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The quantification of Relative Stock Units for horses within a pasture-based production system

Chin Y. Yin[1], Back J. Penny[2], Gee K. Erica[1], Horne K. David[2] and Rogers W. Chris[1,2]

[1]School of Veterinary Science, Massey University, Palmerston North
[2]School of Agriculture and Environment, Massey University, Palmerston North
Email: Y.Chin@massey.ac.nz

Abstract
Overseer® is the primary software tool used to estimate farm level nutrient cycle and management for regulatory purposes in New Zealand. The software uses a modification of stock unit system (standard ewe), the revised stock unit (RSU) to estimate the relative feed demand from different livestock classes and species. For horses, the RSU are upscaled in the model based on bodyweight difference of the horse from the standard ewe. This method does not consider allometric scaling of metabolism to bodyweight and the biological differences between mono-gastric hindgut fermenter and ruminants. As a result, this can lead to overestimation of feed and nutrient intake which can have implication on the farm level nutrient leaching estimation on equine properties. Due to the large scale of the thoroughbred breeding farms in New Zealand (300-600 mares and >500ha), even small over estimations could have significant implications for stock management and economic viability. Bodyweight data for commercial equine stock classes were obtained from a structured literature search and weighted mean bodyweights were obtained. These bodyweights were used to estimate the daily and subsequently annual DE intake based on nutrient requirements for the horse published by the national research council. These annual intake values were subsequently used to develop the *equineRSU* and compared against the default values for equine stock classes within Overseer. For all equine livestock classes, the RSU within Overseer was greater than the *equineRSU* (range 2.5 – 6.8 RSU), with the overestimation driven by an assumption of linear increases in RSU with bodyweight. The overestimation of pasture intake with the RSU would translate to a 52-108% overestimation in mean nitrogen intake. If these values were used in Overseer for regulatory decisions this could have a major impact on stock numbers and stock density, particularly during the breeding season. The *equineRSU* presented reflected metabolic scaling and therefore should provide a more accurate estimation of pasture consumption to be included in the overseer model.

Introduction
The Waikato Regional Council's Healthy Rivers Plan Change 1 (PC1) requires large-scale farming operations located within the catchment area of Waikato regional council to calculate a nitrogen loss baseline and comply to the regional councils' nutrient management plan (Waikato Regional Council, n.d.). This regulatory plan would have a major effect on the New Zealand Thoroughbred breeding industry as the breeding farms are concentrated in a relatively small geographical area in the south of Auckland and within the Waikato basin, and the commercial equine management system is pasture based with farms managing over 370 mares during the breeding season on land sizes up to 526ha (Rogers et al., 2007).

Overseer, a nutrient management software is the primary tool used to generate the nutrient loss estimations for this regulatory framework. The software estimates the nutrient leaching based on the estimated feed demand and the nutrient content of the feed consumed (Wheeler, 2018a). The feed demand is estimated based on the energy requirement of the animal, and the feed ME (Wheeler, 2018a). For horses, the energy requirement of the animal is expressed on annual basis using the revised stock unit (RSU) (Wheeler, 2018b). One RSU represents 6000MJME/year (Wheeler, 2018b), which is a modification from the stock unit system and reflects the feed demand of 54kg ewe to rear a single lamb to weaning ("standard ewe") (Parker, 1998). The RSU for other livestock classes and species are then determined based on their annual energy demand relative to this value.

Currently within Overseer®, horses are classified based on type (pony, broodmare with foal, hack, or yearling), size (small (up to 15.2 hands) or large (500-600 kg)) and activity levels (turned out or light work), with an option to enter user defined RSU (Wheeler, 2018b). Options for other common equine classes such as pregnant broodmare, weanlings, breeding stallions, sport horses and racing Thoroughbreds are not yet available, or do not have the appropriate data collated so that valid RSU could be easily found and utilized within the model by end-users. The RSU currently available for horses are determined by considering horses as an upscaled ruminant based on the bodyweight differences in relation to the "standard ewe". This effectively assumes a linear increase in energy requirement and thus the feed demand with increasing liveweight which ignores the metabolic scaling (allometric scaling (West et al., 2002)). This method also does not account for the difference in the energy requirements for various physiological processes, and the difference in nutrient digestion, metabolism and utilization between the mono-gastric hind gut fermenter and ruminants. In horses, significant digestion and absorption of nutrients (protein, carbohydrates and fats) occur in the small intestine and (Santos et al., 2011; Trottier et al., 2016) horses cannot utilize hindgut microbial protein or recycle non-protein N like the ruminants (Santos et al., 2011; Trottier et al., 2016). Previous deterministic modelling has identified significant differences in protein digestibility and nitrogen utilisation between horses and ruminants, particularly sheep (Chin et al., 2019b). Therefore, the current approach used to assign RSU for horses within the software can lead to over estimation of nutrient intake, and consequently, affect the nutrient excretion and leaching estimations. This is because the nutrient excreted is estimated based on nutrient intake and requirement, and nutrient excretion is a key input value for the nutrient leaching sub-model (Wheeler, 2018c). In addition, there is a need for suitable RSU values for wider range of equine livestock classes particularly, those that are common on commercial stud farms.

