

RESEARCH ARTICLE

# Impact of introducing a herb pasture area into a New Zealand sheep and beef hill country farm system: a modeling analysis

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**Abstract** New Zealand is well known for export of meat and dairy products from low cost pastoral systems. These farm systems are continually evolving for increased efficiency, in part through the use of metabolic energy modeling tools by farmers and farm consultants to explore alternative farm system configurations and identify new efficiencies. One recent innovation is the introduction of a herb pasture area, such as plantain. We used metabolic energy modeling to quantify seasonal feed flows in two successive years in a New Zealand hill country farm system, and to analyze the impact of the introduction of an area of plantain. Models employed were a self-built Microsoft Excel spreadsheet and a commercial New Zealand farm systems modeling package, FARMAX. Herbage production, animal performance and financial results for a base farm scenario created from the average of survey data for hill farms in the southern North Island, and the same farm with 10% and 20% of the area in plantain for the years 2010–2011 and 2011–2012 were modeled. The self-built model performed similarly to the commercial model. The system configuration of the base farm stockpiles surplus autumn feed for release to animals in winter and also incorporates flexibility that confers resilience to interannual weather variation through varying dates animals are purchased or sold. The introduction of an area of plantain was predicted to increase herbage production, animal performance and financial returns. The predicted benefit was higher for the year 2010–2011 where a drought occurred in summer than for the following year with higher summer rainfall. This demonstrates the profitability of introducing a plantain area to New Zealand hill farm systems, and suggests plantain will assist to mitigate adverse effects of warmer and drier summer conditions associated with current climate change trends.

**Keywords** farm system configuration, herb pasture, metabolic energy budgeting, plantain, sheep and beef farming

## 1 Introduction

Due to its geological isolation, New Zealand has a unique flora and fauna with some very ancient lineages including the ancient fern-like plant *Tmesipteris*, the legged velvet worm *Peripatus* (Onychophora), and the lizard-like Tuatara (Rhynchocephalia). Between 1850 and 1930 much of the original mixed podocarp forest was cleared and sown to pastures comprising typically around 10 grass, herb, and clover species resembling an English meadow<sup>[1]</sup> (Table 1). In hilly topography in the hinterland regions those original pastures remain to the present time, as a common land use, occupying about 80000 km<sup>2</sup> with mixed sheep and beef farming in what are called “hill country farms”. In the lowlands, the original pastures have now been replaced by perennial ryegrass dominant pastures with white clover as a companion species, occupying some 50000 km<sup>2</sup> and commonly used for dairy farming. It is a salutary statistic that about 10000 New Zealand sheep and beef farms produce more than 30% of the world trade in lamb meat while about 10000 dairy farmers produce more than 30% of the world trade in dairy produce.

Given its large land resource per capita, few mineral resources and its geographic distance from other developed countries, New Zealand developed an internationally unique economy where agriculture utilizes the land resource, comprises just 4% of GDP<sup>[2]</sup>, but provides some 45% of earnings from international trade<sup>[3]</sup>. With significant transport costs to move goods from New Zealand several thousand km to markets, farmers have had to evolve low cost production systems in order for their products to be price competitive in their export markets. In these systems, the majority of the feed supplied to animals is pasture grazed *in situ*<sup>[4]</sup>. In recent decades farm costs in New Zealand have risen faster than prices received and

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**Table 1** Botanical composition of a typical early 20th century New Zealand pasture taken from a study by Levy and Madden<sup>[1]</sup>

Species sown	Percentage in seed mixture by number of seeds	Percentage of ground cover 3 years later
Browntop ( <i>Agrostis capillaris</i> )	7	39
Crested dogstail ( <i>Cynosurus cristatus</i> )	14	11
Cocksfoot ( <i>Dactylis glomerata</i> )	28	2
Perennial ryegrass ( <i>Lolium perenne</i> )	21	3
White clover ( <i>Trifolium repens</i> )	7	3
Lotus major ( <i>Lotus pedunculatus</i> )	4	21
Danthonia ( <i>Rytidosperma pilosum</i> )	11	11
Subterranean clover ( <i>Trifolium subterraneum</i> )	2	2
Kentucky bluegrass ( <i>Poa pratensis</i> )	4	2
Chewing's fescue ( <i>Festuca rubra</i> )	4	1

Note: Data were collected using a point sampling technique.

New Zealand farmers have needed to continually evolve their farm system configuration to find new production efficiencies in order to survive economically. It has been necessary to refine the tactical management of the grazing systems to be buffered against variable pasture growth arising from interannual temperature and rainfall variation. Farmers seek to optimize utilization by animals of the feed grown through an emphasis on matching pasture supply to animal demand and, and to optimize conversion to animal product of the metabolic energy derived by animals from that feed.

Central to the ongoing evolution of farm system configuration in New Zealand, but with parallel developments in Australia, has been the development in the past 30 years of metabolic energy modeling (feed budgeting) as a tool in farm system planning. Curiously, while now a core part of the curriculum for students at Australasian agricultural universities, the scientific knowledge about feed budgeting is largely held in confidence by commercial software developers or farm consultants and comparatively few publications in the international literature explore the application of metabolic energy budgeting to farm system optimization or understanding of animal grazing systems. After first using a pasture growth prediction model and historic weather data to evaluate interannual, weather-related variation in feed supply as background to the project, here we: (1) use a self-built metabolic energy model constructed in Microsoft Excel to calculate animal feed requirements in monthly time steps of a typical present-day New Zealand hill farm system, (2) use a commercial farm systems optimization package, FARMAX<sup>[5]</sup>, widely used in farm extension circles in New Zealand, to validate the accuracy of the self-built model results; and (3) we evaluate the impact on the system feed supply and animal carrying capacity of converting 10% or 20% of the farm area to a plantain-based (*Plantago lanceolata*) herb pasture. We also use FARMAX to assess the economic advantage to the farmer of adding plantain to the base system. In conducting this

work we aimed to provide a quantitative insight to seasonal feed supply and demand patterns of a typical New Zealand hill farm system and test hypotheses (1) that system performance as measured by efficiency of conversion of herbage dry matter to meat could be improved by the inclusion of an area of herb pasture in a typical system, and (2) that the self-built farm system metabolic energy model would perform similarly to the commercial FARMAX software.

