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Predicting pasture and sheep production in the Victorian Mallee with the decision support tool, GrassGro

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Short title: Predicting sheep and pasture production

Abstract. The GrassGro decision support tool was designed to quantify sheep and pasture production in response to management and climate variability in temperate Australia, and has been tested in temperate but not low-rainfall Australian conditions. Data from field experiments and from on-farm monitoring was used to test GrassGro predictions of annual and perennial pasture production, and sheep production at four locations throughout the low-rainfall (275 to 375 mm annually) Victorian Mallee. Predictions of long-term pasture production were then made.

Predictions of the herbage biomass of annual pastures closely matched observed data for both a sandy loam (1991-2002 data) and a whole paddock (combining sandy loam/loam and sand) (2001-2002 data) soil type, at several locations across the Victorian Mallee. Linear regression between observed and simulated data produced coefficients, significance and root mean square error of $r^2 = 0.81$, $P<0.001$, 217 kg DM/ha, and $r^2 = 0.94$, $P<0.001$, 72 kg DM/ha for sandy loam and whole paddock soil types, respectively. A series of simulations for individual years between 1970-2002 quantified the large impact of climate variability and demonstrated that seedbank and location, but not soil fertility, have a large influence on annual pasture production. However, GrassGro underestimated the production of the perennial pasture, lucerne ($r^2 = 0.2$). GrassGro was also unable to adequately predict sheep production because it failed to take into account the sparse, clumpy structure of the low biomass pastures typical of this region. Methods to improve GrassGro were identified and include: a) the need to adjust sheep intake from low biomass, sparse pastures, b) the ability to predict summer growing and autumn growing plant species, c) the ability to graze crop stubbles, and d) refinements to the coefficients of equations used to model lucerne growth.

Additional keywords: farming system, modelling, pasture growth, climate variability, medic

Introduction

The prediction of pasture and livestock production under different climatic conditions is a valuable tool for optimising management and determining research priorities. By extending short-term results to longer-term production data, reliable predictions can add value to previous research and provide estimates of production under a wider range of variables than can be practically or economically determined through many short-term experiments. The GrassGro decision support tool is designed for use in temperate areas of southern Australia with sown pastures, with the Victorian Mallee being on the boundary of the environmental range it was designed for (Donnelly *et al.* 1997). The GrassGro decision support tool has been shown to satisfactorily simulate pasture and sheep production under temperate conditions (Clark *et al.* 2000; Paul *et al.* 2001; Donnelly *et al.* 2002).

However, despite the importance of sheep production in low rainfall regions, there are no published tests of GrassGro in these regions.

The Mallee region of northwest Victoria is characterised by cereal/sheep production. One or 2 years of cereal cropping are commonly followed by 1 or 2 years of annual pastures, volunteer or sown. Sheep typically utilise crop stubbles over summer/autumn, and pastures during the remainder of the year. The Victorian Mallee has a mean annual rainfall ranging between 275 mm in the north and 375 mm in the south. The high variability of annual rainfall and associated high level of production risk in this environment increase the value of a tool such as GrassGro. The high variability of soil type within paddocks in the dominant dune/swale landscape increases the difficulty in extrapolating trial results to on-farm production. Whole-paddock estimates of both pasture and livestock production would be beneficial. However, GrassGro is designed to simulate soil type separately and the ability to model production from whole paddocks with such variable soils requires testing. The aim of this study was to evaluate the ability of GrassGro to simulate a range of pasture types and sheep production from these pastures in the Victorian Mallee.

Material and methods

Parameters used in simulations

GrassGro version 2.4.1 (Donnelly *et al.* 1997; Freer *et al.* 1997; Moore *et al.* 1997) was used with weather locality files obtained from CSIRO, calculated using climatic data sourced from the Australian Bureau of Meteorology for at least 40 years up to December 2002.

At most sites, no information was available on the physical characteristics of the soil needed to initialise GrassGro. These values were either adapted for a sandy loam soil at Walpeup from existing measurements (Bissett and O'Leary 1996) or from standard default values provided with GrassGro. Soil parameters were estimated for a generic whole-paddock soil type suitable to the dune/swale system of the Mallee which is comprised of sandy loam, loamy sand and sand soil types. The parameters used for the sandy loam and whole-paddock simulations are given in Table 1. A subsoil depth of 2000 mm was used although depth beyond cereal rooting depth (1000 mm) (Incerti and O'Leary 1990) is unlikely to influence production of annual pastures. The fertility scalar was altered according to measured phosphorus when available, or estimated fertility if unavailable, to achieve the best fit to data.

The soil parameters were tested by conducting sensitivity analyses of total live herbage biomass to topsoil depth, stage 1 evaporation and saturated hydraulic conductivity. Because a limited number of years of data were available to check the adequacy of the soil parameters, the herbage biomass of annual medic pasture (*Medicago truncatula* variety Paraggio) was compared in a series of simulations of individual years between 1970 and 2002, using the same starting conditions in each year (tactical runs), on both soil types so that production between the soil types could be compared. GrassGro default rooting depths for all pasture species were used.

Insert Table 1 here

Simulations

Simulations were conducted using data from experiments at Walpeup (35°07'S 142°0'E), Meringur (34°29'S 141°20'E), Murrayville (35°16'S 141°11'E) and Manangatang (35°3'S 142°53'E). The data sources are summarised in Table 2, and are described in more detail below. All historical simulations (which run over all the days in succession between the start and end dates of a simulation) were initiated by running the model for at least 1 growing season prior to the start of the simulation to ensure appropriate start conditions. For historical simulations, when required, a series of simulations were conducted, imported into and combined in a spreadsheet to allow reflection of pasture operations, intermittent grazing, and changing stocking rates and class of sheep. Meringur climate data was used to simulate the Werrimull pastures. For sown pastures, such as the annual medic (*Medicago spp*.) variety trials, sown seed was assumed to be 90% soft ripe seed, and 10% hard seed. Lucerne (*Medicago sativa*) seed cannot be sown in GrassGro, so the herbage biomass of lucerne at a date after sowing was entered to overcome this issue in simulations containing lucerne. Chemical control of pasture was simulated by reducing live herbage biomass by appropriate amounts and adding this to the dead pasture pool.

A series of ungrazed tactical simulations in each of the years 1970-2002 was initialised to January 2001. January 2001 was considered to represent average conditions, since average rainfall had been received for several months prior to this date. Tactical simulations, using the same initial soil moisture and annual medic seedbanks in January of each year, were used to estimate differences in pasture biomass production from the sandy loam and whole paddock soil types under a wide range of climatic conditions. Several situations were also tested at Walpeup using the whole paddock soil type to determine the impact on biomass percentiles: size of initial medic seedbank; a high medic seedbank (300 kg/ha) was compared with the seedbanks used in several of the 2001-2002 paddock tests; the impact of soil fertility over the range observed (fertility scalar 0.75, 0.82 and 0.89); and pasture growth rates at Walpeup were predicted using seedbanks of 25 kg medic and 80 kg early annual grass. Production at different locations was also compared.

