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Journal: Animal Production Science

ISSN: 1836-0939 **Year:** 2014 **Pages:** 1305 - 1310

Volume: 54 **Issue:** 9

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URLs:

FT: http://dx.doi.org/10.1071/AN14072

PL: http://primo.unilinc.edu.au/primo_library/libweb/action/dlDisplay.do?vid=CSU2&docId=dtl_csu64542

Mass to height relationships in annual pastures and prediction of sheep growth rates

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Short title: pasture structure and sheep growth

Abstract. The relationship between pasture height and mass influences the availability of pasture for grazing, and is important for predicting intake of pasture and live weight change by sheep. The relationship between pasture mass and structure and sheep production is poorly defined for low-mass, clumpy pastures in low-rainfall regions. Between 2001 to 2004, 480 quadrats of pastures were measured in 23 paddocks throughout the Victorian Mallee. Pasture height was related to live mass for medic (linear; $r^2 = 0.70$; $P<0.001$) and medic/grass (asymptotic; $r^2 = 0.64$; $P<0.001$) pastures, and prediction of medic/grass height was improved by inclusion of proportion live groundcover. During 2004, pasture dry matter accumulation and live weight changes in sheep grazing annual pastures were measured and compared with predicted outputs from GrazFeed®, a software model used to estimate feed intake and live weight change in sheep. Improved predictions of live weight gain in grazing sheep were obtained using measured height rather than the GrazFeed default height. The results show that the height to mass relationship of annual pastures in the Victorian Mallee differs between pasture types, between years, and may differ from other published relationships. This study provides information that may assist in the development of models of grazing systems.

Additional keywords: simulation

Introduction

The prediction of sheep production from pasture characteristics is integral to simulation modelling of sheep grazing systems. Freer *et al*. (1997) have described the GrassGro® decision support tool which is designed to simulate through time the production of pasture and sheep or cattle for a wide range of sites, pastures and animal types throughout the medium and high rainfall temperate regions of Australia. Its reliability depends, in part, on its prediction of pasture intake. Intake depends, in part, on the mass and structure of the sward (Allden and Whittaker 1970; Black and Kenney 1984), the nutritive value and palatability of the different components (O'Reagain 1993), as well as on limits set by the animal and grazing behaviour (Hamilton *et al.* 1973).

One aspect of pasture structure is the height of the sward. There is relatively little data that defines the relationships between pasture mass and height in different grazing systems and climatic zones, where the height-mass relationship could vary. Pastures in higher rainfall regions may have higher mass and groundcover in comparison with low-rainfall regions (<400 mm annually), where pastures may have a low mass but a relatively tall, low-density and clumpy structure. Height increases the availability of the pasture to the grazing animal and hence its intake (Allden and Whittaker 1970), but if pasture density is also low, grazing efficiency may be reduced. Therefore, it is expected that GrassGro, which is designed for uniform pastures, will sometimes fail to adequately predict animal production in less uniform grazing systems (Clark *et al.* 2000). In GrazFeed® (Freer *et al.* 1997), the problem of differing height to mass relationships is overcome because the user may specify pasture height and mass as inputs into the model. However, better definition of pasture height to mass relationships for low density or low mass pasture has the potential to improve prediction of intake in dynamic models of grazing systems in low-rainfall regions.

This study was conducted to define the relationships between herbage mass, height and groundcover and sheep live weight change for annual pastures in the Mallee region of Victoria, Australia. Such information is needed to provide information that may enable more dynamic grazing systems models to be more useful in a wider range of environments.