## 2 Materials and methods

### 2.1 Data sources

#### 2.1.1 Assessing interannual variability in feed supply

To understand interannual variability in feed supply for the farm systems to be modeled, the monthly total rainfall and mean temperature data from July 2001 to June 2016 were obtained from the National Institute of Water and Atmospheric Research of New Zealand (NIWA) online service (The National Climate Database) for a Palmerston North electronic weather station (40°22'55" S, 175°36'33" E; agent number 21963). These weather data were used to calculate the monthly mean pasture growth rates for the 15 years (July–June) 2001–2002 to 2015–2016 with a model named GROW, written, described and validated by Butler et al.<sup>[6]</sup>. Along with temperature and rainfall data, GROW uses information on soil texture and depth to infer soil water holding capacity to compile a water balance, and also considers factors such as soil fertility and pasture species composition, to estimate annual herbage accumulation in two-weekly time steps. Key input settings specific to our study were: Olsen P (10 mg·kg<sup>-1</sup>), slope (easy hill), and pasture species (ryegrass, white clover and browntop). From the weather data provided, GROW computes a potential herbage accumulation rate based on climate data, and an estimated net herbage accumulation rate that allows

for an assumed, seasonally variable, leaf and stem senescence, and the impact of defoliation on herbage accumulation.

### 2.1.2 Source of farm data for model input

Government support for an agricultural extension service in New Zealand was withdrawn in the late 1980s, as part of a program of economic reform that resulted in elimination of subsidies and exposure of the agricultural sector to open market forces. Since that time, farm advisory services have been provided through a network of private consultancy practices and partly through an industry extension organization funded by levies on farm produce. The relevant sheep and beef industry organization is currently branded as Beef + Lamb New Zealand. One of the functions they perform is collection of statistical data through annual farm surveys in the southern North Island. For this study, they provided five years of farm average data for the five farming seasons 2009–2010 to 2013–2014. Data were for their Class 4 farm group. Farms in this group typically carry 7–13 sheep stock units per hectare, and have a topography and soil fertility intermediate between Class 3 (steep hill country adjacent to mountain ranges) and rolling down land at the edge of alluvial plains associated with major rivers. A high proportion of animals sold are at or near a weight suitable for slaughter, referred to locally in New Zealand as being in prime or forward store condition. The number of farms surveyed was between 27 and 31 depending on the year. Data extracted from the surveys and used as model inputs are provided in the supplementary materials (Table S1). A scenario representing a base farm typical of recent practice was developed for the years 2010–2011 and 2011–2012. The primary reason for selecting these two seasons was that few farmers had herb pastures at that time, whereas if more recent data from the last 3–4 years had been used, the survey data would reflect adoption of plantain by some farmers. The chosen years also represent contrasting weather patterns with late spring/summer of 2010–2011 having much lower rainfall than summer of 2011–2012

(256 mm and 534 mm October to February, respectively). Small numbers of deer recorded in the average farm survey data were excluded from the base farm scenario, as most farms do not have any deer, and the sheep and beef numbers (on a stock unit basis) were proportionately increased to compensate.

## 2.2 Models used and modeling methodology

### 2.2.1 Microsoft Excel model of farm system metabolic energy: origin and structure

The modeling methodology has evolved at Massey University over 15 years<sup>[7]</sup> and uses a Microsoft Excel® template, adapted by the authors for the project from one currently provided to third year agriculture students for use in class projects. Equations used to calculate metabolic energy needs of animals are based on those widely used in the industry<sup>[8,9]</sup> (Table 2). The model uses a monthly time step and the primary output is total animal feed demand for the farm ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1}$  dry matter (DM)). The feed supply may be either inferred as equal to feed demand (with relevant correction for factors such as supplements fed), or as in this study obtained from another source (in this case the GROW model) and used to predict the trajectory through the year of average pasture herbage mass, called ‘pasture cover’ in this paper following common farmer vocabulary in New Zealand. The Microsoft Excel template makes separate calculations of daily feed intake ( $\text{kg DM}$  per head per day) for each class of animal on the farm based on MJ daily requirement and presumed metabolic energy value (ME,  $\text{MJ} \cdot \text{kg}^{-1}$  DM) of the feed. Calculations for the various animal classes are then brought together on a linked overview worksheet which evaluates the whole farm totals. Totals are adjusted for supplementary feed used through a linked supplements worksheet. Daily metabolic energy demand of animals was obtained by separately calculating and summing the energy requirement for body maintenance inclusive of walking, the energy cost of weight gain (or feed saving associated with weight loss), pregnancy, and lactation (including grass

**Table 2** Equations used in the self-built model to calculate the daily metabolic energy needs of sheep and cattle, and their source or logical rationale

Process	Equation	Reference
Maintenance	$\text{ME}_m = 0.55 \times \text{LW}^{0.75}$	[7,8]
Walking	Walking (w) represents about 10% of maintenance: $\text{ME}_m + w = 0.6 \times \text{LW}^{0.75}$	Assumed by the self-built model
Weight change	Gain: $\text{ME}_g = \text{LWG} \times \text{CLWC}$ Loss: $\text{ME}_{\text{loss}} = 0.5 \times \text{LWG} \times \text{CLWC}$	[8]
Pregnancy	$\text{ME}_p = 0.55 \times \text{CW}^{0.75} + 30 \times \text{CWG}$	Assumed by the self-built model, considering the conceptus as a small animal independent of the mother
Lactation	$\text{ME}_{\text{lact}}$ taken as equal to the energy needs of the lamb, calculated based on body maintenance and weight gain, as above	Assumed by the self-built model, representing both milk and grass eaten by offspring

