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Simulation of Pasture and Sheep Production on the Northern Tablelands of New South Wales Australia.

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Abstract.
The paper demonstrates the verification and validation of the mathematical relationships for a Northern Tablelands version of SheepO (version 4.0), a Decision Support System that simulates pasture and sheep production. The current version of SheepO (version 3.0) was primarily developed for the Winter rainfall areas of Southern Australia and fails to work in regions with a Summer rainfall pattern. Therefore, these differences in regions have led to the implementation of a water balance model, a digestibility model and the development of a shoot death model. The development of the shoot death model used production data for fine-wooled Merino wethers (4-5 year old) grazing on a Phalaris/White clover pasture obtained from an experiment conducted at CSIRO, Chiswick, Armidale (Latitude 30°, 31'S, Altitude 1070m). The verification of version 4.0 shows the calibration of pasture and sheep production at a low (9.9 sheep/ ha) stocking rate and the experimentation of making one management change to a high stocking rate (19.8 sheep/ha). Similarly, validation is shown using an independent data set from Glen Innes (Latitude 29°, 42'S, altitude 1057m) of fine wooled Merino wethers (8 months old) at low and high stocking rates, respectively 10 and 15 sheep/ha. SheepO version 4.0 will assist advisers, producers and researchers on the Northern Tablelands of New South Wales, Australia to investigate the outcome of changes to current management strategies.

1. INTRODUCTION

SheepO, a sheep management package that mimics the pasture and sheep production of a farm, addresses "what if" questions regarding different management strategies. The initial development of SheepO dates back to the early 1980's when White et al.[1983] developed a financial and biological simulation model of a breeding ewe flock. SheepO continued to evolve from these early beginnings into a microcomputer Decision Support System (DSS) (SheepO version 3.0, McLeod et al. 1992).

The primary application of SheepO's version 3.0 to date has been in the Winter rainfall areas of Victoria and Southern N.S.W. Under various test conditions it was found that version 3.0 failed to calibrate pastures in a Summer rainfall environment. Therefore, with approximately 21.6 million sheep grazing on the Northern Tablelands it was considered a high priority to develop a regional model for this environment. As Jakeman [1993] indicates, the easiest alternative to a highly complex generic environmental model is to "develop models which have, within each region, a common model structure employing the same set of processes".

SheepO, version 4.0, utilises a common model structure for pasture and sheep production along with three regional models for water balance, shoot death and digestibility of the green pasture. This paper sets out to describe, verify and validate the regional models for the Northern Tablelands version of SheepO (version 4.0).

2. MODEL DEVELOPMENT

2.1 Differences between version 3.0 and 4.0

The main difference between version 3.0 and 4.0 is that version 4.0 has a regional model for the Northern Tablelands with a summer rainfall pattern. The original program, version 3.0, was developed predominantly for the Southern area of Australia with a Winter rainfall pattern generally depicted by an Autumn break occurring between March and June and a drying off period that begins sometime between October and February. However these indicators do not exist on the Northern Tablelands.

Figures 1 and 2 show the failure (Figure 1) and success (Figure 2) of calibrating pasture and sheep production on the Northern Tablelands with and without a regional model.

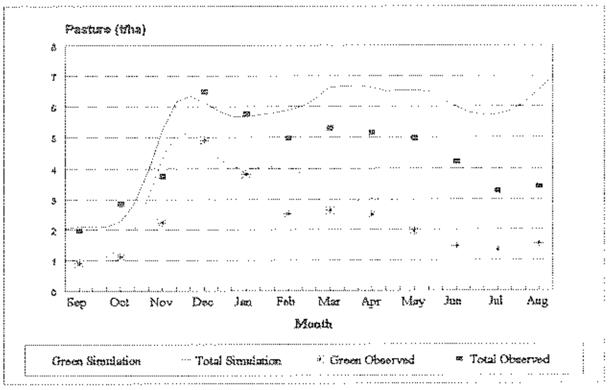

Figure 1: Simulation of Green and Total Pasture Version 3.0 at a Low Stocking Rate.

