit-fed a low or high forage ration at four levels of nitrogen intake. Journal of Dairy Science. 92(5):2078-2094.

Table 1. Management and diets for different classes of horses (Thoroughbred weanlings and yearlings, pregnant and lactating Thoroughbred broodmares, sport horses and racing Thoroughbreds).

Class	Management	Diet
Thoroughbred weanlings (179d)	[1,3,5]Weaning at 4-6 months of age	[3,5]Weanlings were kept on pasture and receive on average 2.9 (range 1–6) kg of concentrates.
Thoroughbred yearlings (360d)	[2]Yearling preparation begins between October and November. Ends at yearling sales in January-February the following year.	[1,2]Most farms used both stabling and pasture turn out allowing yearlings access to pasture up to 12 hrs per day. Fed premixed diets specified for yearling sales preparation providing up to 75% of daily digestible energy requirement.
Mature horses, broodmares (pregnant)	[3]Kept on pasture	[3]Solely pasture diet up to late pregnancy. Supplements fed are intended to meet other nutrient requirements (vitamins, minerals) rather than macronutrients and energy.
Broodmares (lactating)	[3]Kept on pasture	Solely pasture diet.
Sporthorses	[6]Kept on pasture	[6]Pasture, concentrates (either in the form of premix feed or grains), with or without additional roughage, and conserved forages (hay/haylage).
Racehorses	[7]Stabled for >12 hours/day in a confined area (<5x5m)	[7]Fed 2-8 kg concentrate and <2.25-4.5 kg hay with little or no access to pasture.

[1]Rogers et al. (2017), [2]Bolwell et al. (2010), [3]Rogers et al. (2007), [4]Fernandes et al. (2015), [5]Stowers et al. (2009), [6]Verhaar et al. (2014) ,[7]Williamson et al. (2007)

Table 2. Equations used to model protein requirement, protein intake, protein digested, protein and nitrogen excreted in faeces and urine (kg/horse/day) by different classes of horses (Thoroughbred weanlings and yearlings, pregnant and lactating Thoroughbred broodmares, sport horses and racing Thoroughbreds)

Total Nitrogen excreted	N excreted in faeces + Nitrogen excreted in urine		Equation
Total N excreted (kg/horse/day)	Nitrogen excreted in faeces+ nitrogen excreted in urine		1
N excreted in faeces (kg/horse/day)	Protein excreted in faeces/6.25		2
Protein excreted in faeces (kg/horse/day)	Crude protein intake – Crude protein digested		3
Crude protein intake (kg/day)	DMI x Crude protein in food Crude protein content: [1]22% (pasture), [2]13% (premixed diet, grains, hay)		4
Crude protein digested (kg/day)	Crude protein intake x crude protein digestibility Crude protein digestibility: [3]76% (pasture), [4]80% (concentrates, grains), [4]70% (hay/haylage),[5]62% (yearling preparation diet)		5
N excreted in urine (kg/horse/day)	(Protein digested – protein requirement)/6.25		6
Protein requirement (kg/day)	Maintenance requirement + physiological requirements		7
Protein requirement (Growing horses)	[6]Maintenance [6]Growth	BWT x 1.44 g CP/kg BWT ADG x 0.2 [7]ADG (150d): 0.85 kg/day [7,8]ADG (360d): 0.63 kg/day 0.2: assuming 20% of daily gain is protein	8 9
Protein requirement (Mature horses)	[6]Maintenance	BWT x 1.26 g CP/kg BWT	10
Protein requirement (Pregnancy)	[6]Maintenance [A]Pregnancy (2nd and 3rd Trimester)	BWT x 1.26 g CP/kg BWT Fetal gain = 0.283 kg/day	11 12

Protein requirement (Lactating broodmares)	[6]Maintenance	BWT x 1.44 g CP/kg BWT	13
	[6]Lactation	milk yield x [9,10,11,B]30 g CP/kg milk	14
		[C]Milk yield: 13.6 kg/day	15
Protein requirement (Exercise)	[6]Maintenance	BWT *1.44g CP/kg BWT	16
	[6]Exercise	(BWT x muscle gain) + (BWT x sweat loss x 7.8g CP/kg sweat)	17
		Muscle gain (moderate exercise): 0.177 g CP/kg BWT	
		Sweat loss (moderate exercise): 0.5% BWT	

[1]Seasonal average CP% of equine pasture reported in Hirst (2011), [2]Pagan (1998), [3]Grace, Gee, et al. (2002), [4]Kienzle et al. (2002), [5]Bishop (2013), [6]NRC (2007), [7]Morel et al. (2007), [8]Grace et al. (2003), [9]Mariani et al. (2001), [10]Csapó et al. (2009), [11]Malacarne et al. (2002)

[A] Fetal gain was modelled using the model proposed by NRC (2007) and an average fetal gain was obtained for 2nd and 3rd trimester.

[B] Crude protein per kg milk fluctuated around 20-32 g/kg milk with highest CP content during early lactation and decrease as pregnancy progress.

[C] Milk yield was modelled using mare lactation curve proposed by NRC (2007) and an average value was obtained for the first 5 months of lactation.

BWT=body weight

CP=crude protein

Table 3. Modelling assumptions for body weight (kg), the total daily dry matter intake (kg DM/day), the dry matter intake (kg DM/day) from pasture, and other feed supplements (concentrates and conserved forages) of different classes of horses (Thoroughbred weanlings and yearlings, pregnant and lactating Thoroughbred broodmares, sport horses and racing Thoroughbreds)

Diet	Weight (kg)	Total Daily DMI (% BWT)	[A]Daily DMI (kg/day)	DMI from other supplements (kg/day)	Pasture (kg DM/day)
Thoroughbred model					
Pasture					
Weaning (179d)	[1]261	[1]2	5.22	-	
Yearling (360d)	[1]377	[2,7]2	7.54	-	
Mature horse, Broodmare, pregnant	[3,4]560	[5]2	11.2	-	11.2 (100)
Broodmare, lactating	[4]560	[4]2.5	14	-	14 (100)
Mixed					
Weaning (179d)	[1]261	[1]2	5.22	[8]2.9	[D]2.6 (50)
Yearling (360d)	[1]377	[2,7]2	7.54	[B]4.5	[D]3 (40)
Sport horse model					
Mixed					
Eventing	[9]524	[5]2	10.48	[C]4.8	[D]5.68 (54)
Show jumping	[9]531		10.62	[C]5.8	[D]4.82 (45)
Dressage	[9]550		11	[C]7.1	[D]3.9 (35)
Racehorse model	[10,11]500	[5]2	10	[C]7.88	[D]1.12 (11)

[1](Grace et al. 2003), [2](Grace, Gee, et al. 2002), [3](Pagan et al. 2006), [4](Grace, Shaw, et al. 2002),[5](NRC 2007), [6](Oftedal et al. 1983), [7](Bishop 2013), [8](Rogers et al. 2007), [9](Verhaar et al. 2014),[10](Southwood et al. 1993), [11](Suagee et al. 2008)
[A] Calculated by percentage of body weight.
[B] Calculated by assuming concentrates provide 75% of energy requirements of yearlings (Rogers et al. 2017).
[C] Total DMI from concentrates, and other conserved forages.
[D] Calculated by difference (daily dry matter intake – dry matter intake of other supplements).
DMI=dry matter intake
values in () are percentage of pasture in the diet.

Table 4. The daily nitrogen intake (kg/day), the total, urinary and faecal nitrogen excretion (kg/day) and nitrogen utilisation (%) by different classes of horses (Thoroughbred weanlings and yearlings, pregnant and lactating Thoroughbred broodmares, sport horses and racing Thoroughbreds) modelled under different management systems.

Management systems/ horse classes	Daily Nitrogen intake (kg/day)	Total daily nitrogen excretion (kg/day)	Urinary nitrogen loss (kg/day)	Fecal nitrogen loss (kg/day)	Total nitrogen excretion (g/kg BWT)	N Utilisation (%)
Thoroughbred stud farm model, young horses						
100% pasture (P_{100Y})						
Weanling	0.185(2.2)	0.098(53)	0.05(29)	0.044(24)	0.38	47
Yearling	0.268(2.2)	0.161(60)	0.097(36)	0.064(24)	0.43	40
Average	0.23	0.13(57)	0.07(33)	0.05(24)	0.40	43
50% pasture (P_{50Y})						
Weanling	0.143(1.8)	0.055(38)	0.024(16)	0.032(22)	0.21	62
Yearling	0.157(1.7)	0.05(31)	0.018(11)	0.031(20)	0.13	69
Average	0.15	0.05(34)	0.02(14)	0.03(21)	0.17	66
Thoroughbred stud farm model, 100 % pasture (P_{100m})						
Mature horse/ empty mare	0.398(2.2)	0.285(71)	0.189(47)	0.095(24)	0.51	29
Broodmare, pregnant	0.398(2.2)	0.224(75)	0.128(43)	0.095(32)	0.40	25
Broodmare, lactating	0.497(2.2)	0.303(61)	0.184(37)	0.119(24)	0.54	39
Average	0.40	0.27(69)	0.17(43)	0.1(25)	0.48	31
Sport horse model, 50% pasture(P_{50S})						
Show jumping	0.290(1.8)	0.149(51)	0.084(29)	0.065(22)	0.28	49
Dressage	0.267(1.7)	0.121(45)	0.062(23)	0.059(22)	0.22	55
Eventing	0.312(1.6)	0.173(55)	0.103(33)	0.07(22)	0.33	45
Average	0.29	0.147(50)	0.08(28)	0.06(22)	0.28	50.
Racehorse model, 11% pasture (P_{11})	0.224(1.3)	0.092(41)	0.046(21)	0.046(20)	0.18	59

Values in () represents % of nitrogen in diet and nitrogen loss in % of daily intake
BWT=body weight

APPENDIX 2

Title: Livestock and pasture management on commercial Thoroughbred breeding farms: Implications for estimating nitrogen loss.

Short Title: Implication of Thoroughbred stud farm management on estimating nitrogen loss

YY Chin[a]*, PJ Back[ab], EK Gee[b], CW Rogers[ab]

[a]School of Agriculture and Environment, Massey University, Private Bag 11-222, 4442, Palmerston North; [b]School of Veterinary Science, Massey University, Private Bag 11-222, 4442, Palmerston North

*Corresponding author. Email: Y.Chin@massey.ac.nz

Abstract:

Published data on livestock and pasture management on Thoroughbred breeding stud farms were collated to model and estimate farm level variables required to estimate nitrogen leaching. On commercial farms, stocking density doubled during the breeding season (August – December). The effective stocking density increased with farm scale (number of resident mares) but decreased with farm size (total effective area). Therefore, farm nitrogen output fluctuates seasonally and is influenced by farm size and scale. Farm size and scale independently affected the stocking and grazing management (i.e. paddock rotation interval) for the different equine stock classes (empty, pregnant, mares with foals). Stocking and grazing management influenced the pasture available and subsequently, the grazing behaviour as determined by the difference between pasture mass of lawns and roughs. The difference between pasture mass of lawns and roughs was reduced with increasing stocking density and decreasing pasture availability, and increased under conditions of high stocking density (>2 mares/ha) and low pasture availability (<400 kg DM/ha/horse). Modification in grazing behaviour could affect the nitrogen leaching potential by modifying the size of manure deposition area and the N-loading rate on urine and dung patches. The complex relationship between farm, horse and management factors needs to be included when estimating nitrogen leached from equine properties.