Note: LW = live weight (i.e., animal bodyweight); LWG = live weight change; CLWC = cost of live weight change ( $\text{MJ} \cdot \text{d}^{-1}$ , negative, indicating a feed saving when the animal is losing weight,  $30 \text{ MJ} \cdot \text{kg}^{-1}$  LWG assumed for conceptus and lamb weight gains,  $40 \text{ MJ} \cdot \text{kg}^{-1}$  LWG assumed for hogget and weaner cattle LWG,  $45 \text{ MJ} \cdot \text{kg}^{-1}$  assumed for ewe LWG,  $50 \text{ MJ} \cdot \text{kg}^{-1}$  assumed for beef cow and steer LWG); CW = conceptus weight; CWG = conceptus weight gain.

consumed by offspring) (Table 2). The daily feed demand of each animal is then calculated as the daily energy demand per animal divided by the pasture ME. Daily feed demand per animal multiplied by the number of animals per hectare gives  $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1}$  DM for each animal class, and summation of feed demand for the various animal classes gives the total animal demand for the farm system. The model is available in the supplementary information online.

**Pasture cover:** pasture cover is stockpiled and used in New Zealand farm systems to buffer temporary discrepancies between food requirements of animals and pasture herbage accumulation, for example to augment feed supply in winter. The model carries forward feed surpluses and deficits from month to month as change in farm average pasture cover. Pasture cover trajectories with time are not reported in this paper but were inspected by the authors to ensure that model outputs would have credibility to a practicing farmer. With respect to nutritive value of pasture: for this modeling exercise we adopted pasture ME values reported by Machado et al.<sup>[10]</sup>, measured for 15-year-old pastures in a hill country bull farm. Those values (Table S2) are considered by the authors to be representative of those for the hill country farms on which the base farm scenario was based. In farm systems, use of land for hay or silage making, or a crop increases the stocking rate on the remaining pasture area. The self-built model was configured to reflect the reality applicable to the pasture component of the farm system by altering the stocking rate each month (head per hectare) based on the pasture area available for grazing in that month. Farm areas reported in the survey data as allocated to ‘summer feed’, ‘winter feed’ or ‘new grass’ were thus deducted from the farm total area in relevant months to obtain an estimated grazed pasture area for the purposes of calculating stocking rate and growth rate of the grazed pastures. A small number of farms in the survey already had herb pastures in the base scenario years of 2010–2012, but this herb pasture area was not separately included in the survey data so was estimated for modeling purposes as:

$$\text{Herb pasture} = \text{Summer crops} + \text{Winter crops} - \text{New grass}.$$

## 2.2.2 Modeling introduction of herb pasture to the farm system

Potential plantain herbage accumulation rates assumed when evaluating the impact of the introduction to the base farm system of an area of plantain pasture were obtained from two sources that were cross-checked: a published experiment that reported yields<sup>[11]</sup> and data from a large New Zealand commercial farming entity, Landcorp, who have more than 1000  $\text{hm}^2$  of plantain pasture. For data from the published experiment<sup>[11]</sup>, the monthly herbage accumulation rate for plantain pasture was expressed as a

factor of that for ryegrass pasture in the same experiment, and that factor applied to modeled pasture growth rate in the base scenario. The Landcorp data included numbers of animals per hectare of plantain pasture, their estimated weights, the average feed intake per day and the utilization of the plantain pasture for lambs and calves. From those data, a model similar to that outlined in Table 2 was constructed to derive herbage consumed in  $\text{kg} \cdot \text{hm}^{-2}$  DM on a monthly basis. The herbage ME values for plantain (Table S2) were deduced by combining information from several sources, including values used by Landcorp, values published in the literature<sup>[12–16]</sup>, and expert opinion from a professional farm consultant (T. Rhodes, Personal communication). Key points are that after assessing the data, plantain was assumed to produce about 50% more herbage per annum than existing pasture, but with lower productivity than existing pasture in winter and with superior herbage ME, compared to existing pasture, particularly in late summer.

To model the impact of an introduced area of plantain on the farm system, the plantain was effectively treated as a supplement contributing metabolizable energy to carry more stock on the grazed pasture area, but the whole farm performance for comparison with the existing farm systems was evaluated as coming from the combined pasture including the plantain area. After additional feed supply and herbage ME from introduction of plantain were included in the model, stock numbers were adjusted. Two types of changes were evaluated: keeping the animals on-farm longer to obtain a heavier carcass at slaughter or buying more animals to consume the additional feed available.

## 2.2.3 The FARMAX model

FARMAX is one of the most commonly used commercial farm systems software packages available to New Zealand farmers and farm consultants. The company website provides descriptive documents<sup>[5]</sup>. FARMAX is a development of an earlier package, STOCKPOL<sup>[4,17]</sup>. FARMAX calculates animal feed requirement in a manner similar to that described in Table 2, and also reports an annual cycle in monthly time steps, but is unusual among farm systems models in also calculating a farm average pasture cover trajectory for farm system details that have been entered, and declaring if the proposed system is feasible or infeasible. This step requires modeling of leaf death in a sward prior to grazing. Pasture growth rate data may be entered and the cover trajectory calculated for the specified stocking scenario, or vice versa. In this study FARMAX was used in two ways. The first was as an independent validation of the Microsoft Excel model with potential pasture growth data from the GROW model used as input to FARMAX, to check average farm data used in the Microsoft Excel model were feasible in FARMAX. The



second was to extend the Microsoft Excel model output to evaluate the financial gains from adding plantain pasture to the base system. The cost of plantain introduction assumed in these calculations was 3000 NZD·hm<sup>-2</sup>, which would include both the establishment of the plantain from pasture, and the cost of re-establishing new conventional pasture at the end of the production life of the plantain.