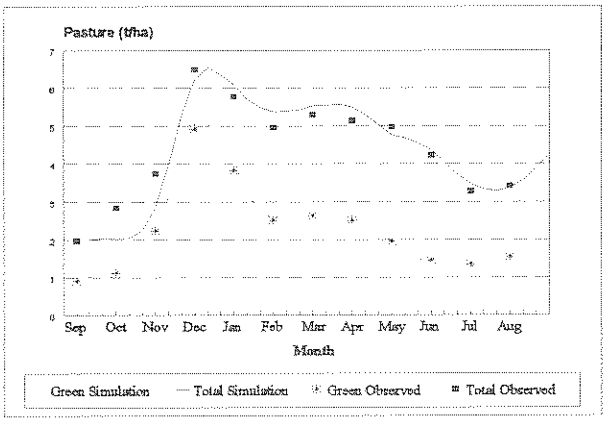

Figure 2: Simulation of Green and Total Pasture Version 4.0 at a Low Stocking Rate

2.2 Overview of pasture model

The critical component of simulating the pasture and sheep production is the ability of the model to calibrate the available pasture (total and green) with the minimum number of inputs. SheepO endeavours to minimise the number of inputs when calibrating a management strategy and allows the user to choose between an automatic or manual calibration.

The common inputs between both methods include monthly rainfall figures and the initial available pasture at the beginning of the simulation and the constant inputs across the chosen region. (Each region comprises of maximum and minimum temperatures, evaporation, a cold stress factor, a terrain factor and a pasture scaler). The remaining inputs differ for manual and automatic calibration. Automatic calibration requires the user to input at least three monthly pasture measurements during the growing season which in turn predicts the growth rates at the Optimum Leaf Area Index (**OLAI**) (the ratio of leaf area (one surface of the leaf) to unit area of land, which should be maintained at a sufficiently high level to ensure maximum light interception and hence maximum herbage relationship) (Frame 1992) Consequently equations (1) and (2) predict the available green and dead pasture at 10 day intervals (i.e. 36 ten day intervals for one year's simulation). Manual calibration requires the user to input monthly OLAI values and similarly predicts the available pasture. This paper has used a manual calibration to verify and validate SheepO version 4.0.

Figure 3 along with (1) and (2) show how the pasture is pooled from pasture growth to decomposition and the calculations that predict the available green and dead pasture. (Note: Δ**G** = difference in green pasture from one period to the next i.e. $G_i - G_{i-1}$ where **G** = green pasture and subscript i - ith 10 day period, **Sg** = pasture growth, **Ig** = intake of green, **Tg** = trampled green, **Sd** = shoot death, Δ**D** = difference in dead pasture from one period to the next i.e. $D_i - D_{i-1}$ where **D** = dead pasture, **Id** = intake of dead, **Td** = trampled dead and **Dr** = decomposition rate.)

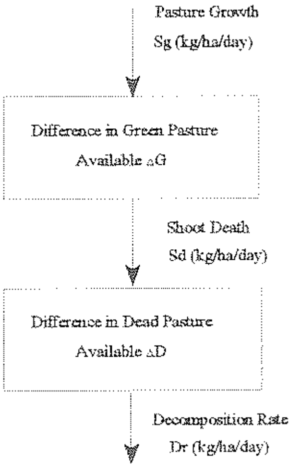

Figure 3: Pasture Available Pool

$$\Delta G = Sg - Ig - Tg - Sd \tag{1}$$

$$\Delta D = Sd - Id - Td - Dr \tag{2}$$

2.3 Water balance model

The water balance model in version 4.0 implemented soil moisture equations from Smith and John (Smith et al. 1974). Their work and the associated equations were chosen for two reasons: firstly, because the research was carried out on the Northern Tablelands (Armidale Lat. 30.5° S, altitude 1000m) and secondly, because the equations incorporated an important parameter, the evapotranspiration (loss of water from the soil both by evaporation and by transpiration). (Note: **Epot** = potential evapotranspiration, **Epan** = pan evaporation, **Cp** = calendar period) The importance of calculating the actual evapotranspiration (**Ea**) (3), is seen in the relationship between Epan and two scalars (Ea/Epot and Epot/Epan) that relate Ea to Epan. The relationship of Ea/Epot "predicts the decline of the actual rate below the potential rate as soil moisture declines" (4). The Epot/Epan scalar was found to be 0.87 (Johns et al. 1973). Therefore (3) improves the prediction of the available soil moisture (**Sm**) (5).