Observed herbage biomass from all data sources was assumed to equal total herbage biomass, rather than available herbage, because residual biomass was only reported for 1 data set in this environment (Robertson 2004) which showed that the quantities of residual biomass were not significant.

Insert Table 2 here

<u>Whole paddock soil type</u>

All pastures for the whole-paddock soil type were annual pastures in the first to third year after a cereal crop, observed in 2001 and 2002. The sheep and pasture management at each location are detailed in Robertson (2004). The period for which each paddock was grazed is shown in Fig. 1*a* and *b*. The stocking rates below refer to the period when sheep were in each paddock, not the annual stocking rate, as grazing of all paddocks was intermittent. Briefly, management for each paddock was:

Walpeup – one paddock (MRS 8) was grazed by Merino ewes mated to White Suffolk rams, lambing from late April (2001, maiden lambing) or early May (2002). This paddock was grazed at a stocking rate of 3.8 ewes/ha. Live weights were recorded for this single flock in both 2001 and 2002.

Meringur – Two paddocks were simulated in 2001 (NBH and JE) and 2002 (NBH and BB). NBH was grazed by 3.3 crossbred weaners or 0.5 unmated ewes/ha during the first 6 months of 2001. JE was grazed by 1.2 Merino ewes/ha during 2001, the ewes lambing in August. The live weights for this flock were monitored in 2001. In 2002, NBH was grazed by maiden April lambing Merino ewes at 0.7 to 0.9 ewes/ha, and live weights for this flock were recorded. BB was not grazed.

Manangatang – Paddocks 7 and 8 were grazed by a number of different flocks at various stocking rates. Paddock 1 was grazed by 1.4 Merino ewes/ha, lambing in March 2002.

Murrayville - Two paddocks were simulated in 2001 using the sandy loam soil type (SW and NW), and one each of the sandy loam (SW) and whole paddock (SE) soil types in 2002. Each year, 3 of the 4 paddocks at this location were intermittently grazed by the same flock of late March lambing Merino ewes mated to Suffolk rams, for which live weights were recorded. All the paddocks were the same size, and the stocking rate was 3.5 ewes/ha when the ewes were in individual paddocks.

Insert Fig 1*a* and *b* here

Initial seed banks for annual medic were adjusted to be within the observed levels of soft seed reserves, and to obtain the best data fit against observed mean biomass production. Initial seed banks used for the simulations at Murrayville and Meringur may not reflect observed seed data because the legume varieties or species present differ markedly from Paraggio, the only annual medic in GrassGro. Annual grass seed banks were adjusted to obtain the best fit of botanical composition with observations. Modelling brassica species and cereals are not options in GrassGro. Seed reserves and fertility were adjusted to obtain the best fit of predicted total pasture production with observed data. The fertility scalar was adjusted according to measured phosphorus content: a fertility of 0.6–0.75, 0.77–0.82 and 0.82–0.89 used for phosphorus levels (Olsen P) of 4–6, 7–9 and 9–11 mg/kg, respectively.

Simulated sheep management was specified to be similar to observed management for each paddock. The grazing pressure on each simulated paddock accurately reflects observed grazing throughout each simulation. Sheep grazed other paddocks at each location for varying periods, for which pasture records were not kept. During these periods, in each simulation the grazing management option allowed sheep to graze paddocks other than the observed paddock, with pasture biomass production estimated. Although pasture records for alternate paddocks were not kept, most were sighted, and the estimates used in the simulations are considered to be realistic. Grazing for recorded paddocks was only sufficiently continuous at Walpeup, Meringur and Murrayville for sheep live weight predictions to be tested.

Sheep typically graze crop stubbles and weeds (skeleton weed, heliotrope, and cereals) over summer in the Victorian Mallee, and neither a cereal species nor summer-growing weeds can be modelled in GrassGro. To simulate any effect of cereal stubbles on pasture and sheep production, dead annual grass (between 500 and 2500 kg DM/ha, varying between paddocks and years, with default digestibility values provided by GrassGro) was included at the start of relevant runs. To overcome unrealistic summer/autumn live weight loss associated with lack of ability to simulate stubble or summer weeds, flocks were simulated only when grazing of pasture paddocks commenced, or were supplementary fed in a feedlot or another paddock. Both ewes and lambs were sold out of the simulation so that sheep were not forced to graze pasture paddocks over summer. The simulations were simplified by specifying a single age group for ewe flocks where possible. Simulations used the lambing date approximately 2 weeks after the actual start of lambing, representing the peak lambing date of the flock.

Frequent changes in feeding levels for some observed flocks, in addition to simulated feeding to achieve target weights on specific days, could not always be simulated due to restrictions in the number and timing of feeding available in GrassGro, without stopping and restarting runs. It was not possible to stop and restart simulations of breeding ewe flocks post-lambing while maintaining correct lambing percentages and stocking rates, when ewes were purchased pregnant and joining date occurred after the start of the simulation. If sheep are purchased after the start of the simulation, the user can specify their live weight and age, but not their fleece weight, which is assumed to be a breed characteristic. This also resulted in slight live weight errors prior to shearing.

GrazFeed version 4.1.1 (December 1999) (Freer *et al.* 1997) was used to check sheep performance from simulated pastures against observed data, because live and dead quantities of pasture can be entered and corrected to observed height.

Statistical analyses

Linear regression equations relating observed to predicted herbage biomass and herbage biomass to rainfall were calculated using Excel (Microsoft 1993). Variation around the mean is shown by standard errors. The calculation of root mean square error (RMSE) of observed compared with predicted live herbage biomass used April to September data only. October data was excluded due to difficulty separating live from dead biomass. Mean, rather than median, values for actual pasture production are shown on graphs and were used in calculations of RMSE.

Results

Rainfall

GrassGro outputs for rainfall (Table 3) adequately represented farm records for rainfall during 2001-2002, except at Meringur. At Meringur the rainfall used in the simulation during the growing season was 6 to 14 mm greater than producer records of rainfall for July and August 2001 and May to July and September 2002.

Insert Table 3 here

Comparison of soil types

Initial sandy loam soil parameters were set using a stage 1 evaporation of 3.5 mmd$^{1/2}$ and produced pasture production matching observed data for the limited years available. However, simulations over a wider range of rainfall conditions indicated that predicted production was excessive in low-rainfall years, and a stage 1 evaporation of 4 mmd$^{1/2}$ was more appropriate.

For tactical simulations between 1970-2002 (300 kg initial seedbank), the peak total live medic herbage biomass ranged from less than 230 to around 5500 kg DM/ha for both the sandy loam and whole paddock soils. Peak production from both soils averaged approximately 1900 kg DM/ha, but in individual years differed by -692 to 428 kg DM/ha. The drought years of 1982, 1994, 1997 and 2002 were predicted to produce less than 500 kg DM/ha peak total live biomass. Predicted pasture production from the sandy loam and whole paddock soil types should not be directly compared, but the similarity between predictions, and testing in average and drought years (2001-2002) indicate the whole-paddock prediction is adequate.

