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Using a Whole Farm Model to explore options for feed grown on-farm to achieve 1750 kg milksolids per hectare in the Waikato

P.C. BEUKES, C.E.F. CLARK, M.E. WASTNEY, C.C. PALLISER, G. LEVY, C. FOLKERS[1], J.A.S. LANCASTER, C. LEYDON-DAVIS AND B.S. THORROLD

Dexcel, Private Bag 3221, Hamilton, New Zealand

ABSTRACT

Dexcel's Whole Farm Model (WFM) is a computer model of a dairy farm that simulates individual cows and paddocks, with pasture growth driven by observed climate data and with management policies guiding decisions on a daily basis. The aim of the study was to design a farm system to produce 1750 kg milksolids (MS)/ha/yr from feed grown on-farm. An average predicted pasture growth curve was derived by initialising the WFM for a typical all-pasture Waikato farm (3 cows/ha) with "best practice" management policies and running the simulation for 29 years of Ruakura climate data. The model was then used with this average growth curve to design the high producing system. Pasture growth alone (17.3 t DM/ha) did not fulfil the feed requirement for the 1750 kg MS/ha scenario, with an overall feed deficit of 3.1 t DM pasture/ha. Improvements in ryegrass cultivars and N-fertilisers could be expected to increase pasture production by around 10%, reducing the overall feed deficit to 1.6 t DM pasture/ha. These improvements together with irrigation at 2 mm/day over the three summer months (Dec - Feb) reduced the feed deficit to zero. Irrigation could be replaced by cropping between 11% and 20% of the farm in a rotation of annual ryegrass yielding 7 t DM/ha and maize yielding 22 to 28 t DM/ha respectively.

Keywords: cropping; irrigation; pasture yield; farm system; high production.

INTRODUCTION

The drive to increase productivity in the New Zealand dairy industry is becoming increasingly linked to growing more feed of better quality on a given land area. In this respect, recent studies conducted by Dexcel at Scott farm, Hamilton (Resource Efficient Dairying (RED) trial) investigated future farm systems for sustainable high milk production. The cows in the RED trial achieved a production of 1443 kg milksolids (MS)/total[2] ha on an irrigated farmlet when supplemented with 10 t DM maize silage/ha/yr (Jensen *et al.*, 2005b). Given that top farmers are currently achieving these levels of MS production/total ha (C. Glassey, pers. comm.), new, higher ‘stretched’ targets are required for the future. In this respect, the strategic framework for dairy farming’s future 2005-2015 (J. Caradus, unpublished report) suggests a target of 20 t DM/ha harvested as forage, converted to milksolids at a conversion efficiency of 90 kg MS/t DM equating to 1800 kg MS/ha. Considering inefficiencies of harvesting and feed-out losses, the farm will have to consistently produce forage yields above 22 t DM/ha, which has been shown to be possible for the Waikato region (Jensen *et al.*, 2005a), but is more the exception than the rule.

Feed pinches develop in late winter and early spring as a result of slow pasture growth due to lower temperatures, and also in late summer and early autumn because of high temperatures and soil moisture deficit (Clark *et al.*, 2001). Modern ryegrass cultivars with improved cool season growth potential (Easton *et al.*, 2002), boosted pasture growth from fertiliser technologies (Smith *et al.*, 2005) and summer irrigation are options to increase pasture yields. Increases in pasture yield alone may not be sufficent to fill feed gaps resulting from demands from high producing herds, and supplementing pasture with crops may be required. A number of annual crops have the potential to increase forage production on-farm by complementing the rapid growth of ryegrass in spring and early summer (Clark *et al.*, 2001), but there are questions regarding the effects of cropping on the rest of the farm, crop yield, and the area of crop grown.

This paper evaluates options of feed grown on-farm to achieve 1750 kg MS/ha. All these options involve interactions between climate, pasture, cows and management decisions. The aim of this paper was to use a farm model, set-up for the Waikato region and representing these interactions, to derive some principles for the high producing, self-contained dairy farm of the future.

[1]Agricultural Software Limited, 47C Poplar lane RD4, Hamilton

[2]Total ha includes the area external to the farm that was required to grow the amount of supplements fed to cows.