#### 2.2.4 Comparison between Excel and FARMAX

Before the analysis of the impact of introducing herb pasture on the feed supply and financial performance of the existing system was evaluated, the pasture supply, total supply and total demand per hectare (effective area) were compared and the percentage difference between the FARMAX and Excel models determined to ascertain equivalence. The calculation of pasture supply includes a loss arising from senescence in both models, although calculated differently. FARMAX calculates the senescence from unpublished algorithms based on farm cover and seasonal factors. In the Excel model, senescence was included, when GROW data were used to define feed supply, by using the estimated net growth data from GROW, and additionally by developing an equation to provide for partial loss by senescence in the event of uneaten herbage mass being accumulated as increased farm cover. To test whether these and other differences between the FARMAX and Excel models resulted in differing model behavior, the outputs from both models for the same input data were compared. Given that the FARMAX model can be considered to be validated by wide industry use and acceptance, this comparison provides an assessment of whether the self-built model is accurate and can reasonably be used in farm extension research and practice, and specifically for evaluation of system changes such as the inclusion of a herb pasture area in a typical farm.

#### 2.2.5 Impact of herb pasture

The impact analysis on the farm system of introducing herb pasture was conducted by comparing the total herbage production and total animal feed demand, calculated using the Microsoft Excel model, for the base system and the system with 10% or 20% of the area as plantain, and then using the FARMAX model to estimate the meat production per hectare, the intake per kilogram of product and the farm profit per hectare and per stock unit. The prices used in the calculations for values per kilogram of meat and wool, varied on a monthly basis according to typical seasonal patterns, and were provided by FARMAX Ltd. as a part of their customer service for their software package. Seasonal variation in price per kilo received by farmers for lamb and steer carcass (the two principal outputs of the model farm) are shown in the supplementary materials (Fig. S1).

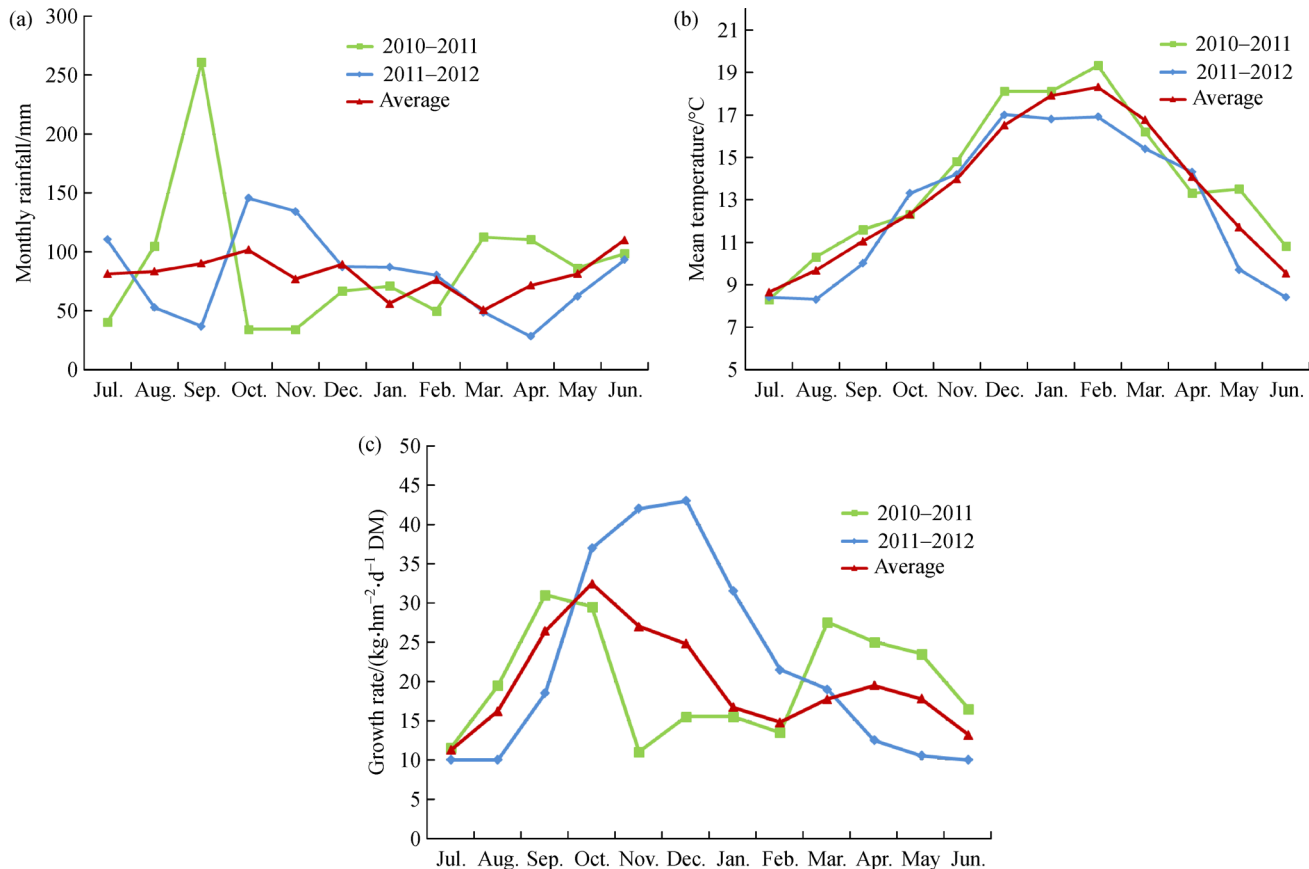
## 3 Results

### 3.1 Interannual variation in feed supply

Modeling of seasonal herbage accumulation for the 15 years from 2001 to 2016 revealed that these farm systems face very large interannual variation in seasonal feed supply pattern (Fig. S2). For the 15-year period for which pasture herbage accumulation rate was simulated in GROW, rainfall averaged 81 mm/month with no strong seasonality but ranged unpredictably from less than 20 mm ( $n = 6$ ) to over 200 mm ( $n = 4$ ) in any one month (Fig. 1a). Meanwhile, temperature followed a sinusoidal curve with a mean maximum of 18.3°C in February and a mean minimum of 8.6°C in July, and random variation in any one month of  $\pm 3^\circ\text{C}$  around the monthly mean (Fig. 1b). The temperature and rainfall data combine to produce seasonal pasture growth patterns that are comparatively consistent between years in winter (June–July) with a mean value of about 10 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM, and also comparatively consistent in early spring (August and September) but highly variable through the late spring, summer and early autumn months of October to May (Fig. 1c; Fig. S2).