Comparison of observed and predicted pasture using a sandy loam soil type

<u>Annual medic variety experiments.</u>

GrassGro was able to predict herbage biomass production in both the years of sowing (from a 10 kg/ha seeding rate), and in regenerating pasture stands. The model adequately predicted the biomass of Paraggio in variety trials grown at Walpeup and Werrimull ($r^2 = 0.94$, $P<0.01$). Other varieties were observed to produce 44 to 299% (-852 to 1753 kg DM/ha) of the peak live herbage biomass of Paraggio, although these large differences may not be representative of long-term variety performance.

<u>Experiment of Latta and Carter (1998).</u>

The predicted live herbage biomass for ungrazed medic dominated (Fig. 2) and grassy medic pastures matched observed production in 1991 and 1992 ($r^2 = 0.78$), except that the spring peak was not achieved. Increasing the rooting depth of medic from the default (360 mm) to 400 mm did not improve the spring peak or seed production. Predicted medic seed production in 1991 was 20% of that observed, which prevented adequate biomass production in 1992. Increasing seed banks at the start of 1992 to match observed levels resulted in a satisfactory match of observed and predicted biomass in 1992 (Fig. 2). Any enhancement of pasture production due to grazing in 1992 was not accounted for in these ungrazed simulations. The predicted rate of breakdown of hardseededness was more than double that observed for Paraggio over summer/autumn 1992.

Insert Fig. 2

Grass-cleaned annual medic and lucerne.

GrassGro was able to adequately predict herbage biomass production of a pure annual medic pasture from 1996 until winter 1998, when it was less than half the observed biomass (Fig. 3). On the same site, biomass predictions for an annual medic in a lucerne/medic mix less closely matched recorded data than the pure annual medic. The biomass of lucerne in this mix was underestimated, particularly in summer/autumn months.

The biomass production of lucerne in variety trials at Walpeup was also underestimated. Altering rooting depth, soil type and soil water content to unrealistic levels did not result in adequate prediction of lucerne biomass.

Insert Fig. 3 here

Comparison of observed and predicted data using a whole paddock soil type

The predicted total live herbage biomass of pasture matched observations during the growing season at Walpeup (Fig. 4), Meringur (Fig. 5), Murrayville and Manangatang, although the match was better in 2001 than in 2002. Live pasture biomass in 2002 was overpredicted at Walpeup, and in 1 of the paddocks at Meringur (paddock NBH), but was similar to observations in other locations. Predicted medic seed production at Walpeup in 2001 of 65 kg/ha was similar to the 60 kg/ha measured.

Insert Fig. 4 and 5, here

The live herbage biomass of weeds (skeleton weed - *Chrondrilla juncea*, heliotrope - *Heliotropium europaeum*, and cereals germinating from residues of the previous crop) recorded during summer and autumn 2001 could not be simulated, and the difference of predicted from observed biomass was clear at Meringur (Fig. 5) and Manangatang.

The biomass of dead pasture during 2002 approximated observations at Walpeup, but was well below observations in some paddocks at Murrayville and Manangatang.

The botanical composition of predictions matched observed data in some paddocks, but not others. At Walpeup, the approximate 50% legume in the predicted pasture for both 2001 and 2002 was similar to observations. At Murrayville the botanical composition of predicted pasture in paddock SW did not reflect observations due to the plant species present. In 2002, in paddock NBH at Meringur, the percentage of legume in pastures in September was similar to observations, but the predicted annual ryegrass component did not then die as observed. Reasons for the difference in botanical composition between observations and predictions in other paddocks were not clear.

The predicted live weights of ewes and lambs did not match observations at Walpeup in 2001 (Fig. 6) or other locations, despite simulated ewes receiving supplement when observed ewes received none. Predictions of ewe live weights at Walpeup in 2002 more closely matched observed data because supplementary feed provided most of the feed requirements of both observed and simulated ewes for much of the year. However, in both years, predicted lamb live weights were half that expected when sold, at all locations. Increasing the nutritional value or quantity of supplement fed did not increase ewe or lamb weights to levels similar to observed weights.

Insert Fig. 6 here

GrazFeed was used to check sheep performance at Walpeup in spring 2001. GrazFeed predictions for lamb growth approximated observed growth only if available pasture was assumed to be total live herbage biomass present. GrazFeed prediction was limited for much of the year because the version of this model used contains an error (corrected in subsequent versions) that does not allow adjustment of live pasture height when live biomass is below 90 kg DM/ha. GrazFeed therefore predicts a height of 0 cm, resulting in zero intakes. In contrast, calculations of energy requirements for observed live weight gains suggest sheep in the Victorian Mallee consume some live pasture from this level during much of autumn/winter.

Breakdown of hardseededness

Approximately 10 to 14% of predicted seedbanks were permeable in January 1988 and 1989, comparable with observed data (Latta and Quigley 1993). However, by autumn the predicted proportion of permeable seed was about 10 to 20% higher than recorded.

Testing biomass production from differing sowing rates

Predicted annual medic herbage biomass from 1 to 256 kg seed/ha sowing rates differed substantially from observed production in September (Williams and Vallance 1982), ranging from 86 to 200% of observed biomass. The probable reason for this disparity is that the soil parameters used in the simulation differed from the actual soil. However, it is possible the variety sown (Jemalong) was not adequately predicted using the Paraggio parameter set in GrassGro. In addition, predicted biomass production did not equilibrate as sowing rates increased, in contrast with observed data. Production at a sowing rate of 1 kg was not adequately predicted because quantities of less than 1 kg soft seed cannot be entered as a starting value in GrassGro.

Adequacy of modelling

Overall, GrassGro adequately predicted the live herbage biomass of annual pastures for both the whole paddock soil type (April to September data RMSE = 72 kg DM/ha; $r^2 = 0.94$; June RMSE = 18; September RMSE = 77 kg DM/ha) and the sandy loam soil type (April to September data RMSE = 217 kg DM/ha; $r^2 =$ 0.81).

The predicted relationship between growing season rainfall and peak live herbage biomass production (Fig. 7*a*) was similar to that observed (Fig. 7*b*) for both the sandy loam and whole paddock soil types, providing predictions were restricted to the range of growing season rainfall received by observed pastures. Increasing the pasture seedbank reduced the slope of the regression. Peak live spring herbage biomass for a medic pasture with a seedbank of 300 kg seed was related to growing season rainfall by: y = 14.9x-932.7 for sandy loam; y = 16.9x – 1261.7 for whole paddock ($P<0.001$; $r^2 = 0.6$), over the rainfall years 1970-2002.

Insert Fig. 7a,b here

1970-2002 tactical predictions of pasture biomass

The predicted total live herbage biomass production at Walpeup increased with size of initial medic seedbank (Fig. 8). The effect of climatic variability on production of annual medic is large - peak production for a pasture with 20 kg/ha seed (8 kg soft seed) in January was predicted at up to 161 kg DM/ha in the poorest 10% of years and up to 3375 kg DM/ha in 90% of years.