METHODS

The Whole Farm Model (WFM) is a VisualAge Smalltalk (IBM) framework, linking sub-models of pasture growth (McCall & Bishop-Hurley, 2003) and cow metabolism (Baldwin, 1995) written in different programming languages, and designed to simulate the complex interactions of climate, pasture, animals and management on a dairy farm. The model was specifically designed to extend farmlet trial results and to simulate trial designs before implementation, and has been tested extensively against observed data from farmlet trials and commercial farms (Beukes *et al*., 2004; Beukes *et al*., 2005a; Beukes *et al*., 2005b). For this exercise, WFM version 9.9.9.8 was used and modelling was completed in three steps:

1) determining an average pasture growth curve for a Waikato farm,

2) modelling a farm with high milk production targets and with the average pasture growth curve in place, to explore options for merging ryegrass and fertiliser technologies and irrigation into the system, and

3) modelling a high production farm with ryegrass and fertiliser technologies together with a cropping rotation of annual ryegrass/maize with different maize yields (low, average, high) to explore the relationships between yield, cropping area and feed deficits.

1) Determining an average pasture growth curve for a Waikato farm

Observed animal and paddock data from the RED trial (Jensen *et al.*, 2005b) for the 2002/03 season were used to initialize the model for an all-pasture farm with no irrigation, 170 kg N/ha and "best practice" management policies (Macdonald & Penno, 1998), stocked at 3 Friesians/ha. The simulated farm was 6 ha (12 paddocks of 0.5 ha each) with average cover starting at 2100 kg DM/ha on 1 June. Pasture growth in the model was driven by observed weather data (daily rainfall, radiation, temperature, evaporation) and was also affected by grazing and conservation policies. For this part of the exercise, 29 years (1974/75 to 2003/04) of observed data were obtained from Ruakura weather station (supplied by NIWA) and the "best practice" Waikato farm was simulated for the 29 climate years. For every year, monthly pasture growths (kg DM/ha/day) were predicted and these values were used to obtain average monthly pasture growth rates over 29 years. A climate year was then synthesised, using daily climate data from different years, which interacted with the "best practice" Waikato farm scenario to produce the best approximation of the average pasture growth curve.

2) Modelling on-farm feed growing options

For the "benchmark" scenario, the "best practice" Waikato farm was altered so that the number of paddocks was doubled and the area of each halved to obtain a better resolution in terms of the proportion of the farm being used for cropping (24 paddocks of 0.25 ha each, totalling 6 ha). The average farm cover at the start of the simulations on 1 June was 2100 kg DM/ha. The farm was stocked at 3.5 cows/ha (470 kg live weight/cow at start of simulation on 1 June; condition score at start of simulation = 5.0). The herd calved over 10 weeks after 1 July and cows were milked for an average of 295 days/cow. Cows had the genetic potential (PVmilk = 700 L) to produce 500 kg MS/cow/yr when fully fed on pasture, giving the potential for the farm to produce 1750 kg MS/ha/yr. This "benchmark" scenario was modelled with the synthesised climate year and started with an empty grass silage feed store (a first run of the "benchmark" showed no grass silage to carry forward) and an unlimited maize grain feed store (13.6 MJ ME/kg DM) in order to determine the size and timing of any feed deficit. The feeding policy was set so that cows were fed pasture first, according to the paddock break size and pasture residual policies. Then, if there was a feed deficit, cows were fed from the grass silage feed store if available (silage was added to this feed store according to a conservation policy that accounted for a total ensiling and feed-out loss of 25%). If there was still a feed deficit after feeding pasture and silage (if available), cows were fed from the maize grain store up to demand. In this way the farm always achieved the production target of 1750 kg MS/ha because of the unlimited maize grain available. The "benchmark" scenario was then altered by growing more feed on-farm with the aim of reducing the amount of maize grain (from an off-farm source) used to zero. Alterations to the "benchmark" were developed as follows:

a). It was assumed that the high producing farm of the future would use N-leaching inhibitors and types of N-fertilisers that would result in 5% increase in total pasture yield (Smith *et al.*, 2005). This was simulated by altering the N response rates in the benchmark scenario from 7 kg DM/kg N to 12 kg DM/kg N with a total fertiliser application of 170 kg N/ha. It was further assumed that a high producing farm would convert to novel endophyte ryegrass cultivars giving a further 5% increase in pasture yield (Woodfield & Easton, 2004). Since the pasture sub-model cannot represent novel endophyte ryegrass cultivars, an adjustment had to be made to "p-slope", a model parameter that represents inherent soil fertility. By adjusting this parameter upwards, annual pasture yield was increased by approximately 5%. These two adjustments resulted in approximately 10% more pasture yield. This "more pasture" farm formed the basis for the irrigation and cropping scenarios.

b). For the "irrigation" scenario, differing quantites of water were applied to each paddock, from 0.5 up to a maximum of 6 mm/day irrigation water, to determine the pasture growth response for every additional millimeter of water/ha over the summer months (1 December to 28 February). Irrigation water was added to 85, 73 and 105mm of rainfall in December, January and February, respectively in the pasture model. The response of pasture growth to irrigation outside the summer months was also tested.