### 3.2 Modeling of industry survey data in Microsoft Excel

The modeling of the industry survey data provides some insight into how operation of farm systems differed in two consecutive years with different weather patterns that led to different farmer behavior. The results obtained from the survey and growth data for 2010–2011 and 2011–2012 seasons are presented in Fig. 2. For both years (Fig. 2a, Fig. 2b), the animal demand was lower in August (15.4 and 15.3 kg·hm<sup>-2</sup>·d<sup>-1</sup>, respectively) and higher in November (25.2 and 26.3 kg·hm<sup>-2</sup>·d<sup>-1</sup>). As seen in Fig. 1c, 2010–2011 began with a higher growth rate than usual, leading to a surplus of pasture supply relative to animal demand (Fig. 2a) in September and October. This surplus permitted storage of cover (Fig. 2a, triangle symbols) and increase in the numbers of trading (purchased) steers. The slow growth in late spring of that season (10.9 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in November), when the needs of the animals were high, resulted in a decline in cover (11.2 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM) to meet animal demand, and led to animals being sold earlier, especially trading cattle and lambs born on-farm. These early sales occurred in January and February, when animals were lighter than normal sale weight. This response by farmers was presumably intended to mitigate the emerging feed deficit and avoid pasture degradation. However, with reduced stock on the farm, the above average growth at the end of the same season (green line, Fig. 2c) created a surplus, allowing those stock that had not already been sold to be kept longer than usual, and also leading to a higher start cover for the next year (1800 kg·hm<sup>-2</sup> DM).



**Fig. 1** Monthly rainfall (mm) (a), mean temperature (°C) (b) and herbage accumulation rate simulated in GROW (kg·hm<sup>-2</sup>·d<sup>-1</sup> DM) (c) for the years (June–July) 2010–2011, 2011–2012 and the average from 2001 to 2016. A full set of curves for each year from 2001 to 2016 is presented in the supplementary materials, Fig. S2.

In 2011–2012, the above average summer growth permitted a comparatively high farm supply with a surplus of 15 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in November and 19.6 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in December (Fig. 2b, Fig. 2d). The farmers were able to keep the animals born on-farm in that year for longer, leading to a higher weight at slaughter, and a higher price to the farmer than if they had been sold earlier. However, a consequence of the above average growth in summer was a loss of herbage through senescence, of 806 kg·hm<sup>-2</sup> DM, that occurred mainly in December and January (Fig. 2b).

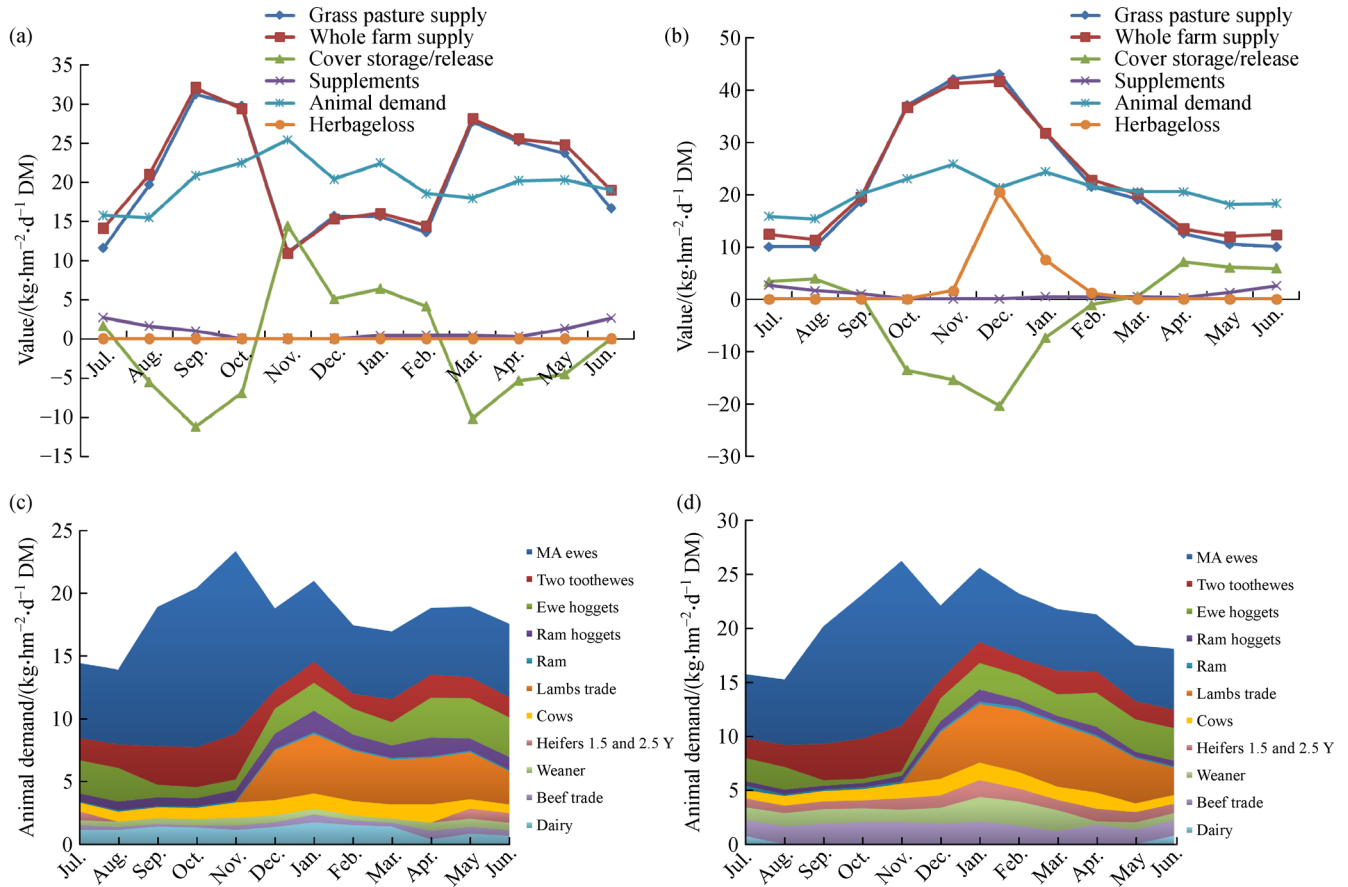
### 3.3 Comparison between Microsoft Excel and FARMAX models