Keywords: horse, grass, nitrate, leaching,

Introduction

On grazed pasture systems, protein that is undigested or excess to requirements will be excreted onto pasture in the faeces and urine (Haynes et al. 1993). Faecal protein and urine contains nitrogen (N) that can be utilised by plants for dry matter production or converted into reactive forms (ammonia, nitric oxide, nitrous oxide, nitrate) which can be volatilised into the atmosphere (ammonia, nitric oxide, nitrous oxide) and leached (nitrate) into ground and surface water (Galloway et al. 2003).

The nitrate leaching loss is dependent on rate and amount of N deposited on pasture (N – loading) in relation to the rate of N removal by plants based on plant fertility requirements. Leaching increases when nitrate accumulates due to N-loading exceeding the plant uptake capacity (Di et al. 2002). The opportunity for plant to remove N depends on the nitrogen retention capacity of the soil (Di et al. 2007). The N retention capacity is affected by soil type, soil conditions (i.e. erosion, compaction, ploughing), season and climate (Bott et al. 2013; Cameron et al. 2017; Di et al. 2002). The main concern of nitrate leaching is the contamination of drinking water and eutrophication of larger water bodies that can affect the aquatic ecosystem (Galloway et al. 2003; Hubbard et al. 2004).

In dairy and sheep pasture-based farming systems, relatively large leaching losses occur with high stocking density, fertiliser application and irrigation (Cameron et al. 2017). A nutrient budget model such as 'OVERSEER' is designed to estimate the balance of nutrient inputs and outputs (available on www.overseer.org.nz). Then, the model uses this information to estimate nitrate leaching losses (Cameron et al. 2017). The component sub-models within 'OVERSEER' that model animal intake and excretion, N distribution and proportion leached were designed using assumptions derived from studies on ruminants, and dairy and beef farming systems (Watkins et al. 2015).

On equine Thoroughbred stud farms, there are seasonal fluctuations in stock numbers and grazing management (as determined by paddock rotation interval). Stocking density increases during the breeding season (August-December) due to an influx of breeding mares (Hirst 2011; Rogers et al. 2007). Grazing management (rotational grazing, semi set-stocked and set-stocked) varies between farms and mare categories (Bengtsson et al. 2018). Therefore, stocking density and grazing management can alter the grazing intensity. Unlike ruminants, horses exhibit selective grazing and 'latrine' behaviour where they avoid grazing in areas they have previously urinated and defecated in (Bott et al. 2013; Ödberg et al. 1976). This grazing behaviour will lead to formation of 'roughs' (areas where horses avoid grazing) and 'lawns' (preferred grazing area) (Bott et al. 2013; Ödberg et al. 1976). When grazing intensity is high, pasture in the lawns will diminish eventually causing defoliation followed by soil erosion and increased soil nutrient losses (Bott et al. 2013). Due to their 'latrine' behaviour, horses exhibit a different faeces and urine deposition pattern on pasture in comparison to ruminants. Thus, in horses, the N-loading rate on urine and dung patches, the size, and the proportion of paddock covered by urine and dung patches could be different compared to ruminants which can potentially alter the N leaching losses. Variation in N-loading rates creates the potential for different N-leaching losses. This variation has been observed in different types of animal grazing systems (e.g. sheep, dairy, beef) due to a difference in N-loading rates created by variation in animal size, frequency and volume of urination, and pasture quality (Di et al. 2007).

When modelling equine Thoroughbred stud farm systems, the 'OVERSEER' program assumes a horse has the protein utilisation of an upscaled small ruminant, and ignores variables such as the seasonal fluctuations in equine stock numbers and density, grazing management, and the unique grazing behaviour previously described which can impact the farm level N output and N leaching estimates. The objective is to model and estimate appropriate farm level variables required to estimate nitrogen leaching on Thoroughbred breeding stud farms.

Methods

To model and estimate appropriate farm level variables required to estimate nitrogen leaching on Thoroughbred breeding stud farms, data from published literature (Bengtsson et al. 2018; Hirst 2011; Rogers et al. 2007) on pasture mass, paddock dimensions, stocking (stocking density, number of mares per paddock) and grazing management (paddock rotation interval), were collated and sorted into a customised database according to farm size (total effective farm area), farm scale (number of resident mares) and season (breeding and non-breeding). Pasture mass, paddock dimensions, stocking density, and grazing management data on 4 commercial breeding stud farms during the 2017-2018 breeding season (spring) (Bengtsson et al. 2018) were applied within a matrix model to estimate the pasture available (kg DM/ha/horse), and the difference between 'lawns' and 'roughs'. Paddock sizes (ha) were log transformed. Average paddock rotations were obtained and then converted into weeks. Pasture available (kg DM/ha/horse), and the difference between 'lawns' and 'roughs' were calculated as below:

Pasture available (kg DM/horse/ha) = Pasture DM kg/ ha ('lawns')/stocking density (mares/ha)

Difference in pasture mass between lawns and roughs = [Pasture DM kg/ha ('roughs') – Pasture DM kg/ha ('lawns')]/Pasture DM kg/ha ('roughs')

The outputs from the matrix model were then incorporated into the customised database where, (1) the effects of farm size and scale, season, and mare category on stocking density, and (2) the relationship between farm variables (stocking and grazing management), pasture available, and grazing behaviour (difference between lawns and roughs) were modelled.

Results

Stocking density

Within the literature (Hirst 2011; Rogers et al. 2007), farms were categorised based on size (total effective sizes, ha) and scale (number of resident mares) into moderate (<100 ha, <70 mares), medium (100-200 ha, 90-199 mares), and large (>200 ha, >200 mares). A comparison of stocking densities during the breeding season between these farm sizes and scales is presented in Fig. 1. On a farm size basis, the stocking density during the breeding season was highest (2 mares/ha) on moderate sized farms (<100ha) followed by large sized farms (>200ha) with 1.2 mares/ha and medium sized farms (100-200ha) with 1 mare/ha. The stocking densities during breeding season were two times higher than during the non-breeding season on all three farm categories. On a farm scale basis, the stocking density increased with number of resident mares. Stocking density was highest on large (>200 mares) farms (1.98 mares/ha) followed by medium (100-199 mares) farms (1.73 mares/ha) and moderate (<70 mares) farms (0.7 mares/ha). Overall, there is a non-linear relationship between stocking density and farm category and scale. The relationship is inversed when farms were categorised based on size instead of number of resident mares.

[Insert Fig. 1 here]

Management of different mare categories (empty mares, pregnant mares, and mares with foals)

The number of mares per paddock was independent of effective farm size for all mare categories but increased with paddock size (Figs. 2a, 2b, 2c). The stocking density decreased when paddock size increased for all three mare categories. The paddock rotation interval of empty mares (3 weeks) was shorter on a smaller farm (20 ha) compared to empty mares on larger farms which were semi set-stocked (16 weeks on 86 and 121 ha farms) or set stocked (160_ha farm) (Fig. 2a). The paddock rotation interval of mares with foals was similar (2.5-3 weeks) regardless of farm size and stocking density and was shorter than that for empty and pregnant mares. The paddock rotation interval of pregnant mares varied with stocking density (Fig. 2b). When stocking density was high (4 and 5.9 mares/ha), the paddock rotation interval decreased (2.5-3 weeks vs 16 weeks-set stocked) compared to lower stocking densities (1.4 and 2.8 mares/ha). Overall, pregnant mares were kept at a higher average stocking density (3.5 mares/ha) than empty mares (2.8 mares/ha) and mares with foals (2.2 mares/ha).

[Insert Fig. 2 here]

Effect of equine stocking and grazing management on grazing behaviour and pasture on offer

On all paddock rotation intervals, pasture availability (kg DM/horse/ha) decreased when stocking density increased (Fig 3). The pasture availability decreased by 30% (set stocked), 50% (16 weeks and 3 weeks) and 70% (2.5 weeks). At a given paddock rotation interval, the difference between pasture mass of roughs and lawns reduced with increasing stocking density and decreasing pasture availability (Figs. 3b, 3c, 3d). However, at high stocking density (>2 mares/ha) and with low pasture DM on offer (< 400 kg DM/ha/horse), the difference in pasture mass of lawns and roughs increased drastically (Figs. 3a, 3c). Every increase in 1 mares/ha would increase the difference between pasture mass of roughs and lawns by 30% when the paddock rotation was 2.5 weeks, and 10% when the paddock rotation was 16 weeks. Under set stocked conditions, an increase in stocking density by 1 mares/ha increased the difference between roughs and lawns by 10%. This effect was observed at a higher pasture DM on offer (628 kg DM/ha/horse) compared to shorter paddock rotations (<400kg DM/ha/horse at 2.5 weeks and 16 weeks) (Fig. 3d). In summary, changes in difference between pasture mass of lawns and roughs showed a ‘U’ shaped response towards decreasing pasture availability and increasing stocking density.

[Insert Fig 3 here]

Discussion

The identification of farms based on size (total effective farm area) or scale (number of resident mares) affected the relationship of stocking density and farm category. Stocking density was highest on moderate sized farms and lower in medium and large sized farms. Whereas, stocking density was lowest on moderate scaled farms and increased with increasing farm scales. This can be due to the fact that number of mares varied (25-80%; Hirst (2011)) at a given farm size, and the farm size varied (up to 80%; Stowers et al. (2009)) at a given farm scale. Therefore, a farm that is operating at larger scale can have a higher nitrogen output per unit area compared to another farm with similar size that is operating at a smaller scale. Therefore, the size and scale of equine farms needs to be considered to reflect the true farm level nitrogen leaching potential. Regardless of farm categories, stocking density doubled over the breeding season due to an influx of non-resident mares and thus a 50% fluctuation in farm level total nitrogen output between the breeding and non-breeding season can be expected.

The stocking and grazing management varied with mare category. Pregnant mares were kept at a higher average stocking density (3.5 mares/ha) than empty mares (2.8 mares/ha) and mares with foals (2.2 mares/ha). The stocking density varied with number of mares per paddock and paddock sizes which was independent of the total effective farm area. These findings suggest that stocking management on equine farms are influenced by mare category, number of mares per paddock, farm layout and paddock dimensions. These variables need to be considered when calculating stocking density to avoid underestimation because the resulting stocking densities were 1-3 times higher than the stocking densities calculated solely based on total effective farm area.

Mare category along with farm sizes also influenced grazing management. The paddock rotation interval of empty mares was influenced by farm sizes (shorter on smaller sized farms) but remained similar (2-3 weeks) regardless of farm size for mares with foals. Whereas, the paddock rotation interval of pregnant mares was primarily influenced by stocking density with a shorter rotation interval under higher stocking densities.

Stocking and grazing management affected pasture on offer and modified the grazing behaviour of mares. There is a 'U' shaped relationship between the difference between pasture mass of lawns and roughs, and the pasture availability and stocking density. The difference between pasture mass of lawns and roughs was reduced with increasing stocking density and decreasing amount of pasture available. However, under conditions of high stocking density (>2 mares/ha) and low pasture availability (<400 kg DM/ha/horse, 628 kg DM/ha/horse under set stocked condition), the difference in pasture mass of lawns and roughs increased. This result suggest that mares become less selective in their grazing (starting to graze 'roughs') when pasture availability decreases which can decrease the area of 'roughs'. This could lead to reduction in manure deposition area and in turn could increase the N-loading rate on urine and dung patches. Under extremely high grazing intensity and low pasture availability, the selectivity becomes apparent again possibly due to horses stopped grazing 'roughs' when pasture reached a minimum height. Therefore, at high and low stocking density and pasture availability, a relative change in stocking density and pasture available can have a different effect on N-loading rate on urine and dung patches in horses. Results also indicate that mares may tend to be more selective under set-stocked conditions suggesting that this grazing method can intensify the N-loading on urine and dung patches. The pasture availability in this study was obtained using pasture mass (kg DM/ha) of 'lawns' divided by the stocking density (mares/ha). Therefore, it is not the actual total pasture mass. Instead, it represents kg DM of pasture available to per horse from per hectare of 'lawn'.