Insert Fig. 8 here

Tactical simulations for the 50th percentile at Walpeup predicted pastures with a high medic seedbank (300 kg) would produce 129 to 453% at the end of July and 120 to 218% more production at the spring peak than some commercial Mallee pastures. The herbage biomass production of pastures representative of those measured on farms indicated spring production 76 to 137% that of a well-managed pasture regenerating in the first year after crop. Soil fertility in the range found in Mallee paddocks caused an estimated 10 kg/ha.day range in spring growth rates at the 50th percentile, which was low relative to the impact of climate variability (Fig. 9).

Insert Fig. 9 here

Live herbage biomass production between Murrayville (western), Walpeup (central) and Manangatang (eastern) regions of the Mallee was similar at the 50th percentile, for pure annual medic (300 kg seed on 1 January) and the same soil conditions. Tactical simulations (1970-2002) showed pastures at Walpeup, Manangatang and Murrayville germinated in mid April, but at Meringur (northern Mallee) did not commence growing until 3 May. Seasonal growth patterns were similar at all locations although herbage biomass at the end of July was 25 to 32% higher at Manangatang and Murrayville compared with Walpeup. A slightly lower spring peak (up to 12%) was predicted for Manangatang compared with Walpeup. In the drier northern Mallee, Meringur produced only 60 to 70% of the biomass at Walpeup throughout the year.

Discussion

This is the first study to test the use of GrassGro in low-rainfall regions where sheep production is a major enterprise. This study shows that the current version of GrassGro does not adequately predict sheep production from pastures of low herbage biomass. Underprediction of live weights during winter and spring cannot be attributed to the lack of summer/autumn growing species (skeleton weed, heliotrope, cereals), insufficient supplementary feeding or insufficient dead pasture. The underprediction of both ewe and lamb live weights is probably due to 2 constraints in the design of GrassGro. Firstly, GrassGro estimates of available live herbage biomass assume that 400 kg DM/ha of live herbage (including senescing and seedling plant material) is not available for consumption by sheep. It is the residue left after harvesting using a shearing handpiece (Moore *et al.* 1997). This calibration is based on data from dense improved pastures and contrasts with the residual biomass of 45 ± 3 kg DM/ha after harvest using blade shears in this environment (Robertson 2004). The tests with GrazFeed reported here demonstrate that sheep in this region must be accessing live herbage biomass well below 400 kg DM/ha to achieve the weight gains observed.

Secondly, the animal nutrition and production model used in GrassGro is calibrated so that a pasture with complete cover will have a height of 3 cm when 1 T DM/ha is present (Freer *et al.* 1997), with a linear relationship between mass and height. Estimates of height will therefore be inaccurate when pastures contain substantial proportions of bare ground, or are clumpy, rather than homogeneous as GrassGro assumes. The relationships between height, mass and cover estimated for Victorian Mallee pastures (Robertson 2004) indicate that GrassGro will underestimate the height of annual pastures in the Victorian Mallee, which usually have less than complete cover, and therefore sheep intake, since intake is related to pasture height.

Clark *et al*. (2000) previously reported the inability of GrassGro to predict sheep live weight during drought and when grazing pastures with incomplete ground cover. In addition to low live weights, the underestimation of pasture intake by sheep manifests in excessive levels of supplementary feeding. These results highlight the need for detailed testing of predictions for models used at or beyond the extremes of their intended range.

Predictions of annual pasture differed from observed data in the areas of levels of hardseed (Latta and Quigley 1993) and spring herbage biomass production not stabilising with increasing seed rate (Williams and Vallance 1982). Predicted medic seed production was sometimes inaccurate. The predicted live herbage biomass may not always represent production by medic varieties other than Paraggio, perhaps due to differences in seed size and hardseededness, as well as growth. However, some of the differences between observed and predicted production may be less due to the errors involved in measurement of production. Despite these discrepancies, predicted annual pasture herbage biomass matched observations for pastures both in the year of sowing and for regenerating pastures between 1991 and 2002, including drought, average and high rainfall years, and at widely separated locations in 2001 and 2002. Production from both a sandy loam and a whole paddock soil was predicted at several locations. This allows some confidence in the use of long-term predictions of pasture production.

Overestimation of live herbage biomass during the drought of 2002 may be partially attributed to error in pasture consumption (Walpeup), and greater rainfall than recorded by the farmer (Meringur). Discrepancies at Manangatang may be due to species differences, but the cause is not clear.

Although predictions of herbage biomass for annual pastures were satisfactory, the application of GrassGro could be improved with the inclusion of a more hardseeded annual medic than Paraggio. The inability to model summer-growing weed species in GrassGro, and the grazing of cereal stubbles, which are the dominant feed sources in the Victorian Mallee for much of the year, restrict the ability to predict sheep production in this environment. Adding a component of dead annual grass to the herbage pools was not a good substitute for cereal stubble as a higher rate of disappearance was predicted than observed. The germination of spilt grain in crops, and indeed the use of cereals as forage crops, warrant the development of a plant parameter set to model at least one cereal species in GrassGro that would be applicable throughout the mixed-farming regions of Australia.

Predictions of lucerne herbage biomass were inaccurate, despite predictions of annual medic on the same site being satisfactory. The parameter set for lucerne currently in GrassGro requires modification.

Large differences in soil type inherent with the Mallee dune/swale landscape increased the difficulty in testing GrassGro. Variation in soil type between experiments and the generic description of soil type as 'sandy loam' made it difficult to use some pasture data for comparisons. Unfortunately, even the most basic soil measurements required to initiate GrassGro are seldom available for specific sites. In addition, many of the observations made in experimental trials are not always suitable for use in GrassGro. For example, reports of plant density rather than seed reserves, insufficient measurements taken over the growing season, or experiments that only report production for a limited climatic range. These restrictions are also potential sources of error in the data as was illustrated by the importance of stage 1 evaporation in determining pasture production during droughts, with little influence in better rainfall years. Comparison of pasture production using the whole paddock soil type with the sandy loam gives more confidence that the whole paddock soil is adequate, despite being validated only for 2001 and 2002.

The tactical simulations indicate a wide range in the performance of pastures, driven by seedbank and climate variability. Both medic trial data and predicted peak biomass production for improved pastures in relation to growing season rainfall were less than 50% of potential predictions (French 1992; Bolger 1999). Lower than optimal fertility is one reason for not attaining potential. Mallee soil types other than those reported here might be more productive.

GrassGro has been used to define the impact of climatic variability on sheep and pasture production in higher rainfall regions (Clark *et al.* 2003) and to indicate to producers the risks involved with different management strategies (Simpson *et al.* 2001). This study has provided a means whereby large differences in pasture production resulting from different seedbanks and species composition can be quantified under different seasonal conditions in the Victorian Mallee. This is a positive step towards quantifying the risk involved in producing sheep and pastures, which is a key concern for Mallee producers and limits adoption of recommended sheep and pasture practices. Further steps will depend on the development of new capabilities for GrassGro.