3) Modelling the relationships between crop yield, cropping area and feed deficits

The cropping policy in the WFM requires the user to specify individual paddocks to be used for cropping, the date a paddock is taken out of rotation, the type of crop grown and yield, date of harvest and whether it is going to be re-grassed and then reintroduced back into the grazing rotation. If it is re-grassed, the pasture model predicts growth and the first grazing depends on the rotation schedule and pasture covers on the rest of the farm. The model currently requires that all crops are harvested and stored (with a user-defined loss factor) from where cows can be fed using the supplement feeding policy (with a user-defined wastage factor). For the "annual ryegrass/maize" scenarios individual paddocks were taken out of rotation for the whole year. Annual ryegrass was sown on 1 April and maize on 20 October. Annual ryegrass was assumed to produce 7 t DM/ha (Clark, 2002) cut for silage of which 2 t DM/ha was available from 9 June, 1.5 t DM/ha from 4 July, 2.0 t DM/ha from 27 August and 1.5 t DM/ha from 30 September to represent the typical availability of this forage. Maize yields were taken from Densley *et al.* (2001) to represent low (17 t DM/ha), average (22 t DM/ha) and high (28 t DM/ha) yields for New Zealand conditions. Maize silage from the crop of the simulated year was made available from 28 March onwards. Ensiling losses and feed-out wastage for annual ryegrass and maize totalled 25%. The "annual ryegrass/maize" scenarios were first run with one paddock (4% of the farm) taken out of rotation for cropping, and thereafter with consecutively more paddocks up to eight (33% of the farm) taken out for cropping. Dry cows and milkers were fed pasture first, followed by annual ryegrass and maize silage. Any further feed deficits were filled with grass silage, if available, followed by maize grain. Each scenario was run twice, first to determine the amount of feed left in the feed stores (annual ryegrass, maize, grass silage) at the end of the year (31 May), the second run started with feed stores set equal to the end feed stores of the first run. Feed deficits/excesses were measured as kg DM pasture equivalents (11.5 MJ ME)/ha required as maize grain to maintain production at the set target of 1750 kg MS/ha. See Table 1 for a summary of model settings.

TABLE 1: Summary of scenario names, aims, user settings for dates and yields of annual ryegrass and maize, feed quality, and predicted yields for pasture.

Scenario	Aim	On-farm feeds	Sowing dates	Harvesting dates	Yield (t DM/ha)	Crude Protein (% DM)	NDF[1] (% DM)	TSC[2] (% DM)	ME (MJ/kg DM)
"best practice"	average pasture supply curve	pasture	N/A	N/A	17.3	23	42	11	10.9
"benchmark"	high production farm	pasture	N/A	N/A	17.5	23	42	11	10.9
"more pasture"	better ryegrass cultivar and fertiliser	pasture	N/A	N/A	19.2	23	42	11	10.9
"irrigation"	extra water	pasture	N/A	N/A	21.6	23	42	11	10.9
"annual ryegrass/maize"	cropping	pasture	N/A	N/A	19.2	23	42	11	10.9
		annual ryegrass	1 Apr	9Jun,4Jul,27 Aug, 30 Sep	7	27	40	19	11.5
		maize	20 Oct	28 Mar	17/22/28	9	46	36	10.5

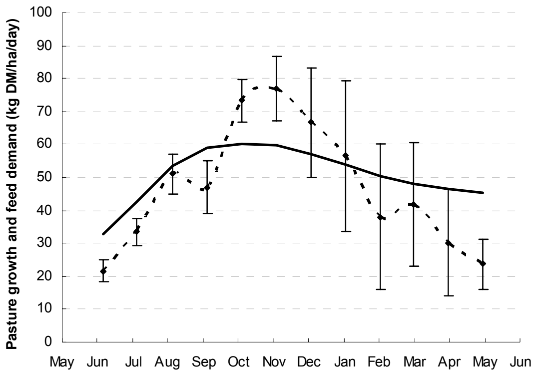
[1] NDF = Neutral Detergent Fibre
[2] TSC = Total Soluble Carbohydrates