Among the scenarios modeled, the difference between values for pasture supply, total feed supply and animal demand between FARMAX and the Excel model ranged from 0.4% to 4% (Table S3). The calculated pasture supply differed on average between the two models by 2.9%. The total feed supply differed by 1.5% and the animal demand by 1.3% on average. Also, for all scenarios, FARMAX determined the input scenario derived from Beef + Lamb average data as feasible.

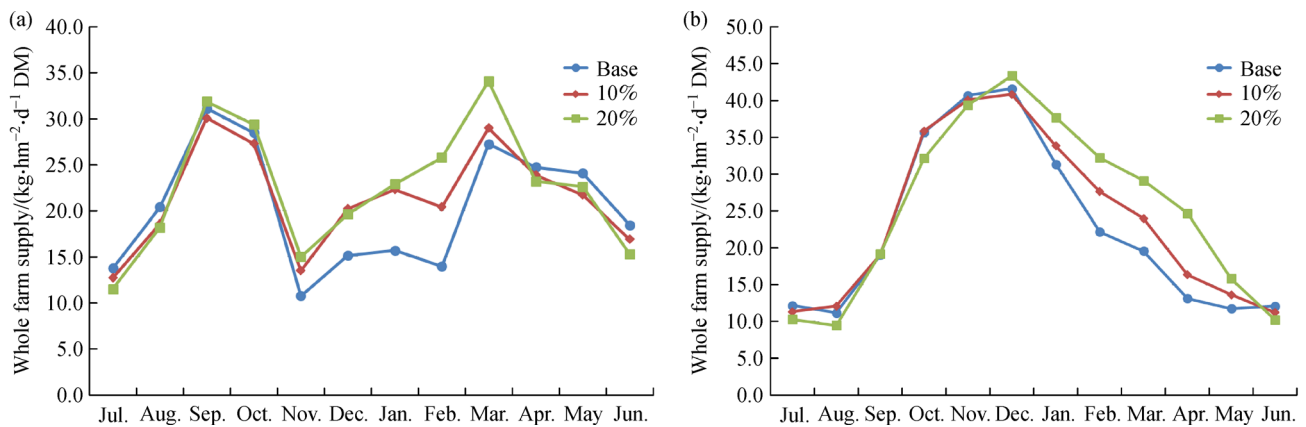
### 3.4 Impact of the introduction of plantain

In 2010–2011, the plantain was mostly grazed from November to March, when the farm supply of the base farm was low (Fig. 3a). The potential increase in feed supply between the base farm and the 10% plantain farm during this period varied from 1.7 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in March to 6.6 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in January. In 2011–2012, most of the plantain was grazed from January to May, when the supply of the base farm started to decrease (Fig. 3b). The potential increase in feed supply for the 10% plantain farm, compared to the base farm during this period varied from 1.9 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in May to 5.4 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM in February. Both years present a lower supply for the 20% plantain scenario than for the base farm, from April to August in 2010–2011 and from June to October in 2011–2012. The maximum difference between the two scenarios was 3.5 kg·hm<sup>-2</sup>·d<sup>-1</sup> DM.

The results of the impact of the introduction of plantain are set out in Table 3. For both years, the presence of plantain was associated with increased total herbage production per hectare, which gave a corresponding increase in animal intake. The 2010–2011 and 2011–



**Fig. 2** Grass pasture supply ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ), whole farm supply ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ), cover storage and release ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ), supplements ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ), animal demand ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ), herbage loss ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ) for the base farm for the years 2010–2011 (a) and 2011–2012 (b), and animal demand for each class ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ) for the base farm in 2010–2011 (c) and 2011–2012 (d).



**Fig. 3** Whole farm supply ( $\text{kg} \cdot \text{hm}^{-2} \cdot \text{d}^{-1} \text{ DM}$ ) for the base scenario and for systems with 10% or 20% of the farm area as plantain, for the years 2010–2011 (a) and 2011–2012 (b)

2012 base models had, respectively, 0.6% and 1.2% of the farm area in plantain. In both years, modeling 10% or 20% of the farm area as plantain resulted in an increase in total herbage production of between 5.0% and 6.2%.

From a financial perspective, for the year 2011–2012, FARMAX reported increased production and profit when comparing the base system and 10% plantain (19.2% more meat produced and 11.8% more profit with 10% plantain);

and a further similar gain (16.7% more meat produced and 11.3% more profit) with further increase in plantain area from 10% to 20% of total farm area. By contrast, for the year 2010–2011 the introduction of the first 10% of the farm area as plantain resulted in a comparatively larger increase in meat production (34.7%) and profit (55.7%), while further increase in plantain had an impact similar to that in the 2011–2012 year (16.1% more meat produced and 6.9% more profit). However, the extra feed resulting from the addition of the first 10% of the farm area as plantain ( $390 \text{ kg} \cdot \text{hm}^{-2} \text{ DM}$ ) was nearly identical to that when plantain area was increased from 10% to 20% ( $389 \text{ kg} \cdot \text{hm}^{-2} \text{ DM}$ ).