Methods

Pasture height, mass and groundcover relationships

Relationships between live pasture mass, height and groundcover were calculated using data from previous studies in the region (2001-2002) (Robertson 2006a; b) and data collected during 2003 and 2004, from a total of 23 on-farm paddocks in the Victorian Mallee. Pastures in commercial paddocks (0.8 to 196 ha) and distributed in the northern, southern, eastern, western and central regions of the Mallee were sampled in 2001 and 2002. The locations sampled covered average annual rainfall belts from 250 to 365 mm. In 2003 only the central and southern regions were sampled, and only the central region in 2004, from the grazing experiment as described below. On each sampling occasion, at least ten quadrats were selected which covered the range of live and dead mass present at each location. The most common species were annual medics (*Medicago spp*.) and annual grasses such as barley grass (*Hordeum leporinum*). Except in the southern Mallee, the locations sampled exhibited a dune/swale landscape dominated by sandy soils. Annual pastures in the region are typically part of a ley-farming system, with median spring biomass in ungrazed pastures of approximately 2000 kg DM/ha (Robertson 2006b).

During months where live pasture was present from 2001 to 2004, in each 0.25m^2 quadrat groundcover was visually estimated and the height of live plants to the top of the sward was measured with a ruler, before quadrats were harvested to ground level using blade shears. The live herbage in the quadrat was visually categorised as being medic only, medic/grass, grass only or other species. Harvested material was dried at 60^{0}C to constant weight, then weighed to calculate dry matter per hectare. In total, 268 records for annual medic (*Medicago spp*.) pastures and 212 for medic/annual grass pastures were available. Quadrats of grass only or other species were few and were not included in further analyses.

Grazing experiment 2004

Three pastures were measured monthly between June and September (paddock 9: 29 ha, a low density grassy medic) or October (paddocks 1: 40 ha, a dense annual medic and paddock 3: 47 ha, a grassy medic) at the Department of Environment and Primary Industries (DEPI), Walpeup, Victoria, research station (35^{o}07’S 142^{o}00’E) during 2004. The main grasses were barley grass (*Hordeum leporinum*) and ryegrass (*Lolium rigidum*), with some wheat (*Triticum aestivum*) present in Paddock 3.

The pastures germinated in June. Plant density was recorded on 3 July in 30 quadrats (0.05 m^2) per paddock. Estimates of live herbage mass were made using 100 visual scores per paddock calibrated against ten 0.25 m^2 quadrat cuts (Haydock and Shaw 1975). In addition, four clusters of four permanent cages were placed across each paddock, and within one cage in each cluster a quadrat (0.25 m^2) was cut each month to measure ungrazed live herbage mass. As for 2001 to 2003 procedures, live groundcover was estimated and height to the top of sward was measured with a ruler.. The mass of dead herbage was cut in ten quadrats (0.25 m^2) per paddock, randomly placed across a grid transect.

For each of the three paddocks, ground cover, botanical composition of live cover and pasture height were measured using a point-quadrat technique (Grant 1981). The pasture component and height above ground at the position at which the pointer first hit a plant, after pushing the pointer vertically downwards through the sward, was recorded at 20 points, distributed in a 10 x 10 cm mesh arrangement in 5 columns and 4 rows, at 30 sites across each paddock. Height was measured to the nearest 0.5 cm using a ruler at the location where the pointer touched the plant. In addition, across each paddock plant height to the top of the sward at the rodpoint was recorded for 100 measurements using the rod-point method (Little and Frensham 1993), on 16 and 30 July, 20 August, 10 September and 12 September.

The pastures were grazed by mixed mobs of 5 year old July-lambing Merino ewes (estimated standard reference weight 60 kg) and crossbred weaners (September born). Paddock 1 (40 ha) was grazed by 117 ewes and 13 crossbred weaners from 16 June. Due to drought conditions, numbers were reduced on 17 August, leaving 28 ewes and their 30 crossbred lambs (July born). Paddock 3 (47 ha) was grazed by 153 ewes from 7 July, with numbers reduced to 31 ewes and their 25 crossbred lambs (July born) on 18 August. Paddock 9 (29 ha) was grazed by 83 ewes and 17 crossbred weaners from 7 July until 17 August. Sheep in paddock 1 were fed 0.9kg/day.sheep mixed grain between 16 June and 17 August. Sheep in paddock 9 were fed 0.9 kg/day.sheep mixed grain from 16 June to 30 August, with 0.4 kg/day.sheep cereal hay also being fed until 28 July. Sheep in paddock 3 were not supplementary fed after 7 July. The ewes, and lambs and weaners when present, were weighed (fasted overnight for September to October weighings only) monthly to monitor weight change.