RESULTS

1) The average pasture growth curve for a Waikato farm

Monthly pasture growths (Figure 1) showed the smallest variability between years (highest predictability) over winter and spring (June – November). From December to May pasture growth was highly variable (Figure 1). Average annual pasture yield for the 29 climate years was 17.3 t DM/ha/yr with a standard deviation of 1.77. Feed deficits were most likely to occur in the first half of the milking season from June to September and in the second half of the season from February onwards (Figure 1).

FIGURE 1: Average (with standard deviation error bars) pasture growth curve (broken line) for a "best practice" all-pasture Waikato farm, modelled with 29 years of Ruakura climate data. Average predicted feed demand from the high producing herd (cows weighing 470kg and producing 500 kg MS/cow and 1750 kg MS/ha/yr) is also plotted (solid line).



2) On-farm feed growing options

The "benchmark" Waikato farm could not produce enough feed to support 1750 kg MS/ha resulting in an energy deficit equivalent to 2.5 t DM maize grain/ha/yr (Table 2). Improved fertiliser and ryegrass technologies increased production by 1.2 t DM/ha/yr, reducing the feed deficit to 1.3 t DM grain/ha/yr. Predicted annual pasture production was further increased from 19.2 to 21.4 t DM/ha/yr with 2 mm/day (1.8 megalitres of water/ha) irrigation over the summer months (December – February), which was sufficient to reduce maize grain fed to zero. Irrigation over and above 2 mm/day had very little additional impact on pasture production (Table 2). The efficiency of pasture utilisation from grazing decreased with an increase in pasture production as excess pasture growth occurred during peak growth months when cows were already fully fed on pasture.

3) The relationships between crop yield, cropping area and feed deficits

The feed deficit was not eliminated at a maize silage yield of 17 t DM/ha over the range of proportions of the farm explored in this study (Figure 2). At higher yields of 22 and 28 t DM/ha, the breakeven point between feed supply and demand for the high producing farm occurred when approximately 20% and 11% of the farm was cropped, respectively (Figure 2).

FIGURE 2: Predicted feed deficit/excess for the "annual ryegrass/maize" scenarios with different proportions of the farm allocated to cropping and with three levels of maize yield (17 t DM/ha = diamonds; 22 t DM/ha = squares; 28 t DM/ha = triangles). A pasture equivalent is the amount of feed equivalent to 1 kg DM pasture at 11.5 MJ ME.

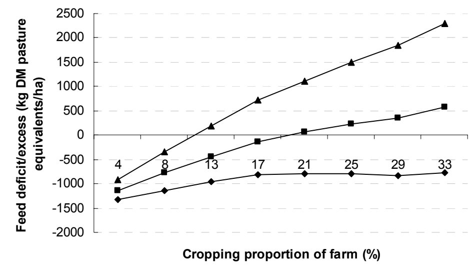


TABLE 2: Predicted results from three modelled scenarios.

Scenario	Irrigation (mm/day)	Pasture production (tDM/ha/yr)	Pasture grazed (tDM/ha/yr)	Silage made (tDM/ha/yr)	Silage fed (tDM/ha/yr)	End farm cover (tDM/ha)	Maize grain fed (tDM/ha/yr)
"benchmark"	N/A	17.5	15.9	0.6	0.6	2.7	2.5
"more pasture"	N/A	19.2	16.8	1.0	1.0	3.0	1.3
"irrigation"	0.5	19.4	16.9	1.0	1.0	3.0	1.2
	1	20.6	17.6	1.3	1.3	3.2	0.4
	2	21.4	17.8	1.7	1.5	3.2	0
	6	21.6	17.7	1.8	1.6	3.2	0

DISCUSSION

Pasture growth alone, given an average Waikato climate year, did not fulfil the feed requirement for the 1750 kg MS/ha scenario. The predicted deficit of 2.5 t DM maize grain/ha with a pasture yield of 17.3 t DM/ha for the "benchmark" scenario can be compared with the results of Macdonald (1999) who reported 5.5 t DM maize grain/ha used on a farmlet with pasture yield estimated at 18.3 t DM/ha and producing 1768 kg MS/ha. No grass silage was made on this farmlet and 0.65 t DM grass silage/ha was fed out. The discrepancy between the farmlet trial and the model prediction can be partly explained by the higher maintenance requirements of the higher stocked farmlet (4.42 cows/ha versus 3.5 cows/ha of the scenario). It also highlighted the efficiency with which the model conserves pasture by predicting 0.6 t DM grass silage/ha made and fed for the above scenario.