The stocking density reported for equine farms of different size and scale during breeding season ranged between 0.7-2 mares/ha (Rogers et al. 2007) and 1-2 mares/ha (Hirst 2011), respectively. Average nitrogen excretion by Thoroughbred mares on pasture based diet was estimated to be 0.27 kg N/day (Chin YY et al, unpublished data). Compared to dairy systems, stocking densities reported for systems 1-5 were 2.5-3.5 mares/ha (Shadbolt 2012) and nitrogen excretion reported was 0.31 kg N/day for dairy cows (Luo et al. 2014). Therefore, the nitrogen output per ha would be 0.27-0.54 kg N/ha on an equine stud farm compared to 0.78-1.08 kg N/ha on dairy properties. However, this does not represent the nitrogen leaching potential on equine stud farms because there are complex farm variables that can influence the nitrogen leaching and this needs to be understood with further studies.

The applicability of our results is limited due to small dataset from a limited number of publications. The pasture and grazing management data were obtained from 4 commercial

Thoroughbred breeding farms, over one breeding season. Hence, may not reflect all the practices on the majority of Thoroughbred farms. The implications discussed in this paper requires confirmation with further studies. At present, no study has been conducted to investigate the effect of grazing behaviour or 'lawns' and 'roughs' on the N-loading rate of urine/dung patches, and N-leaching potential on equine farms. There are anecdotal observations on the variation in area and number of 'lawns' and 'roughs' which may be due to an adjustment in selectivity by horses in response to changes in grazing intensity. However this observation was never studied hence this hypothesis remains untested. More research is required to understand the effect of stocking and grazing management on grazing behaviour and formation of 'lawns' and 'roughs'.

Our findings suggest that farm attributes (farm size, paddock size) and horse factors (mare category, number of mares per paddock) may have an influence on stocking and grazing management decisions which in turn would modify the grazing behaviour of mares, and ultimately, can affect the nitrogen leaching potential. Therefore, estimating nitrogen leaching on equine breeding stud farms requires a specific modelling framework (Fig. 4). Using this framework, the greatest nitrogen leaching potential can be expected on large scale commercial breeding stud farms that operates on a moderate sized property due to increased effective stocking density and semi-set stocked conditions.

[Insert Fig 4 here]

Conclusion

The stocking density on Thoroughbred stud farms doubled during the breeding season suggesting that the total farm N output can fluctuate seasonally. The identification of farm based on size and scale influenced the relationship between stocking density and farm category hence can affect total N output estimations. Our findings suggest that horse factors (mare category, number of mares per paddock) and farm attributes (farm size, paddock dimensions) influenced the stocking and grazing management on equine farms and subsequently, affected the pasture availability and modified the grazing behaviour of mares as reflected by the changes in differences between pasture mass of roughs and lawns. Changes in grazing behaviour can have implications on N leaching estimates because it can affect the manure and urine deposition area hence the N uptake rate by pasture and the N loading rate on urine and dung patches. Therefore, estimating nitrogen leaching on equine breeding stud farms requires a modelling framework that incorporates the complex relationship between farm, horse and management factors.

References

Bengtsson J, Rogers CW, Back PJ, Emanuelson U, Roca J, Gee EK, Bolwell CF. 2018. Characteristics of the grazing and farm management of broodmares on commercial Thoroughbred stud farms during spring. New Zealand Journal of Animal Science and Production. 78:88-91.

Bott RC, Greene EA, Koch K, Martinson KL, Siciliano PD, Williams C, Trottier NL, Burk A, Swinker A. 2013. Production and environmental implications of equine grazing. Journal of Equine Veterinary Science. 33(12):1031-1043.

Cameron KC, Hedley M, Clark H, Di HJ. 2017. Chapter 19, Impact of pasture and supplement feeding on the environement. In: Rattray PV, Brookes IM, Nicol AM, editors. Pasture and supplement for grazing animals. New Zealand: New Zealand Society of Animal Production; p. 317-339.

Di HJ, Cameron KC. 2002. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutrient Cycling in Agroecosystems. 64(3):237-256.

Di HJ, Cameron KC. 2007. Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor—a lysimeter study. Nutrient Cycling in Agroecosystems. 79(3):281-290.

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB, Cosby BJ. 2003. The Nitrogen Cascade. BioScience. 53(4):341-356.

Haynes RJ, Williams PH. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. In: Sparks DL, editor. Advances in Agronomy. Academic Press; p. 119-199.

Hirst RL. 2011. Seasonal variation of pasture quality on commercial equine farms in New Zealand [Masters]. Palmerston North, New Zealand: Massey University.

Hubbard R, Newton G, Hill G. 2004. Water quality and the grazing animal. Journal Of Animal Science. 82(Suppl):E255-E263.

Luo JF, Kelliher F. 2014. Partitioning of animal excreta N into urine and dung and developing the N2O inventory (MAF POL 0910-11528, 09-03). New Zealand: Ministry for Primary Industries.

Ödberg FO, Francis-Smith K. 1976. A study on eliminative and grazing behaviour - The use of the field by captive horses. Equine Veterinary Journal. 8(4):147-149.

Rogers CW, Gee EK, Firth EC. 2007. A cross-sectional survey of Thoroughbred stud farm management in the North Island of New Zealand. New Zealand Veterinary Journal. 55(6):302-307.

Shadbolt NM. 2012. Competitive strategy analysis of NZ pastoral dairy farming systems. International Journal of Agricultural Management. 1(3):19-27.

Stowers NL, Rogers CW, Hoskin S. 2009. Management of weanlings on commercial Thoroughbred studs farms in the North Island of New Zealand. New Zealand Society of Animal Production; Christchurch.

Watkins N, Selbie D. 2015. Technical description of OVERSEER for regional councils. New Zealand: AgResearch Ltd.https://www.overseer.org.nz/overseer-explained/technical-description-of-overseer.

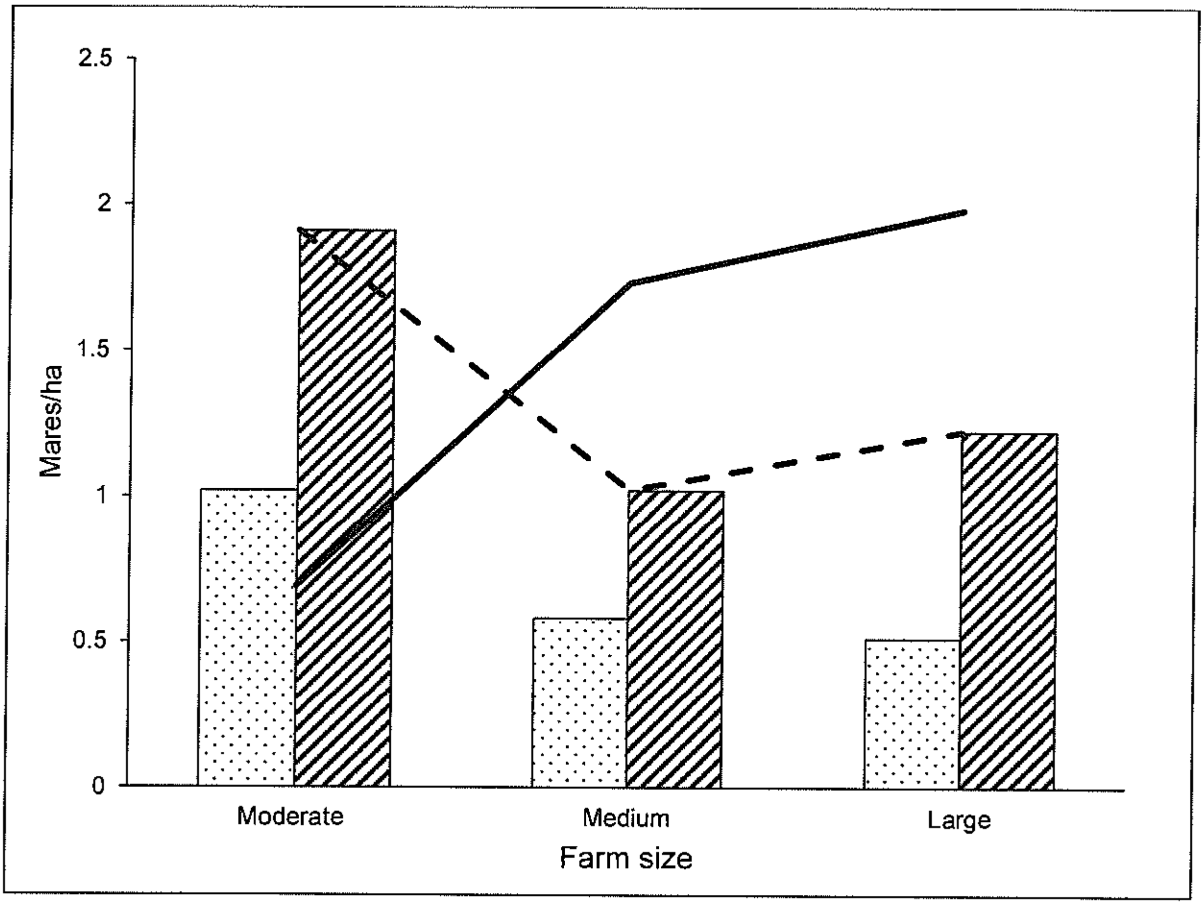

Figure 1. Stocking density (during the breeding season) of farms with moderate (<100ha), medium (100-200ha) and large (>200ha) total effective farm area ('dotted' line) and moderate (<70 mares), medium (90-199 mares), and large (>200 mares) scale (number of resident mares, 'solid' line), and the stocking density of non-breeding ('dotted' bars) and breeding ('striped' bars) season on moderate (<100ha), medium (100-200ha) and large (>200ha) farms .