Monthly samples of the major pasture species in each paddock were randomly collected from a transect across paddocks, cut to ground level, bulked, and dried at 60^{o}C. The dry matter, crude protein and metabolisable energy content of the pasture samples, and of supplements fed, were estimated by FEEDTEST (Department of Primary Industries, Hamilton, Victoria) using near infrared spectroscopy.

GrazFeed estimates of sheep intake

In addition to the 2004 measurements, data from pastures, ewes and lambs at Walpeup in 2002 (Robertson 2006a) were also included in the estimates of weight change. The liveweight change of sheep between successive pasture sampling days was predicted using GrazFeed® version 4.1.10 (Freer *et al.* 1997) using the observed mean rodpoint (to the top of the sward at the rodpoint) live pasture heights. The observed mean height of dead herbage was adjusted to point-quadrat means. Estimates of pasture mass and the amount and nutritive value of supplement fed were used as inputs to the model.

Statistical analyses

Relationships between live pasture herbage mass, height and cover were investigated with linear regression using Genstat® 12th edition (Payne *et al.* 2006), for medic and medic/grass pastures separately, since the height to mass relationship differed ($P<0.05$). Analyses were conducted using data from all years, including quadrats cut from the grazing experiment in 2004, since for inclusion in simulation models, general relationships are required for application across numerous years. However, year was also used as a factor to determine whether the relationship varied between years. The difference between the use of measured height and the default height in GrazFeed was compared by regressing observed sheep live weight change against predicted live weight change. The two linear regressions were compared by assessing the differences in the slope, intercept and root mean square error.

Results

Relationship live pasture height and mass (2001 to 2004 data, including quadrats from grazing experiment)

For medic pastures, height (cm) was linearly related to live mass (kg DM/ha) by the equation y = 1.278+0.004 x mass ($P<0.001$); $r^2 = 0.70$; root mean square error = 2.7 cm). At a pasture mass of 1000 kg DM/ha, live pasture height would be 5.3 cm. However, the relationship varied ($P<0.05$) between years (Figure 1a), with the equations for each year, where height (cm) is predicted from live mass (kg DM/ha) shown below, with the standard error of estimates in brackets. It should be noted that a maximum of 660kg DM/ha was recorded in field data in 2002.

2001: height = 2.104 (0.330) + 0.001650 (0.0005) x mass; 3.8 cm at 1000 kg DM/ha
2002: height = 1.251 (0.411) + 0.00019 (0.002) x mass; 1.4 cm at 1000 kg DM/ha
2003: height = -1.753 (0.548) + 0.004419 (0.0002) x mass; 2.7 cm at 1000 kg DM/ha
2004: height = 1.324 (0.448) + 0.006916 (0.0008) x mass; 8.2 cm at 1000 kg DM/ha

At any measured biomass, the height of medic/grass pastures was greater and more variable than for medic pastures. For medic/grass pastures height (cm) was related to mass (kg DM/ha) by the exponential equation $y = 38.43 - 35.72^{0.9996589 \times mass}$ ($P<0.001$); $r^2 = 0.64$; root mean square error 13.6 cm) (Figure 1b). At a pasture mass of 1000 kg DM/ha, height would be 13.0 cm, but the relationship varied between years, as shown below, with the standard error of estimates in brackets. In 2002, a maximum of 400 kg DM/ha was measured in the field.

2001: height = 420 (2037) – 419 (2037) $^{0.999977\ (0.0001) \times mass}$; 10.5 cm at 1000 kg DM/ha

2002: height = 18.7 (13.5) – 18.8 (12.6) $^{0.99600\ (0.0048) \times mass}$; 18.4 cm at 1000 kg DM/ha

2003: height = 34.62 (6.10) -35.20 (4.28) $^{0.999571\ (0.0002) \times mass}$; 11.7 cm at 1000 kg DM/ha
2004: height = -16.3 (31.1) + 19.2 (30.0) $^{1.000554\ (0.0006) \times mass}$; 17.1 cm at 1000 kg DM/ha