$$Ea_i = \left(\frac{Ea_{i-1}}{Epot}\right) * \left(\frac{Epot}{Epan}\right) * Epan\,[Cp] \tag{3}$$

$$\frac{Ea_{t-1}}{Epot} = 0.00914 \cdot Ea_{t-1} + 0.185 \qquad (4)$$

$$Sm_t = Sm_{t-1} + \frac{Rain\ [Current\ Month\ ]}{3} - Ea_t \qquad (5)$$

The relative soil moisture (**RSM**) routine as shown in Figure 4 is based on a basalt derived black earth with 118mm of stored water available to the plant.

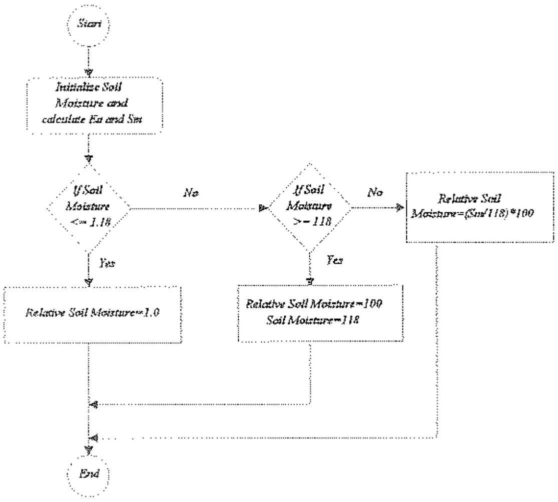

Figure 4: Flow Chart of Water Balance Model

The importance of the relative soil moisture is seen in the following description of the shoot death calculation.

2.4 Shoot death model

2.4.1 Data

The shoot death (Sd) variable is by far the more difficult to model yet the most influential on the Northern Tablelands. Unfortunately, this variable is difficult to source because the data collection process consumes an inordinate amount of time.

Due to this time constraint, Sd was obtained by using SheepO to calculate the intake (Ig and Id), trampling effect (Tg and Td) and decay (Dr) by inputting green and dead ten day periods that were interpolated off a cubic spline (MathCad Plus 5.0, 1994) developed from the observed green and dead pasture. (1) was then used to calculate the Sd for thirty-six ten day periods. (Verified by K.J. Hutchinson., personal communication).

2.4.2 Model

The Sd model (Figure 5) calculates the percentage of Sd and subsequently calculates the Sd (kg/ha/day) as shown in (6). The critical driving variables include the available green pasture and RSM that are used in what are generally classified as exponential quadratic functions (Thornley et al. 1990). (7) through to (12) have been empirically derived using MathCad Plus 5.0 1994 for three periods of the year: for September to December (7), (8) and (9) are used; January to April use (7), (10) and (11) and the remaining months of the year use (12). (Note: **ShImp** = index of shade impact (section 2.4.3), **SdPer** = percentage of shoot death, **GreenIndex, RSMIndex** = exponential quadratic functions respectively derived from green pasture and the RSM.) It is important to note that the green and RSM influences the percentage of Sd more so from September through to April while from May to August the green available is the main influence. Biologically, RSM and the available green form a sound basis to predict Sd on the Northern Tablelands.