The objectives of this paper was to model the RSU for different equine stock classes using published literature on horses. Compare the modelled values to the current Overseer® values and quantify the implications on the estimations of nitrogen intake at animal level and indicate the influence on the farm level nitrogen leaching estimations by Overseer®.

Methods

Data on the feeding, management and bodyweight of common equine stock classes in New Zealand were obtained from recent published reviews. Using a snowballing approach, additional horse bodyweight data were obtained by retrieving any additional studies that were cited in the reviews and citing the reviews using Google Scholar. A further structured literature search was conducted within the Web of Science using the keywords "bodyweight", "horses". Studies published within the last 40 years, reporting values for New Zealand population or from comparable pasture based production systems, sample size that were ≥5 and collected from clinically normal horses were selected. There was no restriction for the country of origin for the studies reporting values for the racing breeds (Thoroughbred and

Standardbred, identified using additional keywords "Thoroughbred", "Standardbred"). Overseas studies were included when there was no comparable New Zealand data available.

Using the data retrieved, weighted average bodyweight and the pooled standard deviation were calculated using the following method:

$$\text{Pooled SD} = (SD^2 \times (n-1)) / (n-1).$$

When SE instead of SD is provided, $SD = SE \times \sqrt{n}$

The weighted average bodyweights and equine specific equations from NRC (2007) (Table 1) were used to calculate the energy requirement of broodmare (empty), broodmare (lactating), young horses from 6-12 months of age, racehorses, sport horses, recreational horses and ponies. The *equineRSU* was then obtained using the following method:

equineRSU = Daily ME requirement * 365 (or total days on farm as weanlings)/ 6000 MJ ME

To account for a Thoroughbred broodmare producing a single viable foal and nursing the foal through to weaning, the calculation of annual feed demand included the lactation and non-lactation feed demand of the foal up to weaning (5 months of age on commercial Thoroughbred farms) (Gee et al., 2017; Rogers et al., 2017)(Table 1).

The daily dry matter intake (DMI), and DMI as percentage of bodyweight were estimated using pasture ME values of 10 MJ ME/kg DM and the weighted average bodyweights or the default reference weight within Overseer. The nitrogen intake were estimates using DMI in this study and assumptions for diets, crude protein content and digestibility of feeds previously described in Chin *et al.* (2019a).

Table 1. Equations and values used to calculate energy requirement of different equine stock classes and energy intake of foals from pasture before weaning.

DE = digestible energy, BWT = body weight, DMI =Dry matter intake, GE = Gross energy, ME = Metabolisale energy

Stock class	
Horses/Ponies/Dry mare turned out	DE maintenance = 0.139 MJ DE/kg BWT
Horses (light work)	DE maintenance x BWT x 1.2 Light work = mean heart rate 80 beats/min over entire exercise bout, 1-3 hours per week, recreational riding, beginning of training program, show horses (occasional) (NRC 2007).
Broodmare lactation	DE maintenance (lactation) + ((milk yield × GE(milk))/0.6]
	DE maintenance (lactation) = 0.152 MJ/kg BWT
	Milk yield (kg milk/day) = $a \times d^{0.0953} \times e^{-0:043d}$ a = 0.0274287 x mature weight (kg) d = day of lactation
	Gross energy (milk): 500 kcal/kg milk = 2.09 MJ/kg milk
	Efficiency of DE for milk production: 0.6 (60%)
Broodmare pregnancy	DE maintenance + DE (maintenance accrued feto-placental tissue + DE feto-placental tissue gain)
	DE (maintenance accrued feto-placental tissue) = 66.6kcal/kg tissue= 0.279MJ/kg tissue