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LIST OF TABLES

Table 1. Parameters for sandy loam and whole-paddock soil types used in simulations

Parameter	**Sandy loam**	**Whole-paddock (dune/swale)**
Soil type description	sandy loam	sandy loam/loamy sand/sand
Topsoil depth (mm)	200	280
Topsoil field capacity (%)	17	16
Topsoil wilting point (%)	7	6
Topsoil bulk density (g/cm^3)	1.6	1.6
Topsoil saturated hydraulic conductivity (mm/hr)	23	40
Subsoil depth	2000	2000
Subsoil field capacity (%)	30	25
Subsoil wilting point (%)	23	17
Subsoil bulk density (g/cm^3)	1.5	1.55
Subsoil saturated hydraulic conductivity (mm/hr)	3.0	3.0
Stage 1 evaporation ($mmd^{1/2}$)	4.0	3.9

Table 2. Summary of simulations

Location	Soil type	Data source	Trial purpose/description of simulation	Grazing observed[A]	Grazing simulation	Year
Walpeup Werrimull	Sandy loam	unpublished	annual medic variety trials	ungrazed	ungrazed	1991-1994
Walpeup	Sandy loam	Latta and Carter (1998) Latta (1994)	selective herbicide/no herbicide annual pasture	ungrazed 1991/grazed 1992	ungrazed	1991-1992
Walpeup	Sandy loam	Ransom unpublished	annual medic and lucerne	crash grazed	biomass reduced manually	1996-1998
Walpeup	Sandy loam	unpublished	lucerne variety trials	crash grazed	biomass reduced manually	1996-1999
Murrayville	Sandy loam	Robertson 2004	annual pastures on commercial farms	intermittent grazing	as observed	2001-2002
Walpeup Meringur Murrayville Manangatang	Whole paddock	Robertson 2004	annual pastures on commercial farms	intermittent grazing	as observed	2001-2002
Walpeup	Sandy loam	Latta and Quigley (1993)	annual medic hardseed breakdown	ungrazed	ungrazed	1987-1989
Walpeup	Sandy loam	Williams and Vallance (1982)	annual medic sowing rates	ungrazed	ungrazed	1981
Walpeup Meringur Murrayville Manangatang	Sandy loam and whole-paddock		tactical simulations: location; seedbanks; soil fertility	ungrazed	ungrazed	1970-2002

[A]Grazing regimes were simulated as accurately as possible. Paddocks were never set-stocked. In the experiment of Latta and Carter (1998) cumulative biomass was reported, so it was more appropriate not to graze simulated pastures.

Table 3. GrassGro records for mean long-term (1960-2002) and monthly rainfall (mm) for 2001, 2002 at four locations

		Rainfall (mm)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec[A]	Total[A]
Walpeup	2001	8.1	17.5	24.4	3.3	17.3	34.2	25.1	38.4	38.8	32.1	11.9	2.3	
	2002	4.6	10.6	13.6	8.7	20.3	20.5	7.8	22.5	11.0	5.3	11.7	n/a	
	Long-term	21	24	21	27	31	29	34	37	35	33	29	23	344
Meringur	2001	13.7	5.0	27.4	4.8	13.6	32.6	35.6	34.8	57.8	43.2	19.2	5.8	
	2002	10.0	6.7	9.8	12.4	19.7	34.5	20.2	13.5	24.5	8.5	29.6	n/a	
	Long-term	22	22	14	24	25	2 7	31	30	29	31	24	18	297
Manangatang	2001	16.8	29.5	30.2	5.5	9.2	42.1	29.5	40.1	35.2	21.7	4.6	3.6	
	2002	2.2	14.2	30.4	16.1	16.6	4.3	9.7	10.3	10.0	10.0	11.8	n/a	
	Long-term	22	23	21	26	31	25	31	32	31	33	27	20	322
Murrayville	2001	13.7	5.0	27.4	4.8	13.6	32.6	35.6	34.8	57.8	43.2	19.2	5.8	
	2002	10.0	6.7	9.8	12.4	19.7	34.5	20.2	13.5	24.5	8.5	29.6	n/a	
	Long-term	19	22	17	24	32	32	39	36	36	34	29	22	342

[A]December rainfall was not available for 2002 using GrassGro, and is not included in the long-term total. n/a = not available

CAPTIONS TO FIGURES

Fig.1. The period each observed paddock was grazed by sheep (dark line) during *a*) 2001 and *b*) 2002. Paddock identities were for *a*) 1 = MRS 8; 2 = JE; 3 = NBH; 4 = 8; 5 = 7; 6 = NW and 7 = SW. For *b*) 1 = MRS 8; 2 = BB; 3 = NBH; 4 = 1; 5 = 7; 6 = SE and 7 = SW.

Fig. 2. Observed (э) and predicted (line) total live herbage biomass (kg DM/ha) of annual medic for the selective herbicide treatment (Latta and Carter 1998; Latta 1994) at Walpeup

Fig. 3. Observed (э) and predicted (line) total live herbage biomass (kg DM/ha) of a crash grazed pure annual medic pasture at Walpeup

Fig. 4. Observed (э) and predicted (line) total live herbage biomass (kg DM/ha) in paddock MRS 8 at Walpeup 2001-2002

Fig. 5. Observed (э) and predicted (line) total live herbage biomass (kg DM/ha) for pasture and weeds in paddock NBH at Meringur 2001 (ungrazed) and 2002

Fig. 6. Observed (% =) and predicted (lines) live weight (kg) for ewes and lambs at Walpeup 2001-2002

Fig. 7*a*. Relationship between growing season rainfall (April to October mm) and predicted peak live herbage biomass (kg DM/ha)

A = sandy loam soil (э) 50 kg initial medic seed , years 1970-2002

B = whole paddock soil (=) grassy medic pasture, years 1970-2002 with growing season rainfall < 220 mm

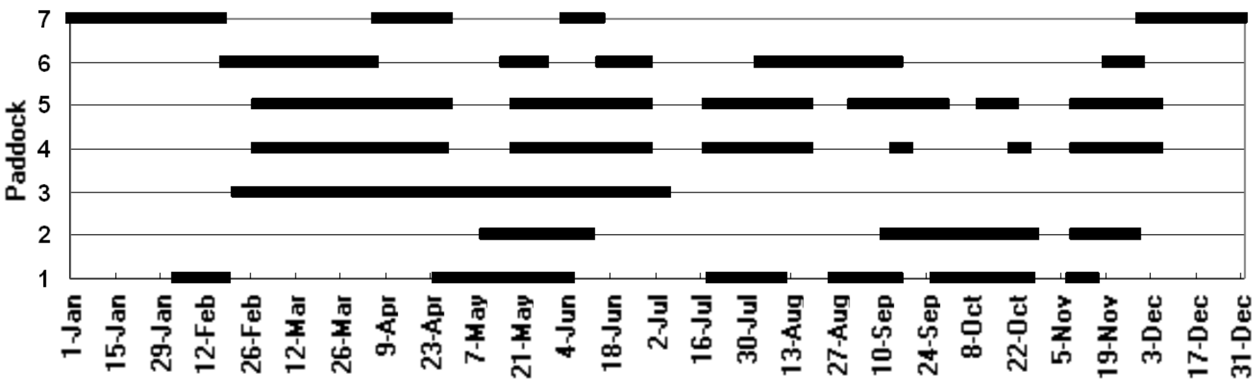
Fig. 7*b*. Relationship between growing season rainfall (April to October mm) and observed peak live herbage biomass (kg DM/ha) in regenerating medic trials (э) and in monitored commercial paddocks 2001 and 2002 (=)