## 4 Discussion

### 4.1 Interannual variation in pasture productivity

Data on interannual pasture productivity variation is seldom collected by direct measurement as this involves very high costs, so modeling provides a pragmatic way to understand the feed supply patterns for New Zealand farm systems. The metabolic energy modeling of a typical farm system provides a scientific description of current practice and will also serve to alert the international community of farm systems specialists, both to the operational characteristics of these farm systems, and to the widespread use in New Zealand of metabolic energy budgeting as a key tool in farm systems technology.

### 4.2 Base scenario farm system configuration

Figure 1c illustrates both features consistent across years and the strong interannual variation, represented by the years 2010–2011 and 2011–2012 but also observed for the 15 years from 2001 to 2016 (Fig. S2) with there being no such thing as an ‘average’ year. Importantly, herbage accumulation is not zero in winter, but is sufficient to meet a large part of the animal feed demand. Individual farmers typically configure their system for reduction of animal demand in winter, mainly through sales of offspring from the previous summer. The portion of animal demand in winter not met from winter pasture growth is often met by stockpiling autumn herbage accumulation as increased pasture cover for release to animals in winter months. There is almost always an excess of herbage accumulation over animal demand in late spring and early summer, leading to accumulation of pasture cover at that time also, so that fluctuation in pasture cover in summer can provide a mechanism to help deal with interannual variation in summer herbage accumulation (Fig. 2a, Fig. 2b). Specifically, in this study 2010–2011 was marked by a high growth rate in late spring, but a low growth rate in summer, following lower than average rainfall from October onwards in that year, leading to development of soil

moisture deficit. Rainfall in March and April combined with warmer temperatures than usual in May and June permitted a growth above average in early winter, at the end of the season. In 2011–2012 the rainfall in the late spring and early summer allow a good herbage accumulation through summer.

For both years, the animal demand was set up to have a deficit in winter compensated by a surplus, generally in spring/summer. The reproduction management aimed to combine the lactation peak, in late spring and the weaning in early summer with the herbage production peak allowing increasing animal demand. However, as lambing and calving dates are decisions that have to be made at mating several months earlier, it was not possible to adjust these dates for seasonal weather events, such as the dry summer with a lower supply in 2010–2011, and other mechanisms have to come into play. One of these is variation in patterns of purchase and sale of animals between years in response to interannual variation in herbage accumulation. During a period of surplus, it is possible for farmers to increase the animal demand on the system by buying more stock (but purchase prices may rise if too many farmers join the market), or the feed surplus can be used as an opportunity to grow sale animals to a heavier weight, or stockpile herbage mass for the winter, or alternatively to allow the animals to build body condition or fat tissues that will help them withstand the winter. Conversely, in a summer with lower than average herbage accumulation, sale of offspring may happen earlier, as discussed in Section 3.2. Often summer drought in New Zealand is regionally localized, so when farmers in one region need to sell offspring earlier in summer, there can be opportunistic purchasing by farmers in another region who have had higher rainfall and still have feed.

The herbage loss from senescence reported by the model in 2011–2012 (Section 3.1) is not necessarily an event for farmers to avoid as death and decomposition of ungrazed leaf material helps the longer term soil retention of C and other nutrients. In fact, the absence of herbage loss by senescence in 2010–2011 could be problematic if this were to be ongoing for several years. The base scenario farm system configuration was built from real data, so it is a meaningful representation of the reality for this category of New Zealand farms.

### 4.3 Introduction of plantain

The introduction of plantain in the model is a good example of the type of scenario farmers can test on the computer, using a farm systems model before implementation on their farm. The increased meat production per hectare with plantain pastures on a farm can be attributed to the higher herbage production and to the higher ME of plantain herbage, compared to grass pastures, which leads to an improved conversion efficiency of herbage to meat. The farm profit per stock unit is directly related to the



**Table 3** Results and variation between scenarios for the years 2010–2011

Scenario	Total herbage production /(kg·hm <sup>-2</sup> DM)		Total animal demand /(kg·hm <sup>-2</sup> DM)		Meat production /(kg·hm <sup>-2</sup> )		Intake per kilogram of product (wool + meat)		Farm profit /(NZD·hm <sup>-2</sup> )		Farm profit /(NZD·SU <sup>-1</sup> )	
	Result	Variation	Result	Variation	Result	Variation	Result	Variation	Result	Variation	Result	Variation
2010–2011												
Base	7418		7104		313.04		19.6		409		31	
10% plantain	7808	5.3%	7625	7.3%	421.7	34.7%	16.0	–18.5%	637	55.7%	45.6	47.1%
20% plantain	8197	5.0%	7893	3.5%	489.5	16.1%	14.4	–10.2%	681	6.9%	46.5	2.0%
2011–2012												
Base	8226		7371		384.3		16.4		705		53.8	
10% plantain	8697	5.7%	7826	6.2%	458.2	19.2%	14.8	–9.7%	788	11.8%	56.9	5.8%
20% plantain	9237	6.2%	8334	6.5%	534.6	16.7%	13.9	–6.4%	877	11.3%	58.8	3.3%

Note: SU, sheep stock units.

balance between expenses for and revenue from the stock, and an improved feed conversion efficiency increases revenue at no extra cost, and therefore increases the farm profit per hectare and per stock unit.

As shown in Section 3.1, a big proportion of stock born on-farm was sold early due to the low pasture growth in the dry summer of 2010–2011. Figure 3a shows that the impact of 10% of the farm area in plantain in 2010–2011, was to increase summer supply and reduce deficit in the base model. It then became possible to keep the stock born on-farm, and the profit per stock unit nearly doubled, as did the profit per hectare. By contrast, a further 10% increase in plantain area had a lower impact even though quantity of extra feed generated was identical. This can be explained by considering the time at which the current system configuration allows the extra feed to be consumed by animals. In these model outputs the extra feed from the first 10% of farm area converted to plantain was consumed earlier, during the late lactation and early weaning period, which are key times for farm performance. With the second increment of plantain area there were insufficient animals to consume the additional feed. For this reason, when adding the second 10% increment of plantain pasture area, the modeling solution was to purchase additional animals, which increased the expenses and led to a lower profit increase than in 2010–2011. Keeping more breeding ewes the previous autumn in anticipation of the increased feed supply after introducing plantain may also have been a viable option (not modeled in this study) though this option would have increased pressure on winter feed supply. In 2010–2011, the model indicated plantain would mostly be grazed in late spring and summer (Fig. 3a) because of the reduced herbage accumulation caused by the drought. In 2011–2012, the model indicated the plantain would mostly be grazed in late summer and autumn, when the pasture production is getting lower (Fig. 3b). The feed supply in winter is slightly lower with the addition of plantain. Additionally, the pasture area to support stock on-farm in winter is then smaller, as plantain is usually not grazed

during winter.