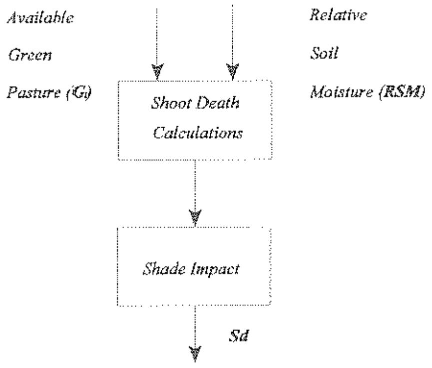

Figure 5: Shoot Death Model

$$Sd_i = SdPer_i \cdot ShImp \cdot G_i \qquad (6)$$

$$GreenIndex_i = 0.007 \cdot e^{\left(0.0002 \cdot \left(1 - \frac{G_t}{2 \cdot 7000}\right) \cdot G_t\right)} \qquad (7)$$

$$RSMIndex_i = 0.008 \cdot e^{\left(0.01 \cdot \left(1 - \frac{RSM_t}{2 \cdot 100}\right) \cdot RSM_t\right)} \qquad (8)$$

$$SdPer_i = 10 * GreenIndex * RSMIndex \qquad (9)$$

$$RSMIndex_i = 0.007 * e^{(0.01*(1 - \frac{RSM_i}{2*100})*RSM_i)} \qquad (10)$$

$$SdPer_i = 35 * GreenIndex * RSMIndex \qquad (11)$$

$$SdPer_i = 0.00000042 * e^{(0.01*(1 - \frac{G_i}{2*1950})*G_i)} \qquad (12)$$

2.4.3 Shade Impact

After the shoot death (Sd) is calculated the shade impact (ShImp) (Figure 6 adapted from a technical paper by Vickery et al.(1972)) increases the amount of Sd in relationship to the available green pasture when the green pasture is greater than 2000kg/ha. The dynamic acknowledged by this aspect of the model is the reduction in the growth rate by increased shoot death as growing pasture shades lower leaves.

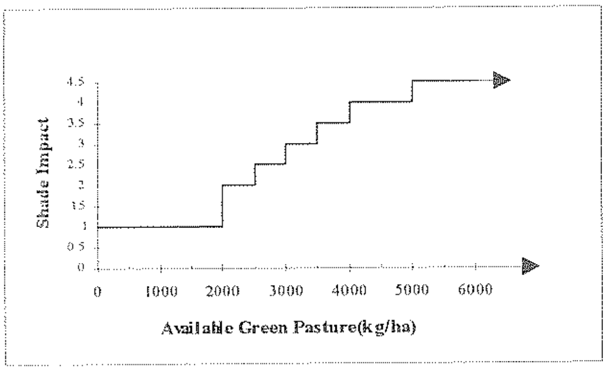

Figure 6: Shade Impact

2.5 Green Digestibility Model

The green digestibility model in version 4.0 for the Northern Tablelands has adapted relationships from the data of Hamilton et al. (1973). These relationships were developed across four species: Fescue, Phalaris, Cocksfoot and Ryegrass. To incorporate the White Clover component of the pasture an optional constant shift factor allows the user to increase the digestibility. (Note: the simulation of the dead digestibility uses the regional model in version 3 excluding the influence of the drying off period.)

3. VERIFICATION OF REGIONAL MODEL

3.1 Methodology

The algorithms developed in section 2 were based on production data averaged over two plots, taken from experimental work of K.J.Hutchinson, CSIRO Chiswick, Armidale (Lat. 30°, 31's, Altitude 1070m).

The sheep production data comprised fine wooled adult Merino wethers (4-5 year old) grazing on a Phalaris/White clover pasture. The simulation was run for low and high stocking rates with flock characteristics, rainfall and OLAI growth rates held constant. Initial pasture availability and animal live weights varied .

Initially a low stocking rate (9.9 sheep/ha) was calibrated and then one management change was made by doubling the stocking rate to 19.8 sheep/ha. Comparisons were then made between the predicted and observed pasture mass and live weights.

3.2 Analysis

Analysis of the simulated and observed data comprises both a visual technique and a statistical method. The graphical presentation of Figures 1, 2, 7 and 8 have been used for the visual technique and the modelling efficiencies (**ModEff**) (13) are used to place a statistical inference on the data. A statistical method that is a "dimensionless statistic which *directly* relates model predictions to observed data." (Mayer et al. 1993) . The modelling efficiency "is thus an overall indication of goodness of fit. Any model giving a negative value cannot be recommended, with preferable values close to one indicating a ' near-perfect' model."