Improvements in ryegrass cultivars and nitrogen fertilisers, combined with irrigation over the three summer months (December to February), reduced the feed deficit to zero. The model predicted a higher response to irrigation (2.2 t DM/ha) compared to the 1.1 – 1.9 t DM/ha measured by Thomson (1996) for the Waikato, however, it falls within the range of 0.1 – 2.5 t DM/ha reported by Thom *et al.* (2001) over 4 years. Both workers identified factors that affected response e.g. irrigation amount, soil type, pasture type, grazing residual, rotation length and weather pattern. In this respect, it is clearly a simplification to report one answer for irrigation response in the Waikato, but the results showed that if summer irrigation, under "average" climatic conditions, was added to a strategy that included "best practice" conservation policies with modern ryegrass cultivars and fertiliser technologies, it could be sufficient to supply the feed demands of the high producing farm. The actual implementation of an irrigation strategy requires a full evaluation of feasibility in terms of costs and availability of water.

When a proportion of a farm is used for continuous cropping, grazing pressure increases on the rest of the farm, reducing farm covers and silage making (Thomson *et al.*, 1997), and increasing the demand for supplements during times of slow growth i.e. the pasture "penalty effect". Animals may also show the penalty effect in terms of lower intakes, body condition scores and milksolids production as shown for turnips by Thomson *et al.* (1997), but this was not reflected by the model since animals were always fully fed to achieve the production target of 1750 kg MS/ha. For every extra paddock of 0.25 ha taken out for cropping there was more feed grown on the farm because of the higher total yield of the annual ryegrass/maize crop compared with the base pasture, but there was also an increase in the pasture "penalty effect" because of less pasture silage made and greater demand for supplements during times of slow growth. Feed grown exceeded the "penalty effect" when up to 17% of the farm was used for cropping. When 17% of the farm was used for cropping, the amount of grass silage conserved reached a minimum. With a larger proportion of the farm used for cropping, supplement demand increased drastically, which explains why feed grown and the supplement demand were equal at 17% of the farm and higher, for the 17 t DM/ha maize yield. Feed grown with the higher maize yields (22 and 28 t DM/ha) always exceeded the "penalty effect", and the high producing herd could be fully fed with approximately 20% and 11% respectively of the farm used for annual ryegrass/maize cropping. In this range the amount of grass silage conserved was at its minimum, which implies that grazing of the base pasture was most efficient. Although it is expected that size and number of paddocks, and interactions with paddock usage and conservation decision rules will affect the result, the recommended range of 11% to 20% depending on maize yield is consistent with the figure quoted by Densley *et al.* (2001). They suggested a proportion of 16% of a farm under a continuous cropping programme of Italian ryegrass/maize, with yields of 8 t DM/ha and 25 t DM/ha respectively, will lift the yield from 18 t DM/ha (all grass) to 21.9 t DM/ha over the whole farm. It is also consistent with the findings of Clark *et al.* (2001) who calculated the proportion of the farm in oats/maize crop (22%) that will maximise DM yield and still maintain crude protein intake at an optimal of 16% of the DM eaten.

This analysis can be improved by linking a climate-driven crop model to WFM, and by doing an economic risk analysis (Beukes *et al.*, 2005c) of the strategies explored here.

CONCLUSION

In the Waikato region the average yield of perennial ryegrass/clover pasture is too low and too variable in the second half of the milking season to consistently support the demands of a dairy herd producing 1750 kg MS/ha. This production target may be achieved by a combination of strategies to increase feed production, including modern ryegrass cultivars, fertiliser technologies and irrigation of 2 mm/day during summer. Irrigation may be replaced by cropping between 11% and 20% of the farm in an annual ryegrass/maize rotation with total yields of 29 to 35 t DM/ha. A production target of 1750 kg MS/ha is achievable with current technologies and sound management, but the financial effects of these have not been tested.

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