Forage crop sequences for pastoral systems in northern New Zealand

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Abstract
The feasibility of achieving the dairy industry's target of producing 45 t DM/ha/yr of forage with an average metabolisable energy (ME) value of 11 MJ ME/kg DM was evaluated for the Waikato and Northland regions of New Zealand. Recent productivity gains from pasture-based dairying systems are below that required to meet the industry's target, hence alternative practices that incorporate high yielding high quality crops into pastoral systems are being developed. A cropping sequence experiment was established in the Waikato to determine the practical upper limits of annual DM yield during the transition from old to new pasture from three different sequences of crops over 2 years. Results from experimental work were tested against climate-driven crop models to determine the theoretical upper limits of DM yield in the Waikato and extrapolated limits for Northland. Dry matter yields and nutritive value of forages from each sequence are reported for the first complete year of sequences (2007-2008). The target of 45 t DM/ha/yr was achieved in the field experiment using a sequence of maize followed by a winter oat crop, however, sequences combining summer brassica and winter cereal crops did not meet the target in either the field experiment or simulation study.
Keywords: crop sequence, dairy cow, supplementary forages, maize, brassica, cereal crops, forage yield, nutritive value

Introduction
The New Zealand dairy industry has set a goal to increase farmer profit and create wealth for the New Zealand economy by achieving a 50% gain in productivity by 2015. Luxton (2005) estimated that an annual production increase of 3.6% of high quality forage would be needed to achieve this target; however, recent annual dry matter (DM) yield gains of perennial ryegrass pastures have been below this at between 0.25 and 0.73% (Woodfield 1999). Hence the development of pastoral systems that incorporate high yielding crops is being sought, such as the integration of a cropping sequence into a pasture renewal program. A cropping sequence is defined here as the practice of growing a sequence of different crops in the same area in successive seasons. Cropping sequences have the potential to increase total forage yield by the inclusion of species that are more efficient utilisers of available resources (light, water and nutrients) as radiation and temperature vary throughout the season. Previous studies in Australia have reported annual yields exceeding 40 t DM/ha from forage rotations over consecutive years (Shrestha *et al.* 2006), much greater than the estimated upper annual production limits of perennial ryegrass and white clover pastures of 20 to 24 t DM/ha (Clark *et al.* 2001). Increases in forage yield using crops can buffer seasonal deficits in pasture production which enables the higher stocking rates required to maximise pasture utilisation during peak growth periods (spring) and maintain forage quality (Clark *et al.* 2007). A further advantage of integrating a cropping sequence into a pastoral system is that the nutritive values of various forage crops can complement pastures at critical supply times (Garcia *et al.* 2008), preserve soil properties and act as a break crop to reduce pasture pests during pasture renovation.

The objective of this study was to use complementary experimental and modelling approaches to determine the regional theoretical and practical upper production limits of forage crop sequences, and to examine the feasibility of attaining 45 t DM/ha/yr with 11 MJ ME/kg DM from forage sequences in the Waikato and Northland regions of New Zealand. This paper reports field research results from year one of a 2 year experiment in the Waikato and a modelling studies of Northland and Waikato.

Field experiment
Methods
Experimental site, design and treatments
The experiment was conducted at Scott Farm, DairyNZ, near Hamilton (37°47'S, 175°19'E, 40 m a. s. l.). Monthly rainfall, temperatures, solar radiation and evaporation data are presented in Table 1. Treatment plots (10 x 19 m) were arranged in a randomised complete block design with four replicates on a Te Rapa Humic silt loam soil (Humose orthic podzol). The treatments were three different crop sequences grown over 2 years. Cropping sequences were: maize grown for silage followed by whole crop oats (MO); single-harvest kale followed by whole crop oats (KO); and

Table 1 Rainfall, irrigation (mm), mean daily minimum and maximum temperature (°C), incident radiation (MJ/m²) and evaporation (mm/d) over the experiment period (October 2007- October 2008). 10 year averages are for period 1997-2006. Data from the Ruakura Meteorological Station, 5 km from study site.