With a limited number of observations feasible of pasture and production, two assumptions have been made. First, that a minimum of 8 observations is required to determine ModEff. The second is that lower ModEff values are acceptable for a high stocking rate to account for the difficulty of predicting the impact on pasture when increasing the stocking rate.

$$ModEff = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \qquad (13)$$

3.3 Pasture.

Figure 2 with modelling efficiencies of 0.94 and 0.90 respectively for total and green pastures indicates an accurate model for the low stocking rate.

The high stocking rate, Figure 7 with ModEff of 0.082 for total pasture indicates that the simulation is not a good fit. But, the ModEff of 0.50 for the green pasture in Figure 7 indicates a fit that is on the borderline of acceptability. Nevertheless, it is an improvement over ModEff of 0.27 for version 3.0 and must be considered in connection with ModEff for live weights (section 3.4).

Analysis by the visual technique also shows that the green simulation follows the overall trend, although, in some instances underestimating observed values. However, the visual analysis of the total pasture confirms a poor simulation. (Note: accuracy in predicting animal live weights depends more on the consumption of green rather than dead pasture therefore calibration of the available green pasture is far more critical than that for total pasture.)

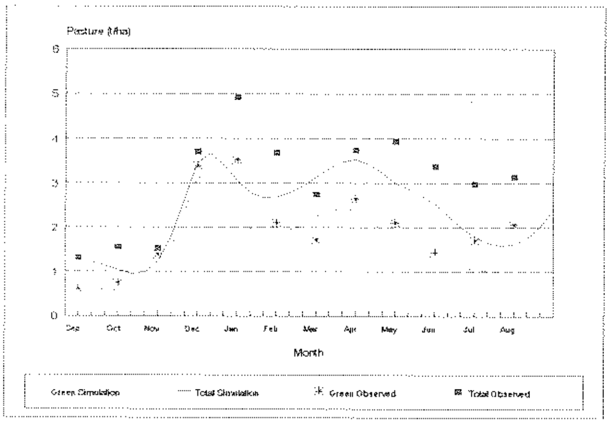

Figure 7: Simulation of Green and Total Pasture Version 4.0 at a High Stocking Rate.

3.4 Live Weights.

The predicted fleece-free body weights for the low and high stocking rates visually show a reasonably good fit that is confirmed by the modelling efficiencies of 0.87 and 0.67 respectively for low and high stocking rates (Figure 8). Again the ModEff is lower for the high stocking rate but acceptable.

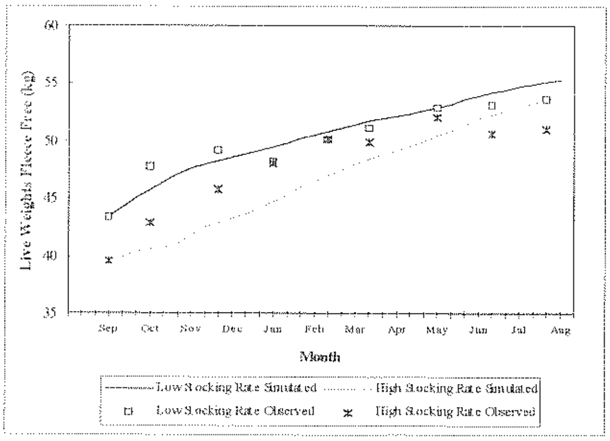

Figure 8: Low and High Stocking Rate Simulations of Animal Live Weights

4.VALIDATION OF REGIONAL MODEL

4.1 Methodology

Validation of the Northern Tablelands regional model have been carried out across a range of years and different species mixed with white clover. In this paper the validation is based on 10 months production data, February to November 1985, 1986 and 1987, averaged over three plots, M.Curll, unpublished data, NSW Agriculture, Glen Innes (Lat. 29°,42'S, altitude 1057m).