Insert Fig 1 here

Relationship live groundcover and pasture mass (2001 to 2004 data, including quadrats from grazing experiment)

For medic pastures, a proportion live groundcover of 0.9 was not attained until live pasture mass reached 3300 kg DM/ha (Figure 2a) ($y = 1.2021 - 1.1552^{0.9995898 \times mass}$; $r^2 = 0.91$; $P<0.001$; root mean square error 0.09), but there was considerable variation in groundcover at any level of live herbage mass. Medic/grass pastures attained 0.9 proportion live groundcover from 4900 kg DM/ha ($y = 1.092 - 1.034^{0.9996610 \times mass}$; $r^2 = 0.77$; $P<0.001$; root mean square error 0.1), but again, there was considerable variation (Figure 2b). The relationship differed ($P<0.05$) between years (data not shown) for both medic and medic/grass pastures, but the maximum field estimate of proportion cover for both pasture types in 2002 was 0.5, while in 2004 the maximum cover for medic estimates was also 0.5.

Insert Fig 2 here

Relationship live pasture height, groundcover and mass (2001 to 2004 data, including quadrats from grazing experiment)

The prediction of pasture height (cm) was improved by inclusion of proportion of groundcover in addition to mass (kg DM/ha) in medic/grass, but not medic pastures:

for medic pastures y = 2.052+0.0037 x mass x cover; r^2 = 0.73, P<0.001 (root mean square error 2.6 cm), and for medic/grass pastures y = 2.455 + 0.014086 x mass – 0.00903 x mass x cover, r^2 = 0.71, P<0.001(root mean square error 5.8 cm).

The relationship varied (P<0.05) between years (data not shown) for both pasture types.

Pastures in the grazing experiment 2004

In the 2004 grazing experiment, the pastures varied in density; legume 603 ± 57.5, 785 ± 76.0 and 206 ± 44.7 plants/m^2 in Paddocks 1, 3 and 9, respectively, while only Paddock 3 contained a large density of annual grasses (27 ± 6.1 plants/m^2). The quantity of pastures in each paddock measured during 2004 is shown in Table 1. Less than 500 kg DM/ha live herbage was present in grazed areas on most sampling occasions. The mean height of the grass was usually at least twice that of the legume component of pastures, and the point-quadrat method tended to result in lower mean pasture heights than the rod-point technique. The maximum height recorded within a paddock was usually at least twice that of the mean height for the paddock. The height of caged, ungrazed pasture was at least double that of grazed areas (3, 6, and 13 cm on 19 Aug., 13 Sep., and 9 Oct. for paddock 1, respectively; 16, 9 and 22 monthly for paddock 3, and 6 and 3 cm in Aug. and Sep. for Paddock 9). Using point-quadrat records, live cover increased after July, and between August and October ranged between 20 and 38% in paddocks 1 and 3, but never exceeded 21% in paddock 9. Annual legumes comprised the bulk of live cover (> 81%) in Paddock 1, but were usually between 32 and 47% in Paddocks 3 and 9, with annual grasses being the other dominant class.

Insert Table 1 here

Predicting sheep growth rates

GrazFeed underestimated the liveweight change by sheep if the default rather than observed pasture height was used with observed mass, with the regressions having different (P<0.05) intercepts but not slope (Fig 3). Using the observed height improved the prediction of liveweight change with a root mean square error (RMSE) of 110 compared with 152 g/day.

A live weight change (fasted) of over 300 g/day was recorded between September and October for both ewes and lambs (actual lamb weight in paddock 1:14.6 ± 3.13 and 23.8 ± 3.62 kg and paddock 3: 18.3 ± 4.15 and 27.8 ± 5.20 kg on 14 September and 12 October, respectively). Using GrazFeed and the default pasture height, lamb growth rates were underestimated by 199 to 205 g/day, while using the observed height, growth rates were underestimated by 11 to 134 g/day. Likewise, ewe growth rates using the default pasture heights were underestimated by 308 to 328 g/day, while with the observed height, the underestimate was 243 to 293 g/day.