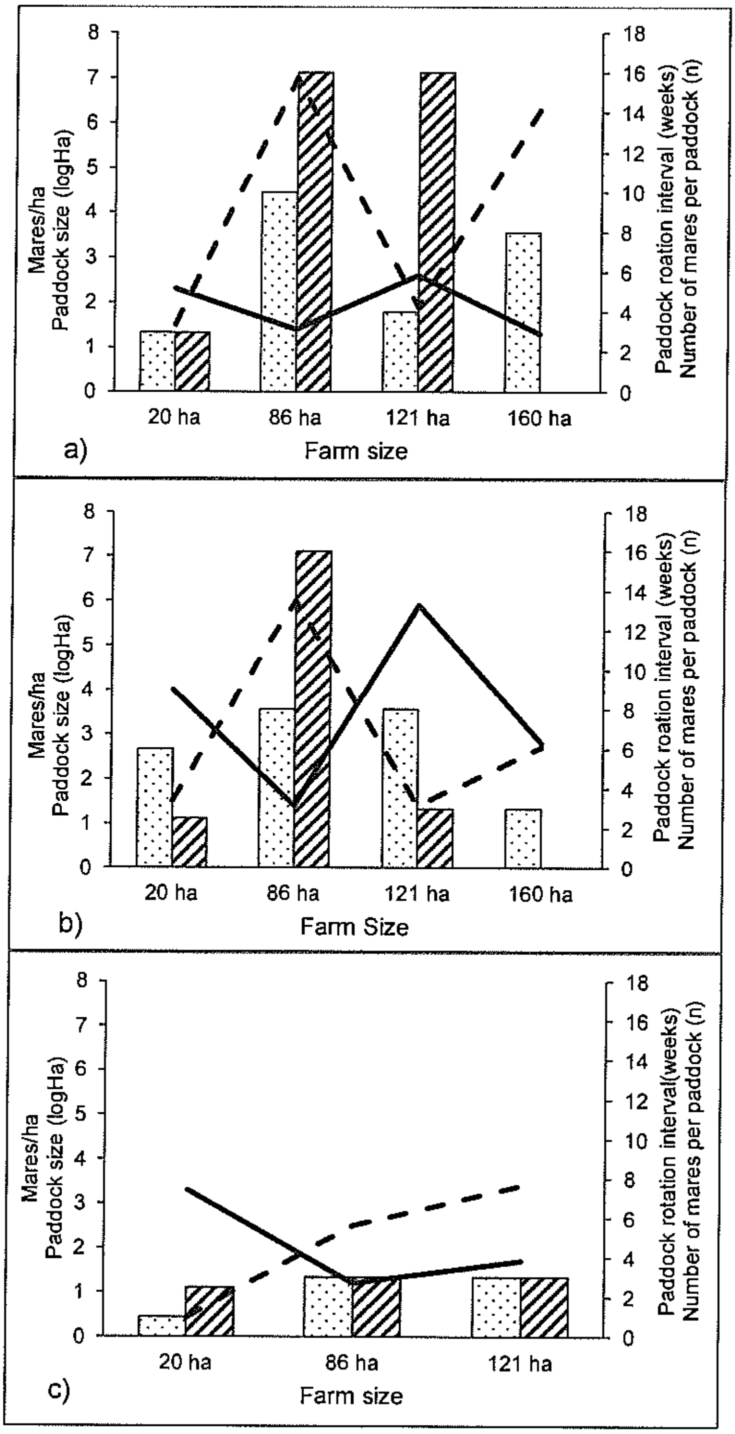

Figure 2. Relationship between total effective farm size (farm category, ha), number of mares per paddock ('dotted' block), paddock rotation interval ('striped' block) paddock size ('dotted' line) and stocking density (solid line) of (a) empty mares/ha, (b) pregnant mares/ha, (c) mares with foals.

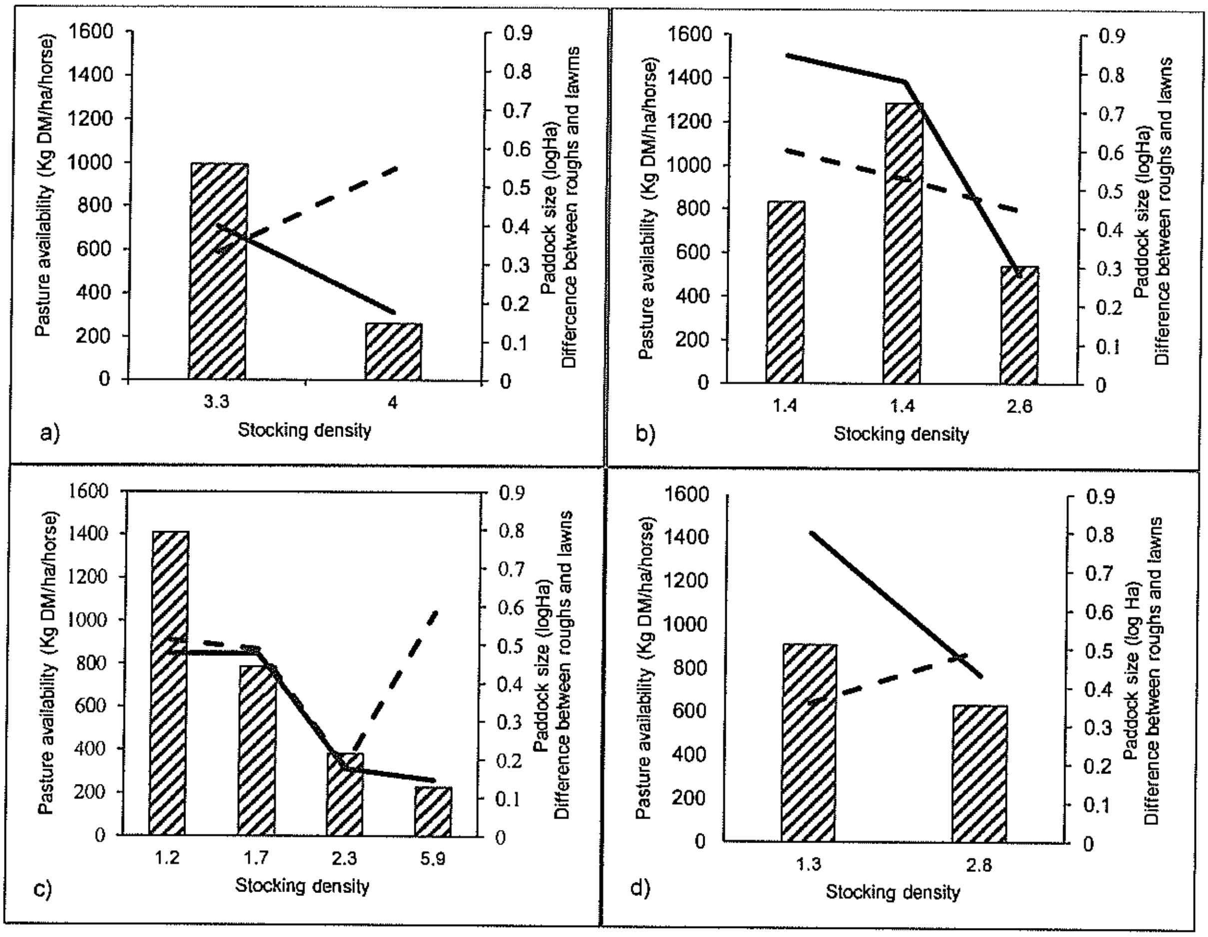

Figure 3. The dynamics between paddock size (logHa, 'solid' bar), pasture on offer (kg DM/ha/horse, 'solid' line), difference in pasture mass between roughs and lawns (%, 'dotted' bar, 0.5 is 50%), and stocking density under paddock rotation interval of (a) 2.5 weeks, (b) 3 weeks, (c) 16 weeks, (d) set stocked.

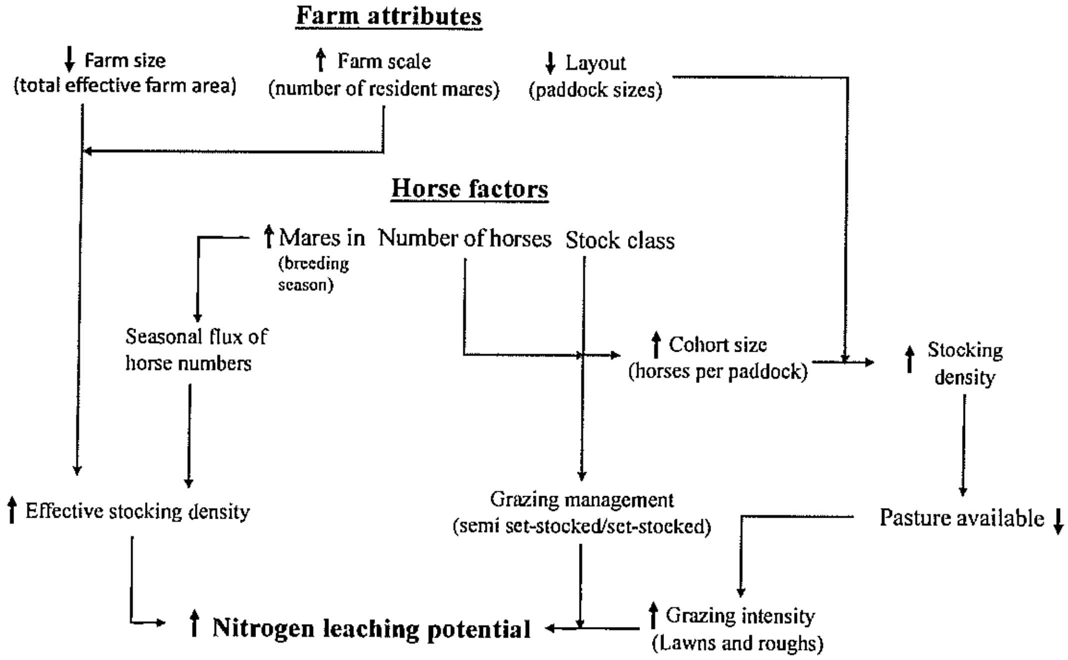

Figure 4. A proposed nitrogen leaching modelling framework for commercial Thoroughbred breeding stud farms.

APPENDIX 3

CSIRO PUBLISHING
Animal Production Science
http://dx.doi.org/10.1071/AN16752

Review

Commercial equine production in New Zealand. 2. Growth and development of the equine athlete

Chris W. Rogers[A,C], *Erica K. Gee*[A], *Charlotte F. Bolwell*[A] *and Sarah M. Rosanowski*[B]

[A]Massey Equine, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand.
[B]Veterinary Epidemiology, Economics and Public Health, Royal Veterinary College, The Royal Veterinary College, Hawkshead Lane, Hatfield, Hertfordshire, AL9 7TA, United Kingdom.
[C]Corresponding author. Email: c.w.rogers@massey.ac.nz

Abstract. During the past 20 years, there has been a contraction in the New Zealand Thoroughbred industry and, to a lesser extent, within the Standardbred industry. These changes have seen an increasing proportion of the market being associated with fewer larger commercial farms. Many of these farms manage their own mares, and the mares and foals of several clients. This, in turn, has increased the similarity of the management of breeding and young stock within New Zealand. The temperate climate allows the majority of the management of breeding and young stock to be pasture based. The predominant pasture is ryegrass–clover mix that has been demonstrated to provide adequate nutrition for growth and development. The temperate climate also permits management of horses at pasture year round, which is proposed to stimulate development of the musculoskeletal system. Apart from a brief period during weaning, most young stock remain at pasture from birth until the start of yearling preparation. Free access to pasture exercise provides the opportunity to stimulate the musculoskeletal system for the future challenges as a racehorse. The export focus of many of the equine industries heavily influences the management decisions. Despite the availability of good-quality pasture post-weaning, many foals receive up to 50% of the daily dietary energy requirement as concentrates, possibly reflecting the emphasis on early sales as yearlings and the drive to optimise growth. The observations of drench resistance of common internal parasites presents an emerging problem for pasture-based production systems. A large proportion of the Thoroughbred foal crop is exported as yearlings or ready to run 2-year-olds. There is an increasing trend for Standardbreds to be sold as yearlings and this has resulted in changes in the management of Standardbred young stock.

Additional keywords: horse, pasture, sport horse, Standardbred, Thoroughbred.

Received 17 November 2016, accepted 9 May 2017, published online 2 August 2017

Introduction

New Zealand's temperate climate permits equine production systems to be pasture based. This pasture-based system provides a cost-effective production system that reflects the horses' ecological niche. The ability to grow horses on forage-based diets at pasture, rather than with concentrate-based rations and confinement, is believed to reduce the exposure to some of the risk factors for developmental orthopaedic disease (DOD; Vander Heyden *et al.* 2013) and stimulate free exercise. Foals at pasture are reported to self-exercise in accordance to the receptivity of the musculoskeletal system to stimuli (Rogers *et al.* 2012*a*). Irregular exercise has been implicated with increased severity of juvenile osteochondral conditions (Lepeule *et al.* 2013). The opportunity to manage foals in stable cohorts at pasture up until the time of yearling preparation may encourage consistent exercise and a regular plane of growth (Rogers *et al.* 2012*a*).