The sheep production data comprised fine wooled Merino wethers (8 months old) grazing on a Phalaris/White clover pasture. As in the pasture verification methodology (section 3.1) the same inputs were held constant or varied when the simulation was run for low (10 sheep/ha) and high (15 sheep/ha) stocking rates.

4.2 Analysis

Analysis used to validate the simulation and observed data is similar to that of section 3.2.

4.3 Pasture

Figures 9 and 10 indicate that the 1985 total pasture at the low and high stocking rates with ModEff respectively 0.78 and 0.64 validate the model. Visually, the simulation shows a reasonably good fit for total and green pasture. (Note: no modelling efficiencies are available for the green pasture because there were only four observations.)

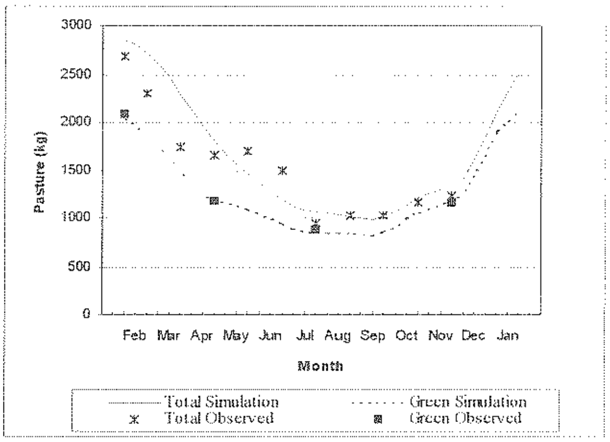

Figure 9: 1985 Simulation of Pasture from Glen Innes at a Low Stocking Rate

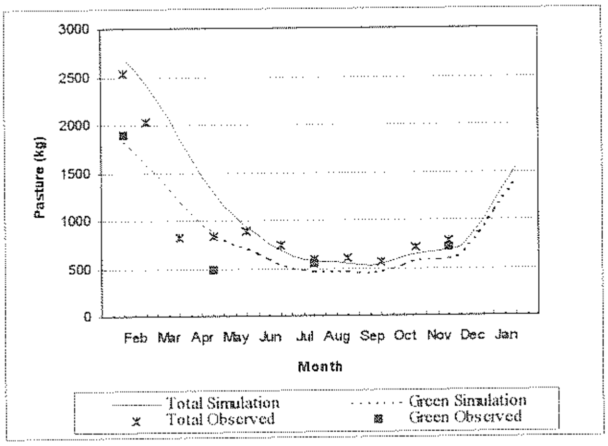

Figure 10: 1985 Simulation of Pasture from Glen Innes at a High Stocking Rate

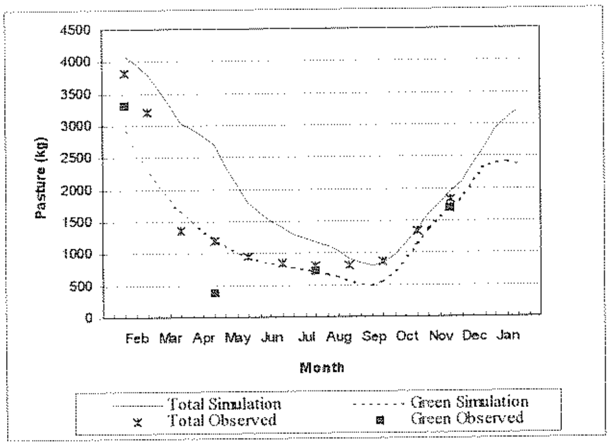

Figure 11: 1986 Simulation of Pasture from Glen Innes at a Low Stocking Rate

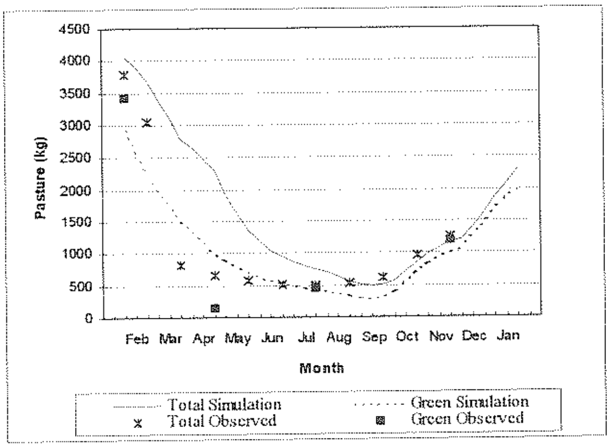

Figure 12: 1986 Simulation of Pasture from Glen Innes at a High Stocking Rate