To evaluate whether selective grazing may have contributed to the underprediction of weight gain, pasture inputs in GrazFeed were increased to approximately the highest live mass observed (1000 kg DM/ha), the maximum height, 80% dry matter digestibility and 30% crude protein produced. This produced an accurate prediction of lamb weight change (mean 336 g/day observed, 334 predicted) and improved the prediction for ewes (mean 323 g/day observed, 226 g/day predicted). Using maximum height and mass for the medic paddock seems reasonable as 16% of visual mass estimates in October were ≥1000 kg DM/ha. However, for the grassy medic paddock, only 1% of estimates were ≥ 1000 kg DM/ha, with a further 6% at 760 kg DM/ha.

Insert Fig. 3 here

Discussion

This study has shown that a higher height at a given herbage mass is predicted for this overall data set than the default in the GrazFeed model (3 cm at 1000 kg DM/ha) (Freer *et al.* 1997) or for clover or annual grass pastures in Western Australia (Hyder *et al.* 2004). However, the relationship between height and mass differed widely between years, such that the use of one prediction equation across different years will inevitably lead to both over and under-estimation of pasture height. The results also indicate that pasture height differs widely between and within pasture types and this variability needs to be accounted for in order to improve the prediction of sheep intake and subsequent live weight change.

For both medic and medic/grass pastures, considerable variation in height remained unaccounted for after considering mass and groundcover. While pasture height may be related to stage of maturity (Hyder *et al.* 2004), in the current study the data suggest that both grazing and seasonal effects are likely to have a larger influence on height than stage of maturity.

There are several potential reasons, apart from pasture height, why GrazFeed may have under or over-predicted sheep weight gain. Error in measurement of pasture mass, height, nutritive value and sheep weights will have contributed, as well as selective grazing (Hamilton *et al.* 1973). For mixed pastures it is not clear whether sheep intake is best related to height to the top of sward, or mean height. Differences in height between species could be expected to be more important where selective grazing occurs. Which component is selectively grazed may also depend on the nutritive value and palatability of the different components (O'Reagain 1993).

The distribution of herbage mass in a paddock is also likely to influence selective grazing. The growth rates of sheep during September were more accurately predicted assuming selective grazing of areas with higher mass and height. Underestimation of growth rates in this study may also result from sheep selecting pasture of a higher digestibility than the 80% possible in GrazFeed. A September dry matter digestibility of 85% was recorded for grass in this study, and for medic leaf in a previous study (Robertson and Smith 2006). It seems likely that use of mean paddock data may not produce reliable predictions of intake is situations where there is high potential for selective grazing.

An estimate of the quantity of live pasture not available for grazing is used for prediction of sheep intake. Residual mass remaining after harvest by blade shears varies between 10 kg DM/ha up to 200 kg live mass, depending on available mass, for annual pastures in this environment (Robertson 2006a). The observations of liveweight change and mass in this study, although few, support the use of a residual live herbage mass near 0 kg DM/ha for similar pastures in this region. Although Grassgro® (Moore *et al.* 1997) factors in different height to mass relationships for different species when calculating residual mass (residual = 400/height ratio, where height ratio is a species specific parameter), for medic and annual grasses the residual live mass is currently 400 kg DM/ha (A. Moore, personal communication). The difference between GrassGro and the observations in this study suggest that estimates of residual mass may also need to alter with different types of pasture (upright or prostrate, sparse or dense) to enable more reliable estimates of intake.

To improve prediction of sheep intake and so growth rates in simulation models, this study indicates a need to adjust pasture height for different types of annual pasture. The factors which cause the relationship of height to mass to vary in different years need to be clarified to improve the reliability of estimates. Models may also need to consider the distribution of mass in paddocks, although incorporating such aspects which affect selective grazing into models is challenging.

Acknowledgments

Richard Simpson, Libby Salmon and Mike Freer, CSIRO Canberra, provided valuable technical advice and helpful comments on the manuscript. The assistance of Kevin Grayling and Bill Beasley in managing the sheep is appreciated.