Fig. 8. Predicted effect of size of initial seedbank on total live herbage biomass (kg DM/ha) of annual medic at the 50th percentile at Walpeup (1970-2002) on a whole paddock soil type

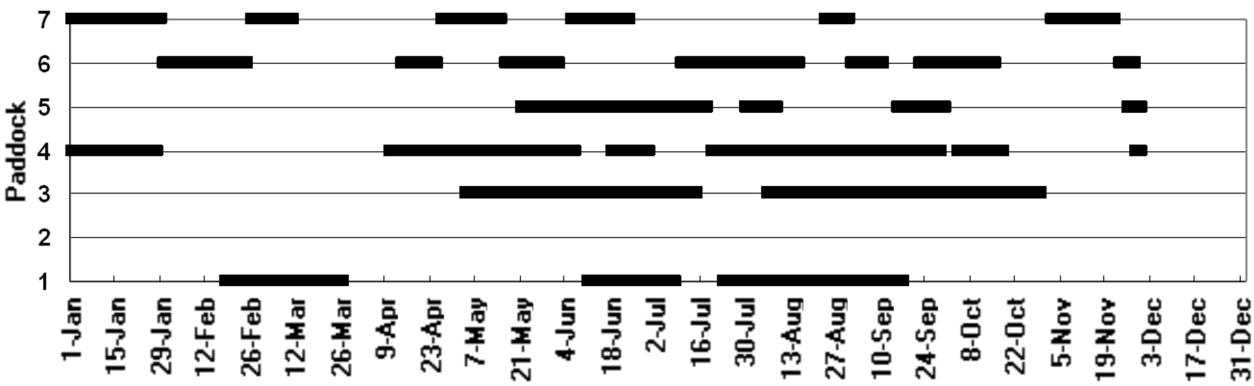
(2, 12, 20, 50, 100 and 300 kg initial seedbank = ascending biomass)

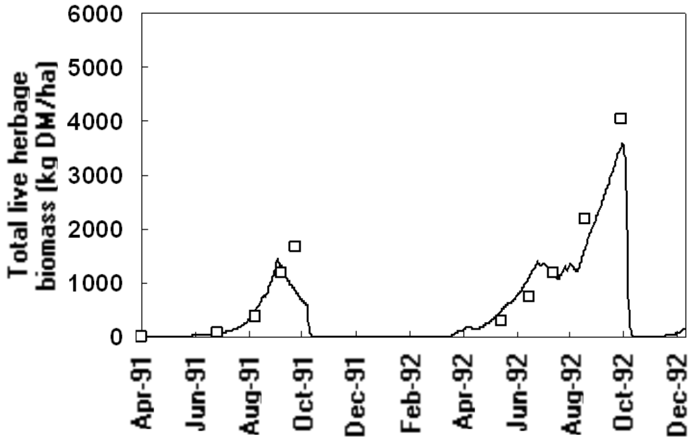
Fig. 9. Predicted mean monthly pasture growth rates (kg DM/ha.day) at 10th (black columns), 50th (grey) and 90th (clear) percentiles (1970-2002) for a grassy medic pasture at Walpeup and average soil fertility (scalar 0.82) on a whole paddock soil type

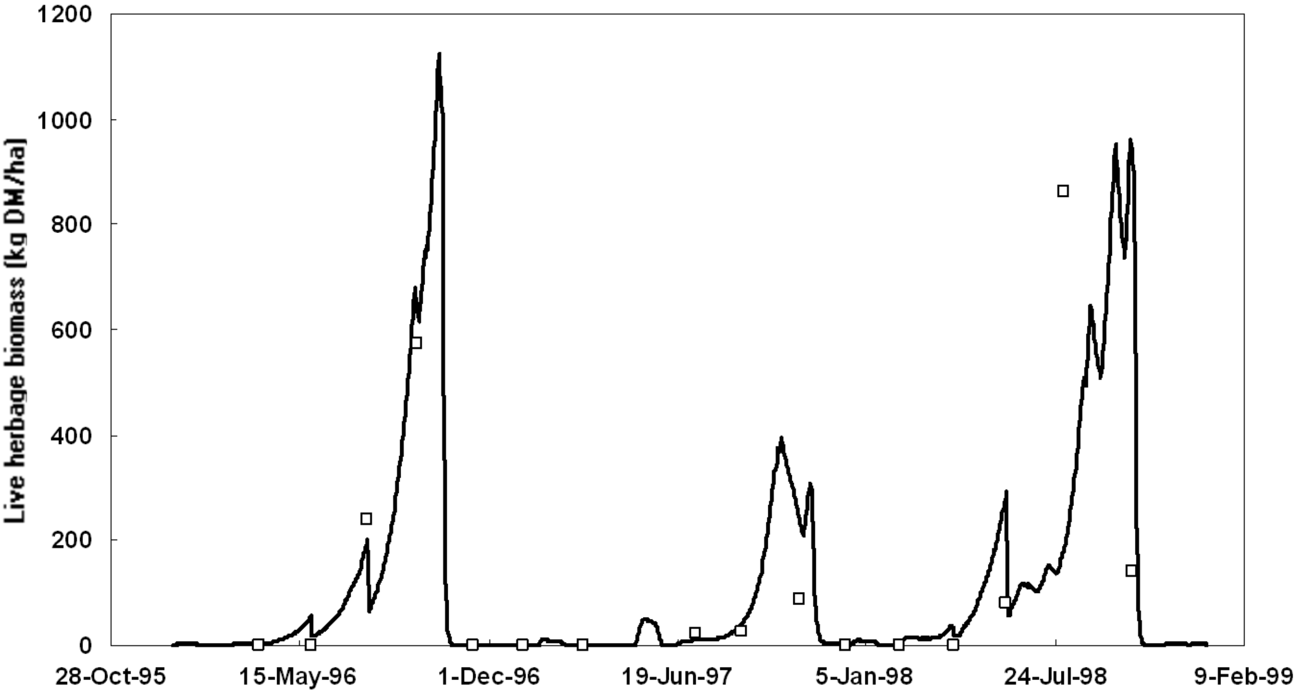
a)