The production system for horses, and particularly Thoroughbreds, can be divided into the following two sectors: an export-focussed system, and a sector focussed on supply of the domestic market (Rogers *et al.* 2016). Despite a rationalisation in the domestic racing industry, there has been little change in the export-focussed sector. At an industry level, this has seen a reduction in the total number of participants, but an increase in the relative number of horses owned and bred by the export-focussed sector. This has resulted in less variation in management among stud farms.

The objective of the present review is to examine the literature describing on-farm management of the foal through to yearling sales, or sale as a racing or sport horse. The management of the mare and the reproductive capability of the industry are described in a companion review paper (Gee *et al.* 2017). The size and scope of the racing and sport industries are covered in a further companion paper (Bolwell *et al.* 2017).

Management of young stock

Foals

Commercial farms have designated foaling paddocks (rather than a foaling box or stable) where foaling is overseen by foaling attendants, who either monitor mares continuously overnight, or are alerted to attend mares in Stage 2 labour by foaling alarms that are typically attached to halters. Many foals are prophylactically treated with antibiotics at birth, and some are routinely given enemas and tetanus antitoxin (Rogers *et al.* 2007). On 50% of the large Thoroughbred farms, foals were administered hyper immune plasma for *Rhodococcus equi*. The observation that only large farms (>200 mares) administered hyper immune plasma may be linked with the observation that large farms and larger groups of horses are considered a risk factor for *R. equi* infection (Cohen *et al.* 2005). The majority of foals will remain in smaller paddocks (~0.128 ha) or loose boxes for the first 2 days postpartum for observation, after which they are placed in larger paddocks (1–2 ha), with cohorts of 6–10 mares and foals (Shotton *et al.* 2015). Foals and mares usually will remain in these paddock cohorts until weaning.

Birthweight and height data are not commonly recorded on commercial breeding farms. Many farms will qualitatively record foal size at birth in association with other data on vigour, time to stand and time to suckle (Rogers *et al.* 2007; Dicken *et al.* 2012). Despite limited use of weight scales on commercial properties, the birthweight and growth parameters for the New Zealand Thoroughbred has been well described (Brown-Douglas *et al.* 2005; Morel *et al.* 2007) and are comparable to international data (Staniar *et al.* 2004). Colts are generally heavier than fillies at birth (55.8 kg vs 54.1 kg) and this gender bias continues through to weaning (235.6 kg vs 232.9 kg; Brown-Douglas *et al.* 2005). Growth rate (average daily gain) is not linear from birth to weaning and decreases in a curvilinear manner from up to 2 kg/day for the first weeks postpartum to ~1 kg/day at the time of weaning (average daily gain of 1.1 kg/day from birth to weaning; Morel *et al.* 2007).

The pastures on studfarms are predominately perennial ryegrass–white clover (*Lolium perenne–Trifolium repens*) mixes (85% : 15%), which are perceived to have a high palatability with horses (Hirst 2011; Randall *et al.* 2014). The dry-matter (DM) digestibility of fresh perennial ryegrass-based pasture is 60–65% (Grace *et al.* 2002*a*, 2002*b*, 2003). The digestible energy and protein content of this pasture is high compared with North American pastures, and in summer is typically 10.8 MJ of digestible energy per kilogram DM and 18.6% crude protein (Hirst 2011). The period of most rapid pasture growth (~60 kg DM/ha.day) coincides with the first weeks postpartum for most commercial Thoroughbred horses (October–November) and remains at ~30 kg DM/ha.day through to when foals are weaned (April). Pasture provides the predominant source of nutrition for the mare and foal up to weaning, and, when provided in sufficient quality and quantity, supports normal growth and development. Concentrates are generally introduced to the mare and foal in the last month before weaning.

Foals are born with a naive musculoskeletal system that is receptive and rapidly responds to environmental stimuli (Brama *et al.* 1999). Analysis of activity data of foals at pasture has identified pre-selection of exercise by foals that overlays directly with the sensitive period for tissue stimuli (Kurvers *et al.* 2006). The quantity of exercise load and the distances travelled by horses at pasture are inversely related to the paddock size and the density of horses (Duruttya 2003; Hampson *et al.* 2010). The movement of foals and mares to larger paddocks 2 days postpartum may provide an opportunity for foals to exhibit self-selected exercise to prime the musculoskeletal system for the future challenges as an equine athlete. While exercise at pasture has been demonstrated to be of greater benefit than is stall-rearing of foals, it appears that an increase in exercise by 30% above that normally achieved at pasture can have positive effects on cartilage viability and stimulation of the equine musculoskeletal system (Dykgraaf *et al.* 2008; Rogers *et al.* 2008; Firth *et al.* 2011). These studies have highlighted the importance of early exercise for musculoskeletal health, but also the limitations in our knowledge of how much exercise is required to optimally prime the equine musculoskeletal system (Rogers *et al.* 2012*b*).

Developmental orthopaedic disease (DOD) is the term originally coined to describe diseases affecting bone and cartilage in the young, rapidly growing foal, including osteochondrosis, physitis, and angular and flexural limb deformities (McIlwraith 2001). Recently, the classification juvenile osteochondral conditions (JOCC) has been proposed to better represent the variety of conditions observed in juvenile (less than 2-year-old) horses (Denoix *et al.* 2013). The prevalence of DOD or JOCC in foals in New Zealand is believed to be low compared with other countries (Pearce *et al.* 1998; Gee *et al.* 2005*a*; Castle 2012), possibly influenced by the pasture-based diet and the ability of foals to exercise. Regular exercise (i.e. consistently managed at pasture) and a consistent growth rate have been identified as lower risk for JOCC (Lepeule *et al.* 2013).

There are limited data on the prevalence of congenital angular, or flexural, limb deformities of foals on commercial breeding farms in New Zealand. On a commercial Standardbred farm, ~20% of foals at birth were recorded as having one or more limbs with a limb deformity (either angular or flexural). However, the data recorded did not identify, or differentiate, the deformities on the basis of a quantitative scale (Stowers *et al.* 2010). Data from a prospective study on commercial Thoroughbred stud farms identified that most flexural limb deformities were mild (Grade 1 of 4), were recorded as laxity at birth and had resolved by repeat scoring at foal heat (~2 weeks later; Shotton *et al.* 2015). The data for angular limb deformities were similar, with most cases scored at birth being mild (Grade 1 of 5), carpus valgus and resolving within 2 weeks (van Lierde 2015). For foals with either angular or flexural deformities, initial management was conservative, with most foals receiving some form of confinement to loose boxes and yards and associated trimming to rectify the deformity. Surgical correction was limited to a few severe cases that had a sustained period of conservative management.

Physitis of the distal third metacarpus and metatarsus are reported to be the second-largest grouping of juvenile osteochondral conditions in Thoroughbreds, after angular limb deformities (O'Donohue *et al.* 1992). An irregular profile of the distal metacarpal or metatarsal region is often the clinical presentation (Ineson *et al.* 2004) and is observed between 3 and 8 months of age. Enlargements in metaphyseal regions of distal third metacarpal and metatarsal bones were commonly observed in 5-month-old foals kept at pasture (Pearce *et al.* 1998; Ineson *et al.* 2004; Gee *et al.* 2005*b*); however, this was shown to be a normal physiological response that occurs with bone remodelling. The addition of conditioning exercise to foals at pasture appears to reduce the severity of the physitis score and this supports the hypothesis that metaphyseal cortical development may be inadequate unless a required level of exercise is obtained (Rogers *et al.* 2008).

The macro-element composition of typical New Zealand pastures is reported to meet the nutritional requirements of lactating broodmares and weanling foals (Grace *et al.* 2002*a*, 2002*b*, 2003). However, the copper concentrations in New Zealand pasture are frequently below the NRC (1987) minimum requirements of 10 mg/kg DM. Pearce *et al.* (1998) showed that oral copper supplementation of mares in late gestation was associated with less evidence of bone and cartilage lesions in foals at 5 months of age. In contrast, supplementation of foals with copper has shown no evidence of a significant effect on bone and cartilage lesions in foals at 5 months of age, compared with unsupplemented foals (Pearce *et al.* 1998). The pasture concentration of calcium may also be marginal according to NRC recommendations (NRC 2007) but does not limit bone development or growth of Thoroughbred foals (Grace *et al.* 2003); calcium in pasture may have high bioavailability (Hoskin and Gee 2004).

The methods of data recording by the two main studbooks (Thoroughbred and Standardbred) make it difficult to accurately estimate measures of loss from birth to weaning, and a detailed prospective on-farm study is, therefore, required to capture these data. Because of this, measures of loss from birth to weaning are limited within the New Zealand production system. Estimates derived from official records have indicated a loss in registrations at weaning due to morbidity and mortality (as well as economic decisions not to register a foal) at ~10% (Rogers *et al.* 2009, 2016). A survey of Canadian breeders identified that during the first 15 days of life, the morbidity rate was 25% and the mortality rate was 5% (Morley and Townsend 1997). This are similar to data from the USA and from Ireland (Cohen 1994; Galvin and Corley 2010). It appears that most mortality and morbidity are associated with the first month of life, with a negligible rate after this and leading to up to weaning.

Weanlings

Weaning of foals usually starts on farms after the completion of the yearling sales series (March–April). Foals are weaned between 4 and 6 months of age in age cohorts, the process starting with the oldest cohort of foals (Rogers *et al.* 2007; Stowers *et al.* 2009). Abrupt box weaning is the most common method used, although many farms will also use paddock weaning. There does not appear to be a significant difference in growth rate between abrupt or progressive methods of weaning and the choice of process often is influenced by physical resources (number of loose boxes, staff) and stud farm preference (Rogers *et al.* 2004). Data within the literature indicate that company and social interaction are important elements to minimise weaning stress and the development of stereotypic behaviours (Heleski *et al.* 2002). This may be one of the reasons why many farms wean foals in pairs.

After weaning, foals are organised into cohorts of four (range 2–8) foals according to sex and commercial appeal, and run at pasture (paddock size ~1.5 ha). The foals remain in these cohorts until the start of the yearling sale preparation. Weanlings with greater commercial appeal, or looking a little light in condition, or behind in development, may be rugged. Weanlings on boutique farms (≤15 mares) and medium-sized farms (71–99 mares) are more likely to be rugged during winter (57% and 50% of foals respectively; Stowers *et al.* 2009).

Weaning represents the start of the foals' education, and irrespective of the prior weaning process (stall or paddock), the weanlings are brought in (housed in loose boxes) at regular intervals for short periods of time (2–7 days), up to the start of the yearling sale preparation process. These short intervals of intensive management (usually on a monthly or 6-weekly cycle) provide the opportunity to observe the foal, trim feet, rug and provide other education (handling) to increase the ease of transition to the yearling preparation phase later in life (Stowers *et al.* 2009).

To offset weight loss around the time of weaning, concentrate feeds are offered. One survey indicated that 87% of foals on 46 Thoroughbred studs were offered concentrate feed before weaning, and all weanlings were offered concentrate feed after weaning (Stowers *et al.* 2009). At 5 months of age, weanlings received on average 47 MJ digestible energy from concentrates (79% of NRC requirements; Stowers *et al.* 2009) in one study, or 2.9 (range 1–6) kg of concentrates (Rogers *et al.* 2007). These findings imply that commercial stud farmers do not use pasture as a major source of nutrition for weanlings, despite the weanlings being kept on good-quality ryegrass–clover pasture, with a typical sward height of 10 cm (~3500 kg DM/ha). This management strategy implies that pasture is used to 'top-up' the nutritional requirements of the weanling, despite Grace *et al.* (2003) demonstrating that good growth rates (300 kg initial liveweight, average daily gain of 0.7 kg/day) were achieved in Thoroughbred weanlings grazing perennial ryegrass–white clover pasture (11 MJ/kg DM). The DM digestibility of the pasture was 0.62, while the weanlings achieved DM intakes of 5.5 kg/day and dietary-energy intake of 63 MJ/day, being within the NRC recommendations (60 MJ digestible energy).