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Table 1. Mean live herbage mass (kg DM/ha ± sem) of grazed and caged[A] areas in three paddocks in the 2004 grazing experiment.

	Pdk 1 Medic		Pdk 3 Grassy medic		Pdk 9 Low density medic	
	Grazed	Caged	Grazed	Caged	Grazed	Caged
	(kg DM/ha)		(kg DM/ha)		(kg DM/ha)	
9 Jul.	68 ± 2.3	72 ± 22.5	94 ± 4.9	93 ± 40.8	23 ± 2.2	17 ± 9.9
20 Aug.	92 ± 5.2	233 ± 49.2	187 ± 8.9	575 ± 57.4	60 ± 4.5	373 ± 165.4
12 Sep.	226 ± 11.6	926 ± 246.4	343 ± 16.8	914 ± 89.2	30 ± 4.5	182 ± 61.9

9 Oct.	534 ± 28.2	1624 ± 283.6	362 ± 18.4	1312 ± 72.7	-	-

[A] Cages cut on 9 Jul., 18 Aug., 13 Sep., and 9 Oct.

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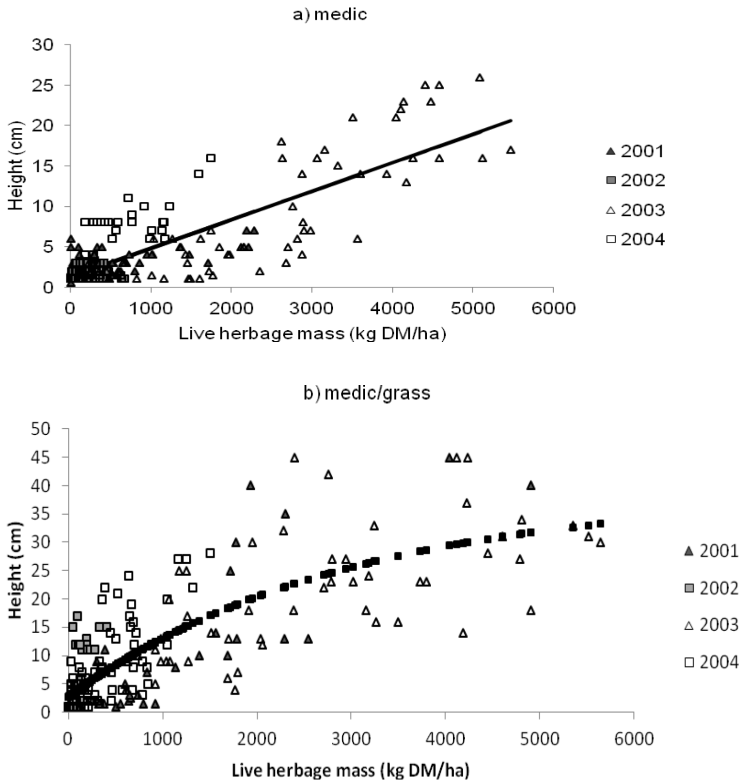

Figure 1. Relationship between live pasture mass (kg DM/ha) and height (cm) (2001-2004 quadrat data) for a) medic pastures and b) medic/grass pastures