	[(FP(lipid) x ADG (kg) x GE(lipid) (Mcal)) + [(FP(protein) tissue x ADG (kg) x GE(protein))]/0.6 FP: 1 unit feto-placental tissue = 20% protein, 3% lipid (0.2 and 0.03) GE content (protein) = 5.6 kcal/g = 0.0234 MJ/g GE content (lipid) = 9.4 kcal/g = 0.0393 MJ/g Efficiency of DE for tissue deposition = 0.6 (60%)
	Fetal weight (kg) = % Birthweight x birthweight (kg)
	% Birthweight = 1 x $10^{7}X^{3.5512}$ ($R2$ = 0.929), X = days of gestation Birthweight = 0.097 x maternal BWT (kg)
	Placental tissue and uterine development: 0.09 g/kg BWT/day
Foal up to weaning	RSU = Energy intake 1-5 months of age (MJ ME)/6000 Energy intake 1-5 months of age (MJ ME) = Σ 1-5 months [DMI (kg DM) * Pasture ME (10 MJ ME/kg DM)*30] DMI (kg DM) = BWT* DMI % BWT
	DMI % BWT: 1 month = 0% 2 months = 0.12% 3 months = 0.40% 4 months = 0.74% 5 months = 1.17%

	BWT of Thoroughbred foals from 1-5 months of age obtained from Huntington et al (2020). DMI % BWT estimated using pasture intake data obtained from Bolzan et al (2020) divided by BWT of foals. Bodyweight of foals (Criollo) in Bolzan et al (2020) was estimated using growth curved expressed in % mature BWT (NRC 2007) assuming mature weight of 454 kg.
Growing horses (6-12 months)	$(56.5X^{-0.145})$ x BWT + $(1.99 + 1.21X - 0.021X^2)$ x ADG X = age in months, ADG = average daily gain in kilograms BWT: growth from 6-12 months modelled using ADG and weanling weight (248±54.33) as starting weight. ADG obtained from (Brown-Douglas et al., 2009; Brown-Douglas, 2003; Grace et al., 2003; Pagan, 1996)
Sporthorse	DE maintenance x BWT x 1.4 Moderate work = mean heart rate 90 beats/min over entire exercise bout, 3-5 hours per week, school horses, training/breaking, show horses, polo, ranch work (NRC 2007).
Racing TB	DE maintenance x BWT x 1.9 Heavy work = mean heart rate 110-150 beats/min over entire exercise bout, racing, Elite 3 day event (NRC 2007).

Results

The structured literature search returned 1,544 potential manuscript and of these, 26 met the selection criteria and presented measure of central tendency (mean) and distribution (standard deviation or standard error) for bodyweight (kg). The details of the studies, horse breed, stock class and the summary statistics of bodyweights reported are presented in Table 2. The weighted mean and standard deviation calculated for different livestock classes, the default reference bodyweights and the RSU values within Overseer® are presented in Table 3. The weighted mean bodyweights of a Thoroughbred broodmare (576±32.65 kg), sport horses (533±62.85kg) and recreational horses (547±67 kg) were within the weight range used to define a large hack (500-600 kg) in Overseer®. Thoroughbred and Standardbred racehorses were equivalent to the category of a small hack (as bodyweight was below the threshold for a large hack). There were no default bodyweight values available within Overseer® for ponies and yearlings, despite these being listed as a default livestock class.

The *equineRSU* across all livestock classes modelled were consistently lower than the default RSU in Overseer® (Figure 1). This difference equated to the RSU providing 52%-84% greater mean estimated DM intake than the *equineRSU* which resulted in the RSU providing 52-108% higher estimated nitrogen intake (Table 4). The RSU was associated with plausible Dry Matter Intakes (DMI) in some situations, however, in several livestock classes such as the small and large hack broodmare and foal, large hack in light work and Thoroughbred yearlings, the RSU provided DMI estimate of 4-5% BWT (Table 5). When the relationship between RSU and bodyweight is examined, the RSU increased linearly with bodyweight and the *equineRSU* approximates a logarithmic relationship with bodyweight (Figure 2).

Table 2 Summary statistics (mean, SD and SE) for bodyweight of different equine stock classes reported in published literature.