The modeling shows a positive impact of plantain, which corresponds to data from research experiments and farmer experience. With either 10% or 20% of the farm area, the addition of plantain leads to improved production and financial results. The benefit is even higher when there is a low herbage production in summer leading to a supply/demand deficit, as plantain can reduce losses of potential earnings in these cases. It was assumed in this modeling that plantain still retains the proportionate production advantage over existing pasture in case of drought. This assumption is supported by Cavers et al.<sup>[18]</sup>, who considered plantain to be resistant to dry conditions, and by other studies of plantain pasture performance, including in situations of drought<sup>[19,20]</sup>.

Some studies have reported low ME for plantain in summer<sup>[12,15]</sup>, which could decrease animal performance. Plantain needs to be well managed to avoid a loss of quality in spring and summer, as large numbers of inflorescences are produced on unbranched stems of 2–3 mm diameter and these lignify on maturity, so that accumulation of ungrazed flowering stems can seriously reduce herbage ME. The grazing management needs to assure a good yield of the plantain while minimizing the proportion of accumulated stem in summer. Timing and intensity of defoliation therefore needs to be carefully regulated to suppress stem accumulation without compromising yield, and so obtain the best results from plantain<sup>[19,21]</sup>. Another problem with plantain is a risk of low herbage crude protein content in early spring. For example, one study<sup>[13]</sup> reported a dry matter crude protein level of 9.1%, lower than ryegrass (12.9%) and chicory (12.7%).

The cost of plantain introduction assumed in these calculations was 3000 NZD·hm<sup>-2</sup>, which would include the cost of re-establishing standard pasture at the end of the production life of the plantain. The cost of plantain seed is about 15 NZD·kg<sup>-1</sup> and the recommended seed sowing rate is from 8 to 14 kg·hm<sup>-2</sup>. Plantain can be sown with or

without clover. Hence, the cost of seed alone in plantain establishment is from 124 to 214 NZD·hm<sup>-2</sup>. Both a farmer informant and the industry expert who provided advice indicated a typical total cost to establish plantain of 650–1000 NZD·hm<sup>-2</sup>. This cost is lower than that used in the modeling calculations, which means that potential profit increase from plantain is conservatively estimated in our study.

#### 4.4 Performance of the Excel model

The fact that annual herbage accumulation modeled by GROW fitted well with the animal demand calculated from metabolic energy modeling of farm survey data for an average farm in the Excel model, and was also declared as feasible by the FARMAX model, is noteworthy, since each of these three evaluations was independent of the other two. The agreement between the Excel and FARMAX models confirms an earlier result<sup>[7]</sup>, obtained using another well-known New Zealand modeling program, Overseer<sup>TM</sup>, used for nutrient budgeting when planning fertilizer application. In that study also, most of the results for a Microsoft Excel farm system model and the proprietary software agreed within 5%. This proves consistency in performance of self-built farm system metabolic energy models using Microsoft Excel, and shows that it is not necessary to purchase commercial software to use metabolic energy budgeting successfully in optimizing farm system configuration in a consultancy context, or in other applications where there is an interest in knowing the energy or herbage yield of a grazing system. This point has also been confirmed by Massey University students and academics on at least 20 individual farms over the past 15 years with good correspondence between on-farm observations and outputs of the model. This type of modeling is particularly powerful for evaluating the impact of change to a base system as distinct from predicting the absolute output of a system. The fact that the feed quantity that was eaten by animals in a given system can be recovered with comparative accuracy by metabolic energy budgeting from data on animal numbers and weights, is what makes this methodology particularly powerful. Compiling a self-built model in Excel allows final-year university students to understand how farm systems work and the implications of alternative farm system configurations. In this way students gain insight equivalent to farmer experience accumulated over a number of years farming. We are also finding that the results from this farm systems modeling methodology integrate the total energy offtake by animals in a grazing system, and so provide a sensitive barometer of system energy yield, even detecting climate change impacts on the system from historic farm system records<sup>[22,23]</sup>. Comparable herbage intake estimates by alternative methods such as alkane dosing<sup>[24]</sup> is resource intensive and costly. The Excel methodology also gives flexibility for the users to configure the equations they need

for their purpose and a better understanding of the farm system than a commercial program which is typically operated with little awareness of its internal equations.

## 5 Conclusions

- Modeling of seasonal herbage accumulation in GROW highlights quantitatively what has been generally recognized, that New Zealand pastoral systems need to be resilient as there is a large interannual variation in feed supply.
- Metabolic energy budgeting of an “average farm” system in Microsoft Excel shows that stocking rate is set conservatively with a deficit in winter of about 300–500 kg·hm<sup>-2</sup> DM and a larger surplus in late spring and early summer. Comparison of consecutive years with contrasting summer rainfall shows buffering of interannual variation in feed supply is achieved through tactical management practices such as variation in sale dates from season to season, and manipulation of animal bodyweight.
- The introduction of plantain permits an increase in animal production per hectare sufficient to recover the cost of sowing and increase the profit per hectare.
- The benefit of plantain is potentially higher in seasons when growth rates of existing pasture are reduced by moderate water deficit.

**Supplementary materials** The online version of this article at <https://doi.org/10.15302/J-FASE-2018202> contains supplementary materials (Tables S1–S3; Figs. S1–S2).

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