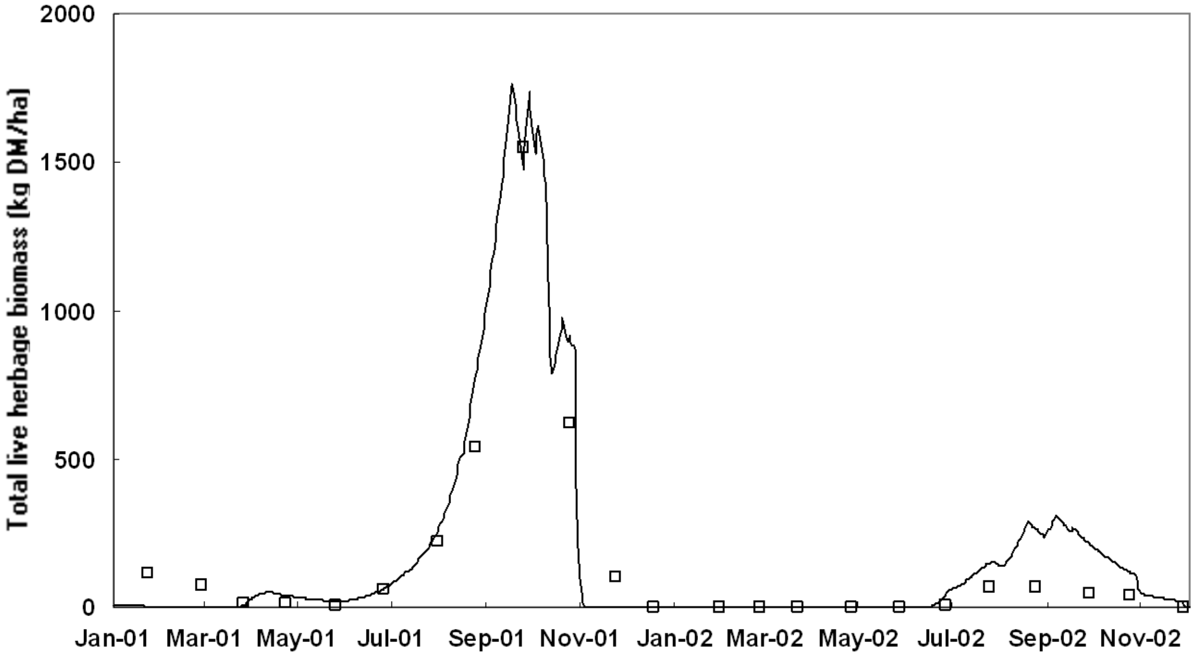


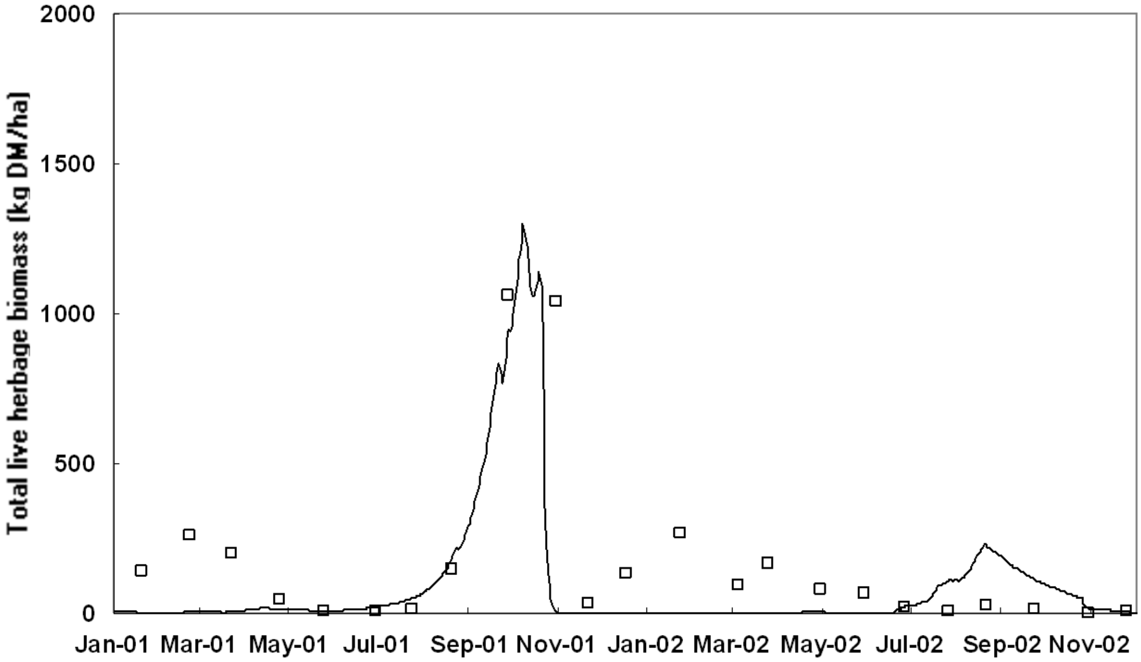
b)