Study	Country	Breed	Stock class	BWT (mean)	SD	SE	n
Santschi and Papich (2000)	USA	TB&QH	Lactating, 1-4 weeks after parturition	518	26		7
Grace et al (1999)	NZ	TB	Lactating, soon after parturition	522	42.6		21
Pagan et al (2006)	USA	TB	Lactating, 1-5 months	578	32.38		3909
Grace et al (1999)	NZ	TB	Lactating, 5th month	537	38.49		8
Santschi and Papich (2000)	USA	TB&QH	Late gestation	578	33		7
Bene et al (2013)	Hungary	TB	Non-lactating	542	39.45		110
Williamson (2006)	NZ	TB	Racehorse	430	6.14		14
Ikeda et al (2019)	Japan	TB	Racehorse	469	30		584
Tozaki et al (2017)	Japan	TB	Racehorse, 2 year old	468	26.1		535

Tozaki et al (2017)	Japan	TB	Racehorse, 3 year old	473	28		851
Tozaki et al (2017)	Japan	TB	Racehorse, 4 year old	478	27.6		734
Cho et al (2008)	Korea	TB	Racehorse	448	28.77		8197
Assenza et al (2012)	Italy	TB	Race training, 2 year old	380	15		17
Connysson et al (2010)	Sweden	SB	Race training	511			12
Leuleu and Cotrel (2006)	France	SB	Race training	466	38		24
Zucca et al (2008)	Italy	SB	Race-fit	435	36		30
Assenza et al (2012)	Italy	SB	Race training 3-4 years old	400	50		15
Gauvreau et al (1995)	Canada	SB	Racing	410	14		5
Waller and Lindinger (2006)	Canada	SB	Race-fit, 3 year-olds	481	47		13
Buhl et al (2013)	Sweden	SB	Race training	510	34		30
Gordon et al (2007)	New Jersey, USA	SB	Race-fit	475	34		34
Piccione et al (2005)	Italy	SB	Race-fit	430	20		10
Beaumier et al (1987)	Canada	SB	Race-fit	423	21		12
Verhaar et al (2014)	NZ		Sport horses	533		5	158
Fernandes et al (2015)	NZ		Recreational horses	547	67		
Fernandes et al (2015)	NZ		Ponies			5	313
Dugdale et al (2011)	Great Britain		Ponies (summer)	246 287.8		50 32	10
Dugdale et al (2011)	Great Britain		Ponies (winter)	219 259.6		20 19.57	10
Martinson et al (2014)	USA	Multiple breeds	Pony	328	76		53
Hoffman et al (2013)	Iceland	Icelandic	Pony	378.92	25.59		13
Watson et al (1993)	UK	Shetland	Pony mares	220	27		6

Pagan et al (2009)	USA		Pony hunters	352.3	11.73	23
Brown-Douglas and Pagan (2009)	Global	TB	Weanlings	248.1	1.8	925
Grace et al (2003)	NZ	TB	Weanlings	261	4.8	17
Brown-Douglas and Pagan (2009)	Global	TB	Yearlings	357.5	3.9	925
Grace et al (2003)	NZ	TB	Yearlings	377	18.3	17

Table 3. Weighted mean bodyweight and the pooled SD, 95%CI for different equine stock classes summarized from data obtained reported in published literature.

Stock class	N	Weighted Mean (kg)	Pooled SD (kg)	Default reference range within Overseer	RSU value within Overseer
Broodmare	3264	576	±32.65	500-600 kg (large hack)	14
Racing TB	10548	454	±28.5	NA	NA
Racing SB	189	460	±35.13	NA	NA
Sporthorses*	158	533	±62.85	500-600kg (large hack light work)	12
Recreational horses*	76	547	±67	500-600kg (large hack light work)	12
Ponies	246	334	±94.06	NA	6
Weanlings	942	248	±54.33	NA	NA
Yearlings	942	357.8	±118	NA	NA
Small hack (up to 15.2 hands) in light work				NA	6

Footnote: Data labelled with * is not pooled due to only one source was available.