	Precipitation (mm)			Temperature (°C)				Solar radiation (MJ/m²)		Evaporation (mm/d)	
Month	Rainfall	Rainfall + irrigation	10-yr average	Min	Max	10-yr Min	10-yr Max	Trial period	Average 2006-2007	Trial period	Average 2006-2007
Oct	94.8	94.8	93.6	8.2	17.6	8.6	18.2	564	700	2.6	2.5
Nov	51.2	51.2	89.0	8.3	20.1	9.8	19.8	622	582	2.7	2.8
Dec	71.8	71.8	107.1	12.3	22.6	12.2	21.7	660	471	3.5	3.4
Jan	4.4	94.4	72.3	13.9	26.7	12.9	23.9	757	347	5.1	3.1
Feb	26.8	116.8	74.8	13.3	24.9	13.2	24.5	591	256	4.1	3.5
Mar	13.6	63.6	69.5	11.4	24.6	11.7	23.4	508	206	3.2	2.8
Apr	125.2	125.2	66.7	9.9	20.5	9.2	20.4	345	215	2.0	1.9
May	87.4	87.4	101.1	3.8	16.6	7.7	17.7	289	290	1.5	1.3
Jun	161.2	161.2	106.8	5.1	14.6	5.3	14.9	200	401	1.2	1.2
Jul	203.8	203.8	128.3	4.5	13.5	4.5	14.3	192	514	1.2	1.3
Aug	181.2	181.2	91.7	5.3	14.3	4.4	14.8	310	599	1.2	1.3
Sept	70.3	70.3	79.8	6.3	16.4	6.6	16.7	429	680	1.6	1.9
Total	1092	1322	1081					5465	5262		

turnips, followed by whole crop forage rape then whole crop triticale (TRT). Choice of species in each sequence was based on considerations of expected yield, forage quality and local climate.

Establishment and management of crops

Soil samples from the study area in July 2007, showed Olsen P levels of 20 µl/ml and pH 5.8. Lime (at 4 t/ha) was applied in mid July 2007. Existing perennial ryegrass and white clover pastures were sprayed with Roundup® Transorb (4 L/ha, glyphosate 540 g a.i./L) plus Pulse® surfactant (200 ml/100 L water) in August 2007. In late September/early October the study area was ploughed, power harrowed and rolled. The first crops in each sequence were all sown on 4 October 2007.

MO sequence: maize (*Zea mays*) (hybrid Pioneer® brand 33J56, CRM 113) was sown using a two row precision planter at a rate of 115,000 seeds/ha. HydroComplex (350 kg/ha; 12.4% N, 5.2% P, 15% K, 8% S) and urea fertilisers (50 kg/ha; 46% N) were applied at sowing, and a further 115 kg N/ha applied during crop growth. Maize was harvested for silage when the crop was near physiological maturity (35 % DM) on 19 March 2008. Oat (*Avena sativa*) (cv. 'Milton') seed was direct-drilled (106 kg/ha) into the harvested area on 3 April 2008. Cropzeal20N fertiliser (200 kg/ha; 19.3% N, 10.1% P, 12% S) was broadcast on to the plots after sowing, and a further 69 kg N (as urea) applied during crop growth.

KO sequence: kale (*Brassica oleracea*) (cv. 'Gruner') seed was sown at 1 cm depth using a Taege drill, in 15 cm row spacing, at 4 kg seed/ha. Diammonium phosphate (300 kg/ha; 18% N, 20% P, 1% S) and boronate (15 kg/ha; 15% boron) were applied the plots before sowing. A further 150 kg N/ha (as urea) was applied in 3 applications during crop growth. A post-emergence spray of Radiate (300 ml/ha, 150 g picloram and 225 g clopyralid a.i./L) with Uptake oil was applied. Pre-emergence pesticide (Diazinon, 1 L/ha, 800 g Diazinon a.i./L) was applied to prevent crop damage by springtails (*Bourletiella spp.*); further applications of pesticide (either Lorsban at 1L/ha, 50 g chlorpyrifos a.i./L; Diazinon, as above, or a combination of Diazinon with Perfekthion at 1 L/ha, 500g dimethoate a.i/L and 549 g cyclohexanone a.i./L) were applied on eight separate occasions in an effort to control white butterfly (*Pieris rapae*) populations. The kale crop was harvested on 19 March 2008 and oats direct-drilled into the plots as for the MO sequence.