Hintz (1998) suggested that the dietary calcium (Ca) intake of young horses grazing pastures containing 3.5 g Ca/kg DM may not be adequate to meet Ca requirements, or to promote good bone development. However, Grace *et al.* (2003) demonstrated that Ca supplementation of weanlings grazing pastures containing 3.5 g Ca/kg DM had no effect on the apparent absorption of Ca, which remained constant at 0.56, nor on pQCT measures of bone strength and Ca content.

Another advantage of raising foals at pasture is the ability for foals to exercise freely, the benefits of which have been summarised in several reviews (Rogers *et al.* 2012*a*, 2012*b*, 2014). Confinement and restricted exercise pre-weaning prevents optimal cartilage development in Warmblood foals (Brama *et al.* 1999; Barneveld and van Weeren 1999). Irregular exercise (changes between confinement and exercise) has also been identified as a risk factor for JOCC (Lepeule *et al.* 2013). Additional exercise, 30% greater than normal paddock exercise, was observed to increase chondrocyte viability at 18 months (Dykgraaf *et al.* 2008), reinforcing the advantage of keeping weanlings at pasture (Rogers *et al.* 2008).

The most abundant data on growth from weaning to yearling phases in New Zealand has been collected and quantified for the Thoroughbred. The growth rate of the Thoroughbred at pasture is most rapid pre-weaning and reaches a plateau at a consistent rate of 0.6–0.7 kg/day (Brown-Douglas *et al.* 2005;

Morel *et al.* 2007). At the time the horse is ready for yearling sales, it has completed the majority of the longitudinal long-bone growth and is close to mature height (~90–95% mature height) and ~80% of mature weight (Fig. 1). These growth rates and mature weights are similar to those reported from other international populations of Thoroughbred horses (Brown-Douglas *et al.* 2005). The level of exercise at pasture does not appear to alter height or weight parameters, but may alter the deposition of fat. In foals provided a 30% increase in pasture exercise, there was a lower score of 'fatness' (body condition score) and greater apparent muscularity, despite there being no significant difference in wither height or bodyweight when compared with conventionally reared foals at pasture (Rogers *et al.* 2008).

Published growth-rate data for Standardbred and Sport horses in New Zealand are currently lacking. The similarity of the growth data for Thoroughbreds and the significant international inter-exchange of genetic material would imply that growth rate and growth characteristics for Standardbreds and Sport horses should not differ from those published internationally.

The practice of separating foals post-weaning into gender-based cohorts may be associated with the onset of puberty in both sexes in the spring following weaning. The horse is a photoperiod breeder and under New Zealand management conditions, foals will have reached the minimum bodyweight (~50% of adult weight) by June–July (mid-winter). However, the increasing daylength required for onset of puberty is not achieved until early September, and completed by mid-October (~11 months old; Brown-Douglas *et al.* 2004). Analysis of growth data indicates that there is a small spike in growth associated with the transition into spring, which may be associated with a pre-pubertal growth spurt (Fig. 2).

Pastures in temperate climates can provide ideal conditions for larval helminth development, and high stocking rates on studs during the breeding season mean that all horses can potentially ingest large numbers of infective larvae. Young horses kept at pasture are susceptible to helminth infections, especially *Parascaris equorum*, and cyathostomes (Bishop *et al.* 2014). There are limited data describing helminth parasite-control practices in young horses in New Zealand. Three Thoroughbred stud farms have reported that their foals are given their first anthelmintic between 4 and 20 weeks of age (Bishop *et al.* 2014). There is evidence that interval dosing strategies are commonly used in New Zealand; Thoroughbred weanlings receive anthelmintics every 6–7 weeks (range 3–14 weeks) (Rogers *et al.* 2007; Stowers *et al.* 2009), and more than 50% of Thoroughbred and Standardbred farms surveyed indicated that they used 6–8-week dosing intervals for young stock (Bolwell *et al.* 2015). With evidence of suboptimal efficacy of ivermectin against *Parascaris equorum* in Thoroughbred foals and widespread resistance of cyathostomes against benzimidazoles (Bishop *et al.* 2014), concern has been expressed about the overuse of anthelmintics in New Zealand when interval dosing strategies are used, and the lack of monitoring of anthelmintic efficacy (Scott *et al.* 2015).

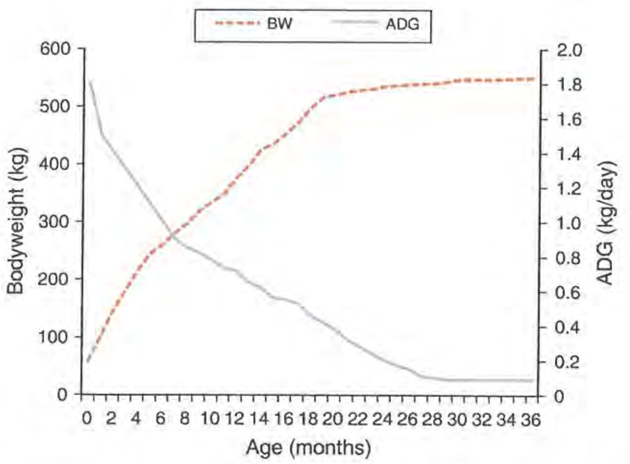

Fig. 1. Mean bodyweight (BW) and average daily gain (ADG) from a cohort of New Zealand Thoroughbred foals (Rogers *et al.* 2008).

Yearlings

The management of the yearling is largely dependent on whether the yearling will be entered for sale as a yearling (and the sales category) or held over as a 'store' and sold at a later date. On farm, foals are identified as sales candidates either before weaning (36%) or just after weaning (39%) (Bolwell *et al.* 2010*a*). Stud farms nominate foals for entry into the sales before the start of the season (June–July) and staff from the auction sales company will screen potential candidates (pedigree and conformation) and indicate the likely sales category before the horses become yearlings (before 1 August; Waldron *et al.* 2011).

Prior to sales preparation, all yearlings are kept at pasture, and there is an increasing focus on the management needs of the individual horse rather than the cohort of horses. In the literature, there is among-farm and among-horse variation in the level of concentrates provided to yearlings (1–6 kg as fed) and this, in part, may reflect the two different production streams (sales candidates and stores) and the desire to increase the plane of nutrition, and thus the rate of growth and development, of some individuals (Rogers *et al.* 2007). During this period, quantitative measures of height and weight, and thus growth rate, were rarely obtained, with only 11% of farms weighing their yearlings.

The presence of osteochrondrosis and osteochondrosis desicans (OCD) either clinically, or radiographically, negates the marketability of the yearling. Stud-farm managers are, therefore, pro-active in avoiding management practises that are perceived to increase the risk of yearlings presenting with OCD at the time of the yearling sales. In the literature, there is limited evidence that feeding of high levels of concentrate feed has been associated with an increased prevalence, or odds, of the yearling presenting with DOD and OCD (Vander Heyden *et al.* 2013). The commercial response to this has been the increased use of 'low-glycaemic feeds' and a greater use of fibre-based (generally Lucerne) supplementary feed. Despite this industry perception of associated risk (for what is a complex multifactorial problem), many farms will provide over 75% of the yearling digestible-energy requirement pre-yearling preparation as concentrate feed, despite maintaining the yearlings at pasture, which is capable of providing the

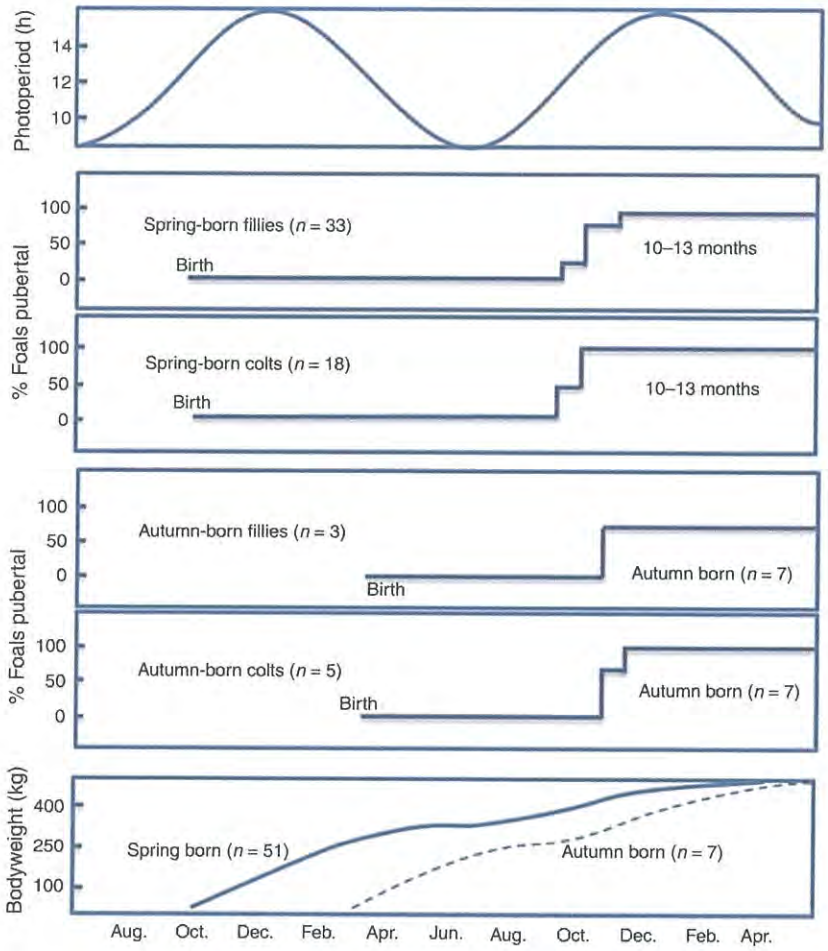

Fig. 2. Onset of puberty for autumn- and spring-born Thoroughbred fillies and colts grown at pasture. Adapted from Brown Douglas PhD Thesis, 2003, Massey University, Palmerston North, New Zealand.

majority of the young horse's digestible energy and maintaining adequate growth rates (Brown-Douglas *et al.* 2005; Stowers *et al.* 2009).

Many farms will screen yearlings for OCD with a radiographic survey before the start of yearling preparation. Data from these radiographs indicate that the prevalence of OCD in Thoroughbred yearlings in New Zealand is 13%, which is approximately half of that observed in a similar cohort of Australian yearlings (Castle 2012). On the basis of screening of pre-sale radiographs submitted to the X-ray repository at the yearling sales, the prevalence and distribution of radiographically evident lesions in the hock and stifle appear similar to those presented for Thoroughbred yearlings in the United States (Oliver *et al.* 2008).

Yearling preparation and yearling sales

The New Zealand Yearling Sales Series is held in late January and early February, where the oldest stock are ~16 months old. Preparation of yearlings for sale begins 13 (range 6–20) weeks before the sales, with 84% of the farms starting in the last week of October or first week of November (Rogers *et al.* 2007). The timing of entry into the yearling preparation and the level of exercise/management associated with the preparation are associated with the sales category the yearlings are entered in. This is a logical partitioning of resources, as sales category largely determines the opportunity to maximise yearling sale price. During the yearling preparation on the majority of farms, horses are housed in loose boxes for ~12 h/day and at pasture (in small individual turn-out paddocks) for ~12 h/day. Controlled exercised is performed on 80% of farms and this is usually in the form of in-hand walking 3–5 days per week. Mechanical horse walkers are used only on 20% of farms. Exercise is provided to yearlings generally as part of their education for the final auction sales presentation, rather than specifically as part of a physical conditioning program (Bolwell *et al.* 2010*a*). This reflects the industry drivers (auction sale price) for a yearling that is well conditioned and above median for height (Pagan *et al.* 2006) and that there is no association between the exercise level during yearling preparation and time taken to enter the first race trial (Bolwell *et al.* 2012).