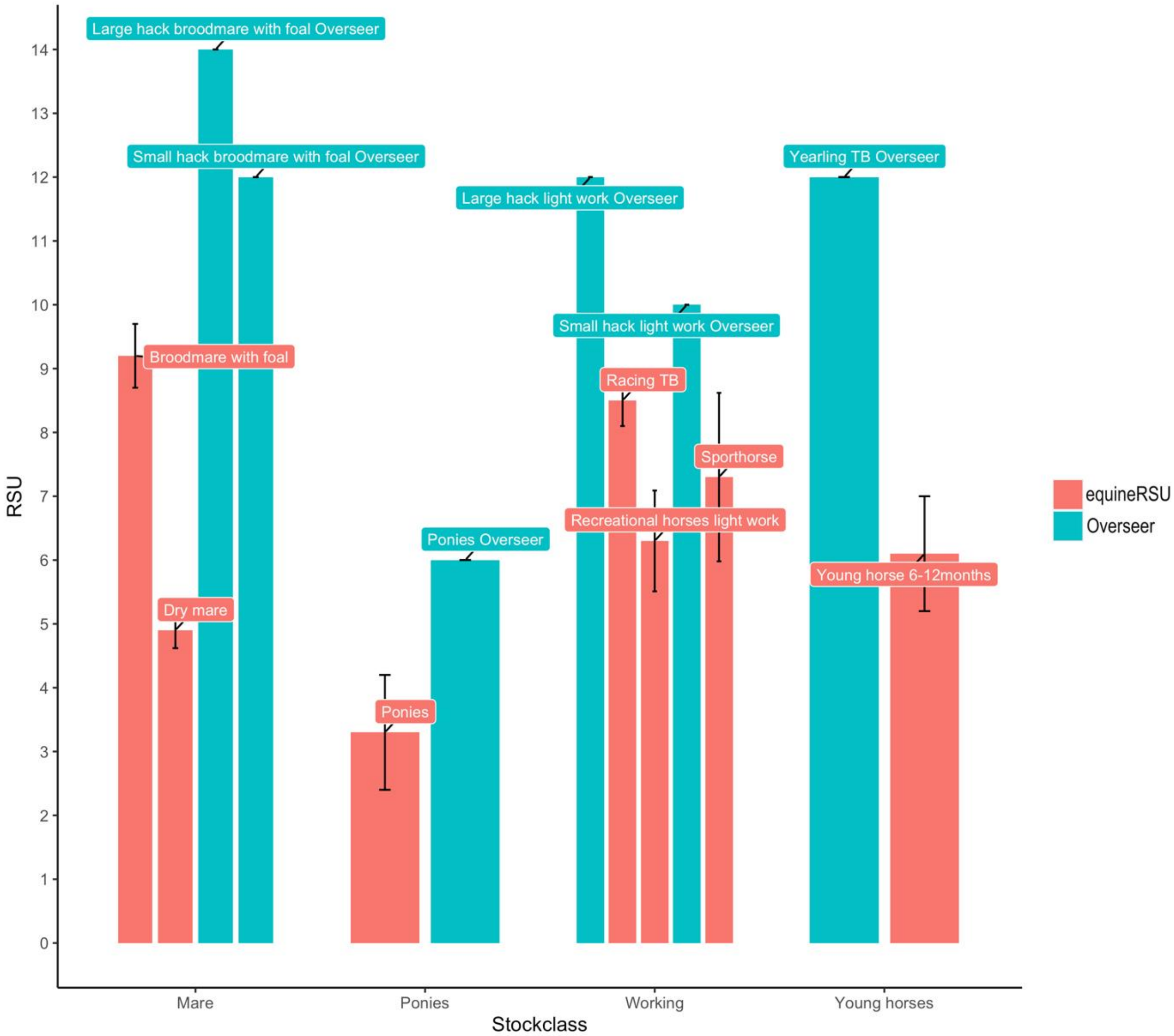

Figure 1. The *equine*RSU derived using equine specific model (NRC 2007) and current RSU used within the Overseer® for horses.

Table 4. The annual energy requirement (MJ ME), estimated DMI (kg/year), estimated nitrogen intake (kg/year) obtained using NRC 2007 recommendation and the published RSU within Overseer.

Stock class	Annual energy requirement Mean±SD	Annual energy requirement (Overseer)	Estimated DMI (kg/year)	Estimated DMI (Overseer)	DMI difference vs Overseer(%)	N intake (kg/year)	N intake (Overseer)	N intake difference (%)
Broodmare and foal	55409±3000	84000	5520	8400	52±5%	147.67±16.69	224.72	52±9%
Sport horse	44019±7928	NA	NA	NA	NA			
Ponies	19565±5535	36000	1956±554	3600	84±28%	52.32±15.40	96.31	76±22%
Broodmare (Empty)	29223±1656	NA	NA	NA	NA			
Recreational horses (light work)	37730±4742	60000	3780	6000	58%±13%	101.12±26.36	161	59±25%
Racing TB	50773.67±3194	NA	NA	NA	NA			
Young horses (6-12 months)	36707±5413	72000	3660	7200	96±15%	87.2±14.4	181.91	108%±17%

Footnote: Overseer annual energy required was calculated based on the published RSU multiplied by the ME for a single stock unit (6000 MJ ME /yr).