Figures 11 and 12 indicate that the 1986 total pasture with ModEff of 0.37 for both low and high stocking rates do not validate the model. However, visually the simulation follows a trend with the model predicting the actual values with greater accuracy from August to November.

Lastly Figures 13 and 14 indicate that the 1987 total pasture with ModEff of 0.95 (low) and 0.78 (high) stocking rates validate the model. Visually, the simulation shows a reasonably good fit for total and green pasture.

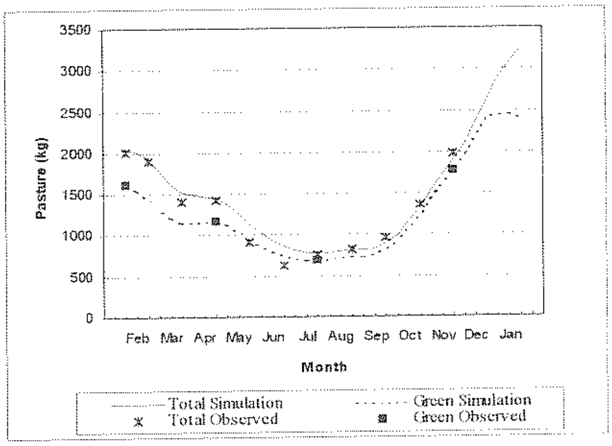

Figure 13: 1987 Simulation of Pasture from Glen Innes at a Low Stocking Rate

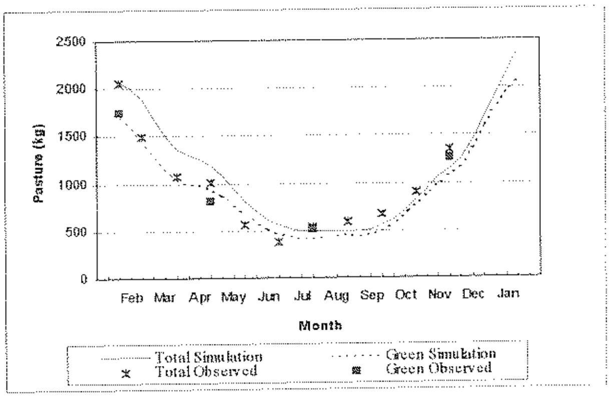

Figure 14: 1987 Simulation of Pasture from Glen Innes at a High Stocking Rate

4.4 Live Weights

The body weights (including fleece) for 1985 (Figure 15) indicate a reasonable fit for the low stocking rate with a ModEff of 0.61 but fails to simulate the high stocking rate with a ModEff of -1.58.

The 1986 data (Figure 16) indicates that the simulation failed to model the low and high stocking rates with ModEff, respectively, 0.21 and -2.74.

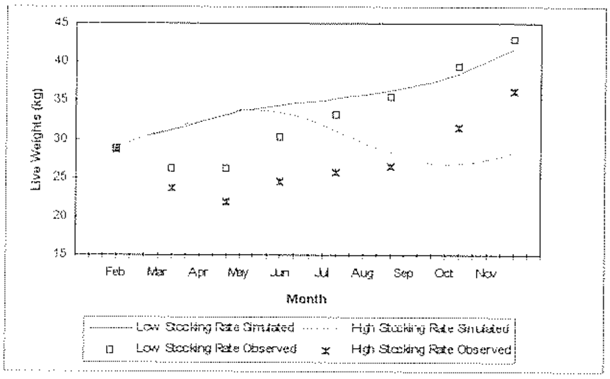

Figure 15: 1985 Simulation of Live Weights at Low and High Stocking Rates from Glen Innes