There are no data on the management or feeding of Standardbred yearlings during the yearling sale preparation. In contrast to the Thoroughbred, the proportion of the Standardbred foal crop offered for sale as yearlings is low and this has implications on the management of the yearling horses. The assumption is that feeding and management of the Standardbred as a yearling is generally more pasture based and less intensive than has been observed within the Thoroughbred industry. Most sport horses are not marketed as yearlings but as 3–4-year olds and often 'broken-in' and as riding prospects. This later age of sale, the perception of a slower-maturing horse and less commercial focus (60% of breeders breed as a hobby rather than as a commercial enterprise) translates to a pasture-based and less intensive management of the yearling and young horse (George *et al.* 2013).

Yearling sales to race training

The sale of a yearling at auction is the major form of marketing within the Thoroughbred industry. Annually, 1500 yearlings are sold across the three sales categories, representing ~40% of the annual foal crop (Waldron *et al.* 2011). Slower-maturing horses often will not be presented for sale as yearlings and are kept as 'stores' to sell as 2-year olds either at the ready-to-run sales or as horses 'in work' (Bolwell *et al.* 2010*a*).

The significant demand for the New Zealand Thoroughbred has seen export levels remain consistent, despite a global economic downturn, with ~1500 Thoroughbred horses being exported each year (Rogers *et al.* 2016). Traditionally, ~40% of foals from the Thoroughbred foal crop are exported; however, with reducing foal numbers, this percentage will most likely increase in the coming years (Bolwell *et al.* 2016*a*, 2017). Australia remains the major market for New Zealand Thoroughbred, accounting for ~65% of all exports, with many of the horses sold as yearlings out of the National Yearling sales series (Waldron *et al.* 2011). South-east Asia, particularly the racing jurisdictions of Hong Kong, Macau and Singapore, are responsible for the majority of the remaining export numbers, but tend to purchase horses that are trained 2-year olds (Fennessy 2010).

The sales category within the yearling sales series has a significant effect on the auction sales price of the yearling. Bloodstock agents from the sales company will allocate yearlings to the sales series on the basis of pedigree (commercial appeal) and physical correctness (Waldron *et al.* 2011). Foals that are larger tend to achieve greater sales returns than do the median-sized horses, for horses with the same pedigree and sales series. This greater return explains the focus of breeders in attempting to have mares breed as early as possible to produce an early foal that is at optimal size when presented for sale (Gee *et al.* 2017; Rogers *et al.* 2016). Across the sales categories, there is a sales category by sex interaction in relation to the auction price, with fillies selling for less than colts of similar pedigree and type. The effect of this sex bias is greater at the lower end of the sales series categories. The drivers for this relate to the opportunities to market the yearling purchase once in training as a 2-year-old. Many horses at the lower sales category will be purchased on the basis of type (conformation and size) rather than pedigree, and the major Asian markets will purchase only colts or geldings as racing prospects (Rogers and Gee 2011).

In contrast to the large focus on the export market with the Thoroughbred industry, the Standardbred is bred primarily for domestic consumption, with exports accounting for 15% of the foal crop and most of these are 'in work' racehorses rather than yearlings (Bolwell *et al.* 2016*b*). There is an increasing trend for some Standardbreds to be marketed as yearlings through the annual auction sales series, and this has resulted in yearling preparations similar to those of the Thoroughbred industry. However, at present, these represent a minority of the Standardbred foals born each year.

In a cross-sectional survey of race training practises, it was identified that Thoroughbred racehorse trainers classified as having large stables, or located in the Northern Districts, were more likely to have horses sourced from the yearling sales, have them broken-in and pre-trained off-site by a separate contractor, and were more likely to have a larger proportion of 2-year olds in training than did other trainers, or trainers located in the Central Districts region (Bolwell *et al.* 2010*b*).

Wastage up to racing

Across many racing jurisdictions, there is considerable loss or wastage due to the failure of foals to progress thorough to racing. In some cases, as few as 50% of the foals born will enter in a race (Bailey *et al.* 1997; Wilsher *et al.* 2006). A more accurate measure of wastage during the production phase is perhaps the percentage of foals that are never registered with a trainer. These horses are never officially identified as receiving any training and represent the horses that are lost due to injury or perceived lack of talent. Within the New Zealand Standardbred industry, 32% of foals are never registered with a trainer (Tanner *et al.* 2011). There was a similar trend within the Thoroughbred industry, with 33% failing to be registered with a trainer (Tanner *et al.* 2012). It would appear within the Standardbred industry that the presence of a limb deformity at birth does not prohibit the entry of the horse intro race training and racing, but there is an associated delay in the age when those animals have their first race start (4 years vs 3 years; Stowers *et al.* 2010). It is difficult without prospective studies to identify the reasons for ~1/3rd of the foal crops failing to be registered with a trainer. Given the reduction in the annual foal crop for both the Standardbred and Thoroughbred and, therefore, fewer foals to satisfy the demand for domestic racing product, it will be increasingly important to minimise wastage within the industry. Preliminary examination of the changes in the production system following the global financial crisis has shown an international decline in the number of horses bred and offered for sale. In New Zealand, the relative decline in the number of Thoroughbred horses bred (43% reduction) has not been reflected in the reduction in the proportion of Thoroughbreds exported (24%) or in the reduction in numbers of horses involved with domestic racing (6.5%; Rogers *et al.* 2016). These data imply that, while total numbers have decreased, there has been a lift in the relative efficiency within the Thoroughbred production system.

Conclusions

The temperate New Zealand climate permits a predominately pasture-based production system for breeding and growing horses. This offers several advantages for the growth and development of the equine athlete, as this system permits free exercise during essential developmental periods. In contrast to most Thoroughbred racing nations, the majority of breeders in New Zealand focus on the large export market. This export focus and the contraction in the domestic market has seen increasing similarity in production processes across the commercial operators. The trend to sell Standardbreds as yearlings rather than the traditional base of owner-breeder-trainer has resulted in more intensive management of young stock in this industry.

References

Bailey CJ, Rose RJ, Reid SW, Hodgson DR (1997) Wastage in the Australian thoroughbred racing industry: a survey of Sydney trainers. *Australian Veterinary Journal* **75**, 64–66. doi:10.1111/j.1751-0813.1997.tb13836.x

Barneveld A, van Weeren PR (1999) Conclusions regarding the influence of exercise on the development of the equine musculoskeletal system with special reference to osteochondrosis. *Equine Veterinary Journal* 112–119.

Bishop R, Scott I, Gee E, Rogers C, Pomroy W, Mayhew I (2014) Sub-optimal efficacy of ivermectin against *Parascaris equorum* in foals on three Thoroughbred stud farms in the Manawatu region of New Zealand. *New Zealand Veterinary Journal* **62**, 91–95. doi:10.1080/00480169.2013.843146

Bolwell CF, Rogers CW, Firth EC, French N (2010*a*) Management and exercise of Thoroughbred yearlings during preparation for yearling sales: a cross-sectional survey. *Proceedings of the New Zealand Society of Animal Production* **70**, 157–161.

Bolwell CF, Russell LJ, Rogers CW, Firth EC (2010*b*) A cross-sectional survey of training practices of 2-year-old racehorses in the North Island of New Zealand. *Comparative Exercise Physiology* **7**, 37–42. doi:10.1017/S1755254010000103

Bolwell CF, Rogers CW, French N, Firth EC (2012) The effect of interruptions during training on the time to the first trial and race start in Thoroughbred racehorses. *Preventive Veterinary Medicine* **108**, 188–198.

Bolwell C, Rosanowski SM, Scott I, Sells PD, Rogers CW (2015) Questionnaire study on parasite control practices on Thoroughbred and Standardbred breeding farms in New Zealand. *Veterinary Parasitology* **209**, 62–69. doi:10.1016/j.vetpar.2015.02.011

Bolwell CF, Rogers CW, Gee EK, Rosanowski SM (2016*a*) Descriptive statistics and the pattern of horse racing in New Zealand: Part 1. Thoroughbred racing. *Animal Production Science* **56**, 77–81. doi:10.1071/AN13442

Bolwell CF, Rogers CW, Gee EK, Rosanowski SM (2016*b*) Descriptive statistics and the pattern of horse racing in New Zealand: Part 2. Standardbred racing. *Animal Production Science* **56**, 82–86. doi:10.1071/AN13443

Bolwell CF, Rogers CW, Gee EK, Rosanowski SM (2017) Commercial equine production in New Zealand 3: the racing and sport industries. *Animal Production Science.* doi:10.1071/AN16753

Brama PA, Tekoppele JM, Bank RA, Van Weeren PR, Barneveld A (1999) Influence of different exercise levels and age on the biochemical characteristics of immature equine articular cartilage. *Equine Veterinary Journal. Supplement* **31**, 55–61. doi:10.1111/j.2042-3306.1999.tb05314.x

Brown-Douglas CG, Firth EC, Parkinson TJ, Fennessy PF (2004) Onset of puberty in pasture-raised Thoroughbreds born in southern hemisphere spring and autumn. *Equine Veterinary Journal* **36**, 499–504. doi:10.2746/0425164044877422

Brown-Douglas CG, Parkinson TJ, Firth EC, Fennessy PF (2005) Bodyweights and growth rates of spring- and autumn-born thoroughbred horses raised on pasture. *New Zealand Veterinary Journal* **53**, 326–331. doi:10.1080/00480169.2005.36568

Castle K (2012) Investigating the genetic and genomic basis of osteochondrosis in Thoroughbred horses from Australia and New Zealand. University of Sydney, Sydney.

Cohen ND (1994) Causes of and farm-management factors associated with disease and death in foals. *Journal of the American Veterinary Medical Association* **204**, 1644–1651.

Cohen ND, O'conor MS, Chaffin MK, Martens RJ (2005) Farm characteristics and management practices associated with development of *Rhodococcus equi* pneumonia in foals. *Journal of the American Veterinary Medical Association* **226**, 404–413. doi:10.2460/javma.2005.226.404

Denoix JM, Jeffcott LB, Mcilwraith CW, Van Weeren PR (2013) A review of terminology for equine juvenile osteochondral conditions (JOCC) based on anatomical and functional considerations. *Veterinary Journal (London, England)* **197**, 29–35. doi:10.1016/j.tvjl.2013.03.038

Dicken M, Gee EK, Rogers CW, Mayhew IG (2012) Gestation length and occurrence of daytime foaling of Standardbred mares on two stud farms in New Zealand. *New Zealand Veterinary Journal* **60**, 42–46. doi:10.1080/00480169.2011.632340

Duruttya M (2003) Use of an ethological test to calculate a distance covered by selected categories of Thoroughbred horses. *Czech Journal of Animal Science* **48**, 46–50.

Dykgraaf S, Firth EC, Rogers CW, Kawcak CE (2008) Effects of exercise on chondrocyte viability and subchondral bone sclerosis in the distal third metacarpal and metatarsal bones of young horses. *Veterinary Journal (London, England)* **178**, 53–61. doi:10.1016/j.tvjl.2007.08.016

Fennessy PF (2010) An overview of the New Zealand Thoroughbred industry. *Proceedings of the New Zealand Society of Animal Production* **70**, 137–139.