Table 5. The dry matter intake (kg/day and as % of bodyweight) obtained based on energy requirement of different equine stock classes calculated using NRC 2007 recommendation and published RSU within Overseer.

Stock class	DMI (kg/day)	DMI (% BWT)
Broodmare and foal		
NRC 2007	15.1±0.8	2.6±0.8
Small hack (Overseer)	19.7	4-5
Large hack (Overseer)	23	4-5
Working horses		
Recreational horses light work (NRC 2007)	10.4±1.3	1.9±1.9
Racing TB (NRC 2007)	13.9±0.9	3.1±0.03
Sport horse (NRC 2007)	12±2.2	2.6±0.05
Small hack light work (Overseer)	16.4	3-4
Large hack light work(Overseer)	19.7	4-5
Ponies		
NRC 2007	5.4±1.5	1.3±0.3
Overseer	9.9	2-4%
Growing horses		
Thoroughbred 6-12 months (NRC 2007)	10±1.5	3.3±0.1
Thoroughbred Yearling (Overseer)	19.7	4-5%
Broodmare (Empty)	8.1±0.5	1.4±0.1

Footnote: Horses classified as small in Overseer assumed to have bodyweight between 400-500kg, those classified as large (500-600kg). Similar bodyweight (353±105kg) used for calculating DMI (%BWT) for Ponies and Ponies (Overseer).

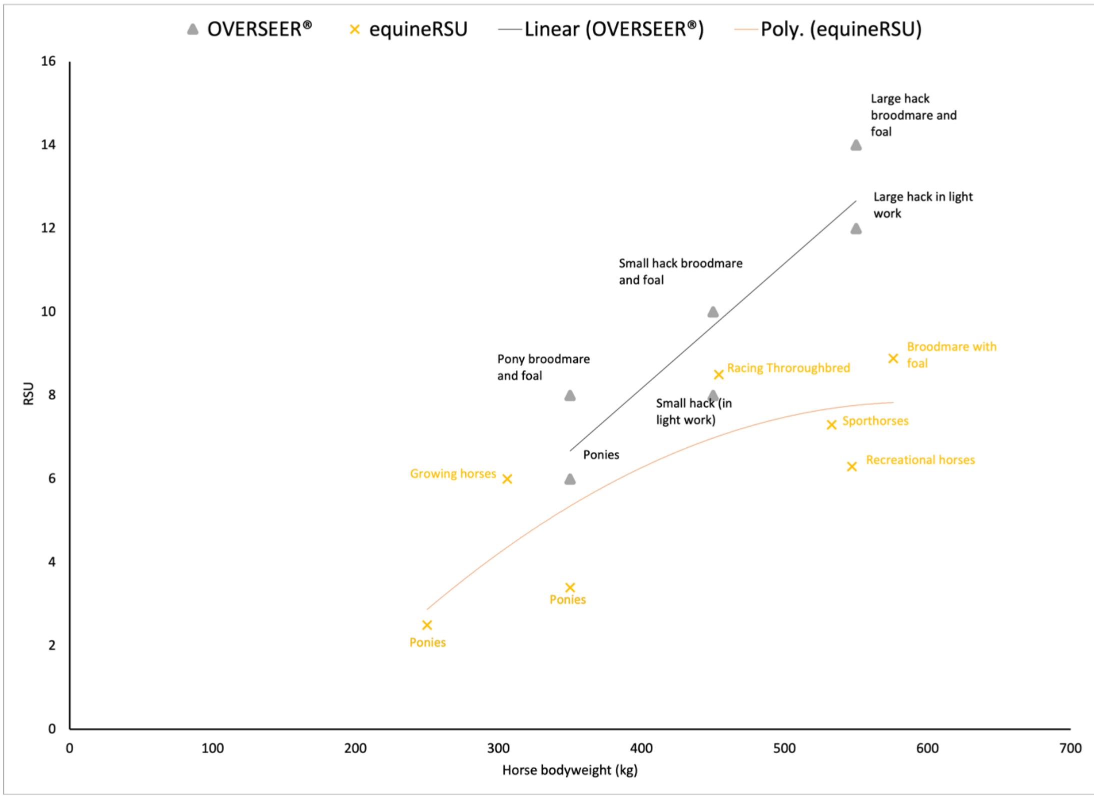

Figure 2. The revised stock unit (RSU) and *equine*RSU derived using equine specific model (NRC 2007) at different equine bodyweight (kg).