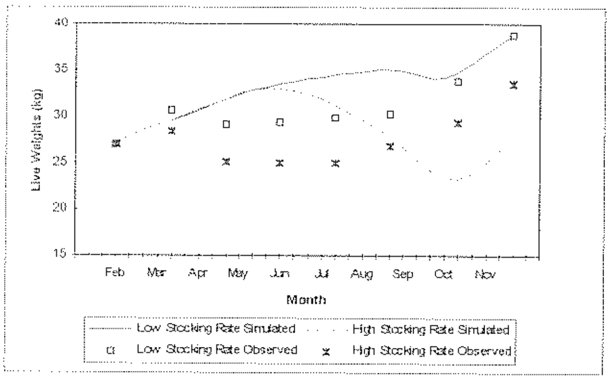

Figure 16: 1986 Simulation of Live Weights at Low and High Stocking Rates from Glen Innes

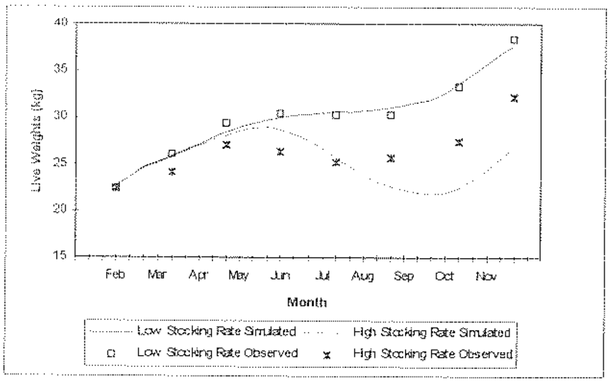

Figure 17: 1987 Simulation of Live Weights at Low and High Stocking Rates from Glen Innes

Lastly, the 1987 data (Figure 17), indicates an excellent low stocking rate simulation and a poor high stocking rate simulation with ModEff respectively 0.98 and -0.22.

5. DISCUSSION

The simulation of total and green pasture for 1985, 1986 and 1987 overall indicate that the Northern Tablelands regional model is capable of calibrating pasture and production at the low stocking rate. However, the high stocking rate failed to mimic the observed live weights even though the total pasture calibrated for 1985 and 1987. The under prediction of the available green pasture (below 500kg) at the critical period of the year as seen in Figure 14 needs to be addressed. But by inspection the 1987 data (Figure 17) does follow a definite trend.

Associated simulation errors within the model need to be addressed! This could lead to further improvements to the digestibility, shade impact and shoot death models as technology improves and additional data becomes available.

A further complexity exists in the actual live weights of 1985 and 1986 which dropped in March and April. These decreases in weights suggest possible problems due to the health and welfare of the animals.

6. CONCLUSIONS

SheepO's simulation of pasture and sheep production on a Phalaris/White Clover pasture mixture at Armidale 1966/67 and Glenn Innes 1987 have been verified and validated visually and statistically against the observed data. However, due to the complexity of modelling pasture and production the high stocking rate of animal live weights has failed to be statistically validated but generally follows a visual trend during the spring growth.

The regional model for the Northern Tablelands employs similar processes to version 3.0. In order to address regional climate, rainfall and resulting pasture growth patterns, version 4.0 employs models specifically designed to take into account relative soil moisture and the available green pasture in the prediction of shoot death. This biological relationship is used to simulate the available pasture at ten day intervals. The adaption and adoption of relevant mathematical equations has also played a critical role in the development of the water balance, shoot death and green digestibility models.

Simulation of pasture and sheep production on the Northern tablelands has the potential to assist advisers, producers and researchers to investigate the outcome of different management strategies. The "what if" questions that are addressed will enhance and improve the sustainability of the sheep and wool industries of Australia.

7. ACKNOWLEDGMENTS

The assistance of Keith Hutchinson in providing data and expertise in pasture modelling is gratefully acknowledged.

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