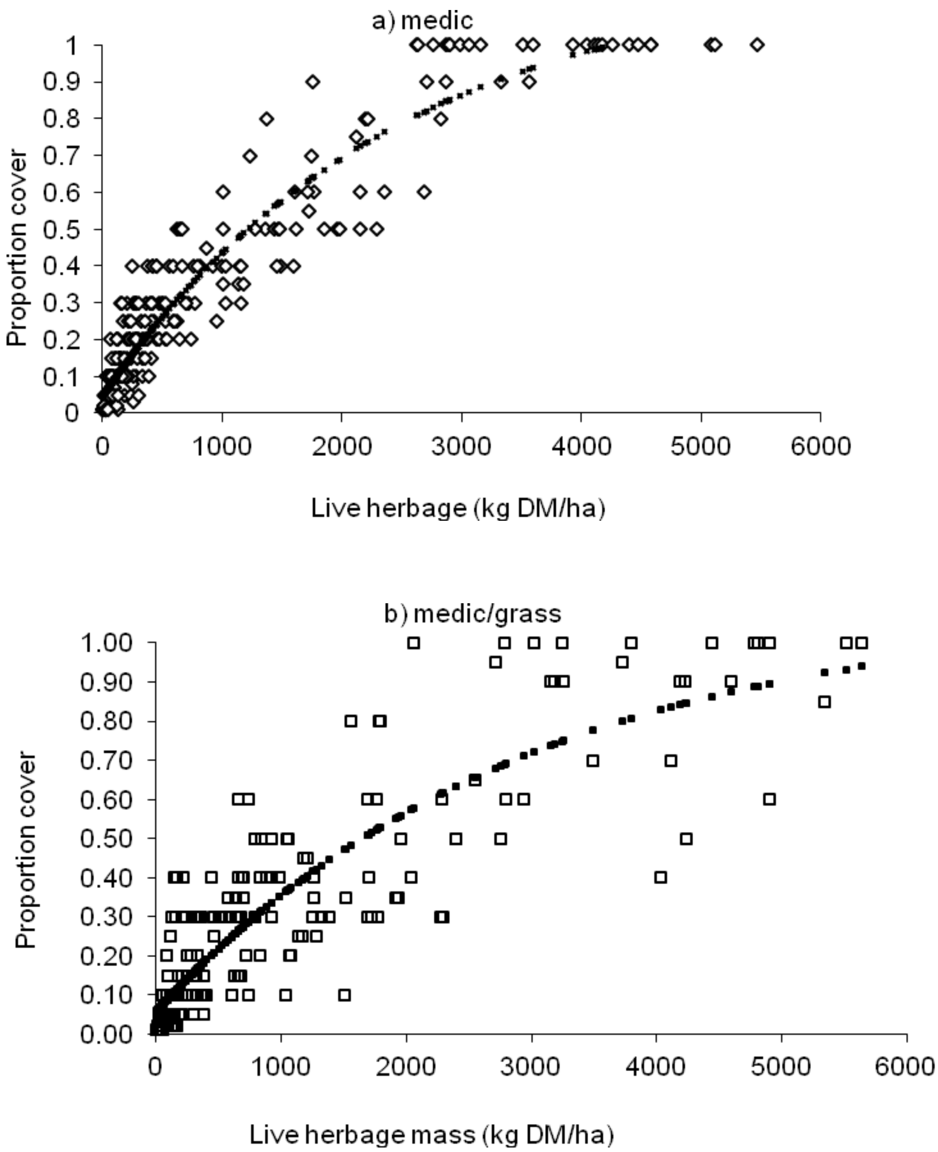

Figure 2. Relationship between live pasture mass (kg DM/ha) and proportion live groundcover (2001-2004 quadrat data) in a) medic pastures and b) medic/grass pastures

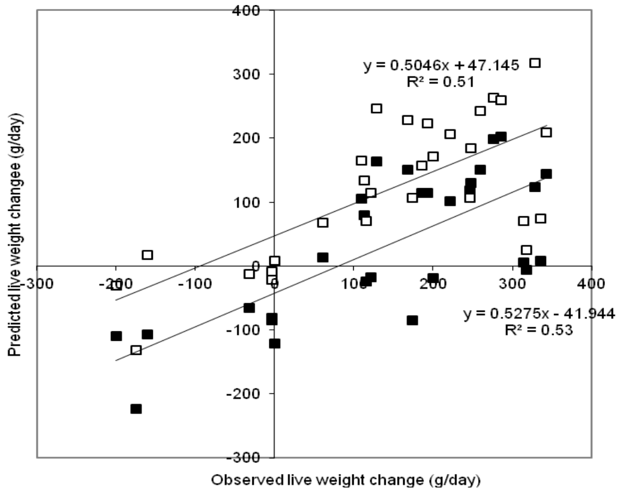

Figure 3. Observed live weight change (g/day) compared with GrazFeed predicted change at default (■) or observed (□) pasture height.