Firth EC, Rogers CW, Van Weeren PR, Barneveld A, Mcilwraith CW, Kawcak CE, Goodship AE, Smith RKW (2011) Mild exercise early in life produces changes in bone size and strength but not density in proximal phalangeal, third metacarpal and third carpal bones of foals. *Veterinary Journal (London, England)* **190**, 383–389. doi:10.1016/j.tvjl.2010.11.016

Galvin NP, Corley KTT (2010) Causes of disease and death from birth to 12 months of age in the Thoroughbred horse in Ireland. *Irish Veterinary Journal* **63**, 37–43. doi:10.1186/2046-0481-63-1-37

Gee EK, Firth EC, Morel PCH, Fennessy PF, Grace ND, Mogg TD (2005*a*) Articular/epiphyseal osteochondrosis in thoroughbred foals at 5 months of age: influences of growth of the foal and prenatal copper supplementation of the dam. *New Zealand Veterinary Journal* **53**, 448–456. doi:10.1080/00480169.2005.36591

Gee EK, Firth EC, Morel PCH, Fennessy PF, Grace ND, Mogg TD (2005*b*) Enlargements of the distal third metacarpus and metatarsus in thoroughbred foals at pasture from birth to 160 days of age. *New Zealand Veterinary Journal* **53**, 438–447. doi:10.1080/00480169.2005.36590

Gee EK, Rogers CW, Bolwell CF (2017) Commerical equine production in New Zealand. 1. Reproduction and breeding. *Animal Production Science.* doi:10.1071/AN16728

George HEA, Bolwell CF, Rogers CW, Gee EK (2013) A cross-sectional survey of New Zealand sport horse stud farms. *Proceedings of the New Zealand Society of Animal Production* **73**, 71–75.

Grace N, Shaw HL, Gee EK, Firth EC (2002*a*) Determination of the digestible energy intake and apparent absorption of macroelements in pasture-fed lactating Thoroughbred mares. *New Zealand Veterinary Journal* **50**, 182–185. doi:10.1080/00480169.2002.36308

Grace ND, Gee EK, Firth EC, Shaw HL (2002*b*) Digestible energy intake, dry matter digestibility and mineral status of grazing New Zealand Thoroughbred yearlings. *New Zealand Veterinary Journal* **50**, 63–69. doi:10.1080/00480169.2002.36252

Grace ND, Rogers CW, Firth EC, Faram TL, Shaw HL (2003) Digestible energy intake, dry matter digestibility and effect of increased calcium intake on bone parameters of grazing thoroughbred weanlings in New Zealand. *New Zealand Veterinary Journal* **51**, 165–173. doi:10.1080/00480169.2003.36359

Hampson BA, Morton JM, Mills PC, Trotter MG, Lamb DW, Pollitt CC (2010) Monitoring distances travelled by horses using GPS tracking collars. *Australian Veterinary Journal* **88**, 176–181. doi:10.1111/j.1751-0813.2010.00564.x

Heleski CR, Shelle AC, Nielsen BD, Zanella AJ (2002) Influence of housing on weanling horse behavior and subsequent welfare. *Applied Animal Behaviour Science* **78**, 291–302. doi:10.1016/S0168-1591(02)00108-9

Hintz HF (1998) Mineral requirements in the horse: a historical perspective. In 'Advances in equine nutrition'. (Ed. JD Pagan) pp. 51–56. (Kentucky Equine Research Incorporated, Nottingham University Press: Nottingham)

Hirst RL (2011) 'Seasonal variation of pasture quality on commercial equine farms in New Zealand.' (Institute of Veterinary Animal and Biomedical Sciences, Massey University: Palmerston North, New Zealand)

Hoskin SO, Gee EK (2004) Feeding value of pastures for horses. *New Zealand Veterinary Journal* **52**, 332–341.

Ineson AC, Rogers CW, Firth EC, Gee EK (2004) A comparison of subjective and quantitative methods for detection of physitis in Thoroughbred foals. *New Zealand Veterinary Journal* **52**, 65–69. doi:10.1080/00480169.2004.36406

Kurvers CMHC, Van Weeren PR, Rogers CW, Van Dierendonck MC (2006) Quantification of spontaneous locomotion activity in foals kept in pastures under various management conditions. *American Journal of Veterinary Research* **67**, 1212–1217. doi:10.2460/ajvr.67.7.1212

Lepeule J, Bareille N, Robert C, Valette J-P, Jacquet S, Blanchard G, Denoix J-M, Seegers H (2013) Association of growth, feeding practices and exercise conditions with the severity of the osteoarticular status of limbs in French foals. *Veterinary Journal (London, England)* **197**, 65–71. doi:10.1016/j.tvjl.2013.03.043

McIlwraith CW (2001) Developmental orthopedic disease (DOD) in horses-a multifactorial process. In 'Proceedings of the 17th equine nutrition and physiology society', Lexington, Kentucky. pp. 2–23.

Morel PCH, Bokor A, Rogers CW, Firth EC (2007) Growth curves from birth to weaning for Thoroughbred foals raised on pasture. *New Zealand Veterinary Journal* **55**, 319–325. doi:10.1080/00480169.2007.36788

Morley PS, Townsend HGG (1997) A survey of reproductive performance in Thoroughbred mares and morbidity, mortality and athletic potential of their foals. *Equine Veterinary Journal* **29**, 290–297. doi:10.1111/j.2042-3306.1997.tb03126.x

National Research Council (2007) 'Nutrient requirements of horses.' (National Academy Press: Washington, DC)

O'Donohue DD, Smith FH, Strickland KL (1992) The incidence of abnormal limb development in the Irish Thoroughbred from birth to 18 months. *Equine Veterinary Journal* **24**, 305–309. doi:10.1111/j.2042-3306.1992.tb02841.x

Oliver LJ, Baird DK, Baird AN, Moore GE (2008) Prevalence and distribution of radiographically evident lesions on repository films in the hock and stifle joints of yearling Thoroughbred horses in New Zealand. *New Zealand Veterinary Journal* **56**, 202–209. doi:10.1080/00480169.2008.36834

Pagan JD, Nash DM, Koch A, Caddel S, Brown-Douglas CG (2006) The influence of bodyweight, wither height and body condition score on sale price of Thoroughbred yearlings at public auction. *Proceedings of the Australian Equine Science Symposium* **1**, 27.

Pearce SG, Firth EC, Grace ND, Fennessy PF (1998) Effect of copper supplementation on the evidence of developmental orthopaedic disease in pasture-fed New Zealand Thoroughbreds. *Equine Veterinary Journal* **30**, 211–218. doi:10.1111/j.2042-3306.1998.tb04490.x

Randall L, Rogers CW, Hoskin SO, Morel PCH, Swainson NM (2014) Preference for different pasture grasses by horses in New Zealand. *Proceedings of the New Zealand Society of Animal Production* **74**, 5–10.

Rogers CW, Gee EK (2011) Selection decisions in Thoroughbred broodmares. *Proceedings of the New Zealand Society of Animal Production* **71**, 122–125.

Rogers CW, Gee EK, Faram TL (2004) The effect of two different weaning procedures on the growth of pasture-reared thoroughbred foals in New Zealand. *New Zealand Veterinary Journal* **52**, 401–403. doi:10.1080/00480169.2004.36458

Rogers CW, Gee EK, Firth EC (2007) A cross-sectional survey of Thoroughbred stud farm management in the North Island of New Zealand. *New Zealand Veterinary Journal* **55**, 302–307. doi:10.1080/00480169.2007.36785

Rogers CW, Firth EC, Mcilwraitht CW, Barneveld A, Goodship AE, Kawcak CE, Smith RKW, Van Weerew PR (2008) Evaluation of a new strategy to modulate skeletal development in Thoroughbred performance horses by imposing track-based exercise during growth. *Equine Veterinary Journal* **40**, 111–118. doi:10.2746/042516408X268923

Rogers CW, Gee EK, Vermeij E (2009) Retrospective examination of the breeding efficiency of the New Zealand Thoroughbred and Standardbred horse. *Proceedings of the New Zealand Society of Animal Production* **69**, 126–131.

Rogers CW, Bolwell CF, Tanner JC, Van Weeren PR (2012*a*) Early exercise in the horse. *Journal of Veterinary Behavior: Clinical Applications and Research* **7**, 375–379. doi:10.1016/j.jveb.2012.01.003

Rogers CW, Bolwell CF, Gee EK (2012*b*) Proactive management of the equine athlete. *Animals (Basel)* **2**, 640–655. doi:10.3390/ani2040640

Rogers CW, Bolwell CF, Gee EK (2014) Early exercise in the juvenile horse to optimise performance later in life. In 'Horses breeding, health disorders, and effects on performance and behavior'. (Eds A Paz-Silva, MSA Vazquez, RS-A Fernandez) pp. 1–20. (Nova Publishing: New York)

Rogers CW, Gee EK, Bolwell CF (2016) Reproductive production constraints within the New Zealand racing industry. *Proceedings of the New Zealand Society of Animal Production* **76**, 146–150.

Scott I, Bishop RM, Pomroy WE (2015) Anthelmintic resistance in equine helminth parasites: a growing issue for horse owners and veterinarians in New Zealand? *New Zealand Veterinary Journal* **63**, 188–198. doi:10.1080/00480169.2014.987840

Shotton A, Bolwell CF, Rogers CW, Gee EK, Sells PD, Connel J, McIlwraith CW (2015) Flexural limb deformities in a cohort of Thoroughbred foals on commercial stud farms. *Proceedings of the New Zealand Society of Animal Production* **75**, 188–190.

Staniar WB, Kronfeld DS, Treiber KH, Splan RK, Harris PA (2004) Growth rate consists of baseline and systematic deviation components in thoroughbreds. *Journal of Animal Science* **82**, 1007–1015. doi:10.2527/2004.8241007x

Stowers NL, Rogers CW, Hoskin SO (2009) Management of weanlings on commercial Thoroughbred studs farms in the North Island of New Zealand. *Proceedings of the New Zealand Society of Animal Production* **69**, 4–9.

Stowers NL, Erdtsieck B, Rogers CW, Taylor TB, Firth EC (2010) The prevalance of limb deformities in New Zealand Standardbred foals and their influence on racing success: a preliminary investigation. *Proceedings of the New Zealand Society of Animal Production* **70**, 140–142.

Tanner JC, Rogers CW, Firth EC (2011) The relationship of training milestones with racing success in a population of Standardbred horses in New Zealand. *New Zealand Veterinary Journal* **59**, 323–327. doi:10.1080/00480169.2011.617029

Tanner JC, Rogers CW, Firth EC (2012) The association of 2-year-old training milestones with career length and racing success in a sample of Thoroughbred horses in New Zealand. *Equine Veterinary Journal* **45**, 20–24.

Vander Heyden L, Lejeune JP, Caudron I, Detilleux J, Sandersen C, Chavatte P, Paris J, Deliege B, Serteyn D (2013) Association of breeding conditions with prevalence of osteochondrosis in foals. *The Veterinary Record* **172**, 68–71. doi:10.1136/vr.101034

van Lierde M (2015) 'An epidemiological study of the presence and significance of angular limb deformities in a sample of New Zealand thoroughbred foals.' (Institute of Veterinary, Animal and Biomedical Science, Massey University: Palmerston North, New Zealand)

Waldron K, Rogers CW, Gee EK, Bolwell CF (2011) Production variables influencing the auction sales price of New Zealand Thoroughbred yearlings. *Proceedings of the New Zealand Society of Animal Production* **71**, 92–95.

Wilsher S, Allen WR, Wood JLN (2006) Factors associated with failure of Thoroughbred horses to train and race. *Equine Veterinary Journal* **38**, 113–118. doi:10.2746/042516406776563305