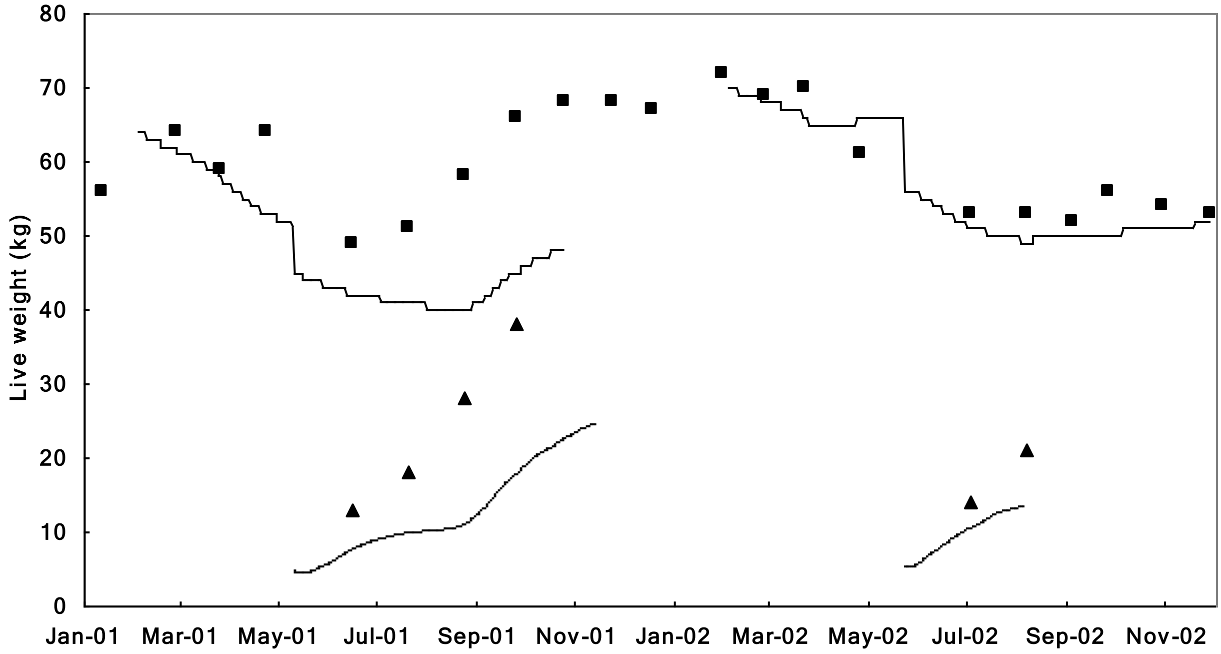


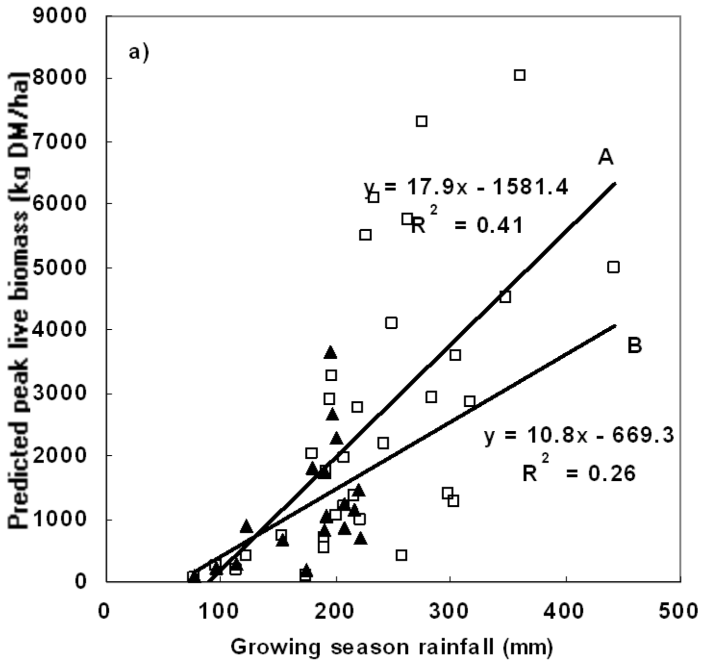

Total live herbage biomass [kg DM/ha]
6000
5000
4000
3000
2000
1000
0
Apr-91
Jun-91
Aug-91
Oct-91
Dec-91
Feb-92
Apr-92
Jun-92
Aug-92
Oct-92
Dec-92

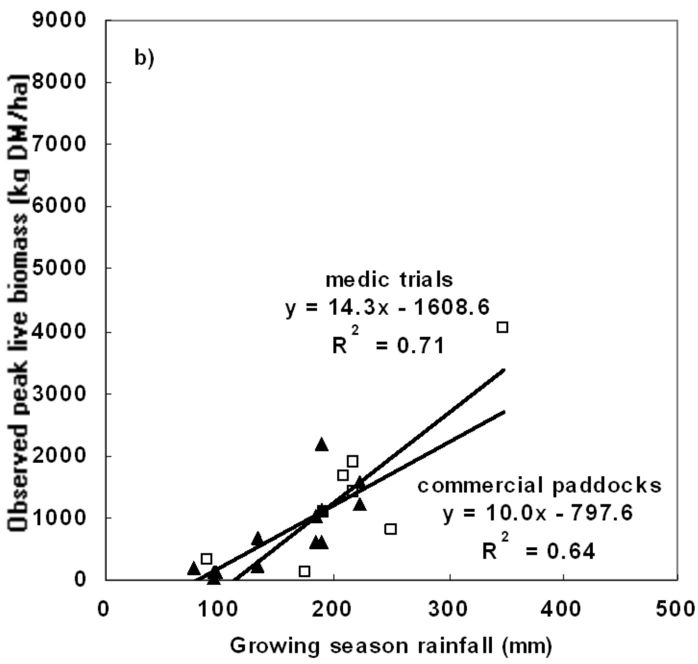

Live herbage biomass [kg DM/ha]
1200
1000
800
600
400
200
0
28-Oct-95
15-May-96
1-Dec-96
19-Jun-97
5-Jan-98
24-Jul-98
9-Feb-99

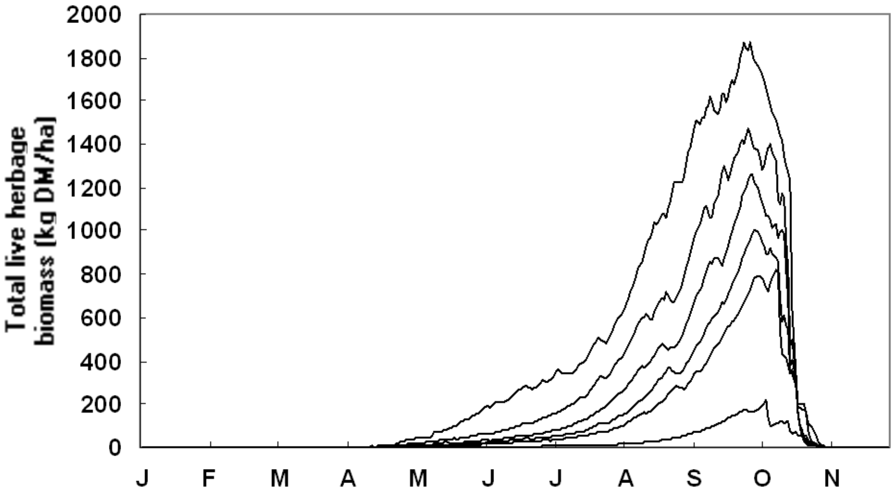

Total live herbage biomass (kg DM/ha)
2000
1500
1000
500
0
Jan-01 Mar-01 May-01 Jul-01 Sep-01 Nov-01 Jan-02 Mar-02 May-02 Jul-02 Sep-02 Nov-02

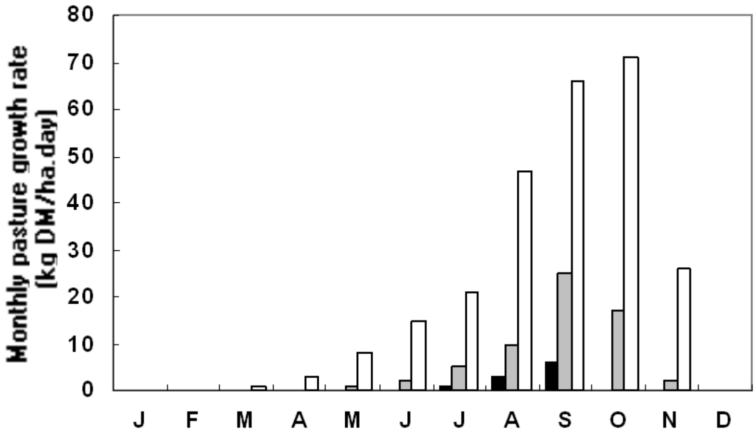

Total live herbage biomass (kg DM/ha)
2000
1500
1000
500
0
Jan-01 Mar-01 May-01 Jul-01 Sep-01 Nov-01 Jan-02 Mar-02 May-02 Jul-02 Sep-02 Nov-02


Live weight (kg)
0
10
20
30
40
50
60
70
80
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02


a)
Predicted peak live biomass (kg DM/ha)
Growing season rainfall (mm)
A
y = 17.9x - 1581.4
R² = 0.41
B
y = 10.8x - 669.3
R² = 0.26
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
100
200
300
400
500


b)
Observed peak live biomass (kg DM/ha)
Growing season rainfall (mm)
medic trials
y = 14.3x - 1608.6
R² = 0.71
commercial paddocks
y = 10.0x - 797.6
R² = 0.64
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
100
200
300
400
500


Total live herbage biomass [kg DM/ha]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
J F M A M J J A S O N


Monthly pasture growth rate [kg DM/ha.day]
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D