Discussion

There is currently no RSU available for the common equine stock classes. Using the currently available RSU can result in overestimation of energy requirement and subsequently the feed demand in comparison to values obtained using equine specific models. The estimated DMI associated with the current RSU values in Overseer® exceeds the accepted physiological range of DMI in horses (2-3% bodyweight) (Chin, 2018). The assumption of linearity in feed demand with increasing bodyweight and failure to moderate the differences in requirements and feed conversion between horses and ruminants appears to be the primary source of this bias. These differences in feed demand observed equated to substantial differences in nitrogen intake estimations. A difference in 1 RSU would result in a difference in estimated crude protein and nitrogen intake of 65-110 kg and 10.4-17.6 kg per animal per year, respectively. For a commercial farm with 200-300 animals, errors at farm level for nitrogen may then be amplified to 600-2100 times and impact the nitrogen excretion and N loss estimations.

Therefore, the greatest economic implications for errors in input data with the nutrient management software is for the commercial racing and breeding sector of the equine industry. The large scale of these operations, in both number of mares and youngstock during the breeding season and the economic contribution to the local and national economy, means that even small errors in in the reference data could have severe consequences for the ability of the industry to operate commercially (Chin et al., 2019a, 2019b). In contrast, the sport horse industry consists of many breeders or owners with smaller land area and number of horses, with many classified as “lifestyle blocks” (George et al., 2013) which fall under the minimum effective area required to comply with a nutrient management plan.

The equine feed requirements proposed by the NRC (2007) were derived from published data, and the estimates for a broodmare during pregnancy and lactation are in close agreement with other commonly used equine feeding systems which are the French (INRA) and German horse feeding standards (Chin, 2018). For racehorses, recent surveys showed close agreement between what was offered to Thoroughbred racehorses in training (140.9±3.13 MJ ME/day) (Wood et al., 2019) and the NRC values for a Thoroughbred in heavy training (139±8.75MJ ME/day). The consistency of these values across studies and feeding systems that used differing methodologies than those used to derive NRC estimates indicate that the NRC model can represent the current consensus on the best estimates for equine feed requirements and provide a relative degree of precision when used as the basis for deriving *equineRSU*. The low variation in bodyweight in Thoroughbred and Standardbred horses between populations within the literature can be due to several factors such as large inter exchange of genetic material, operation of closed studbooks, and limited variation in management practice resulting in similar environment for growth and racing across the major racing nations (Huntington et al., 2020). The bodyweights reported for sport horses were surprisingly homogeneous given the differences in genotype and phenotype between sports such as eventing and dressage. This enables tight estimation of RSU values of these stock classes. The logarithmic relationship between the *equineRSU* and bodyweight demonstrated that the effects of allometric scaling on metabolism can be addressed, reducing the overestimation of feed demand, particularly at heavier bodyweights. Therefore, the *equine*RSU as proposed in Table 6 should be used in the modeling of on-farm nutrient cycling as these reflect the biology of the horse and account for metabolic scaling with increasing bodyweight.

Conclusion

Findings show that the current RSU overestimates the feed demand in horses and the primary driver for this appears to be the assumption of linearity in feed demand with increasing bodyweight and ignoring the metabolic difference between horses and ruminant. The overestimation of feed demand can result in 52-108% greater nitrogen intake which would translate to over-inflation of nitrogen excretion and the subsequent nitrogen leaching estimations. This may erroneously result in equine stock numbers and density on commercial Thoroughbred breeding operations to be restricted, particularly during the breeding season which can have great economic implications to the industry. Therefore, the use of *equineRSU* presented here is recommended when modelling nutrient leaching on pasture-based equine properties as it represents the consensus on the best estimates for equine feed requirements which were derived from equine measurements, accounts for the allometric scaling of metabolism and thus reflect the equine biology.

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