TRT sequence: Turnip (*Brassica rapa*) (cv. 'Barkant') seed was sown at 2 kg/ha using a Taege drill. Diammonium phosphate (300 kg/ha) and boronate (15 kg/ha) were drilled into the plots before sowing. Nitrogen fertiliser (100 kg N/ha in total) was applied in two applications during crop growth. A post-emergence spray of Radiate (300 ml/ha) with Uptake oil was applied. Pesticides (Diazinon and Lorsban, each at 1 L/ha) were applied on six occasions to control pest populations. The turnip crop was harvested on 9 January

2008, and forage rape (*Brassica napus*) (cv. 'Titan') seed was direct-drilled at 4 kg/ha on 15 January 2008. Diammonium phosphate (300 kg/ha) and boronate (15 kg/ha) were broadcast over the plots before sowing. 200 kg N (as urea) was applied in two applications during crop growth. Pesticides (Diazinon and Perfekthion, each at 1 L/ha) were applied on six occasions to control pest populations. In May 2008 the forage rape was harvested and Triticale (*x Triticosecale*) (cv. 'Crackerjack') seed direct-drilled (152 kg/ha) 5 days later. Cropzeal20N fertiliser (200 kg/ha) was broadcast on to the plots after sowing, and a further 100 kg N applied during crop growth. Banvel (400 ml/ha, 200 g Dicamba a.i./L) herbicide was applied to control broadleaf weeds. Winter cereals from all three sequences were harvested (cut and carry) on 29 September 2008.

The experiment was irrigated using a travelling irrigator system. Irrigation timing was determined by monitoring of soil moisture using a capacitance based meter (Hydrosense) weekly from late December until April.

Herbage sampling and measurements

Forage yield was assessed monthly in a 3.75, 2 and 1 m^2 sampling area for maize, brassicas and cereals, respectively. All crops were cut to ground level, except maize which was cut to retain a 5 cm stubble, and whole turnip plants were removed by hand. Fresh weight was recorded in the field and a subsample dried for DM determination in a forced-air oven at 95°C. From a second subsample, individual plants were divided into green and dead leaf, stem, seed head or ear before drying. At each crop's final harvest, a third subsample was freeze dried before being ground to pass a 1 mm screen then analysed for indicators of feed quality by near infrared spectroscopy (NIRS). Growth rates of different forages were estimated from the DM yield at sequential harvests. Nitrogen and water use efficiency was calculated by dividing the DM yields by the amount of nitrogen and moisture (rainfall plus irrigation) applied, respectively.

Statistical analyses

Total DM yields were calculated for each sequence by first obtaining the mean yield for each crop and adding them together. Sequence totals were then analysed using analysis of variance (ANOVA) in Genstat 8.1. Calculated annual metabolisable energy (ME) yield was weighted according to DM harvested.

Simulation study

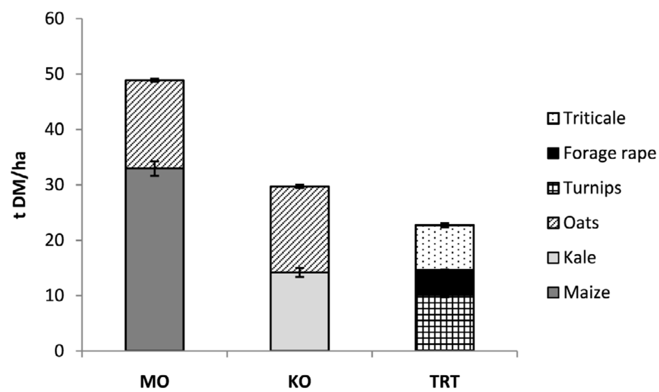
The simulations used the potential yield models of Wilson *et al.* (1995) and Li *et al.* (2006) to simulate the maize crop, the Sirius wheat model (Jamieson *et al.* 1998) to simulate the winter cereal crops, and the forage brassica model of Wilson *et al.* (2004) and Zyskowski *et al.* (2004) to simulate each of the kale, turnip and rape crops. There are no data that specify growth differences between brassica crops, therefore, all brassica crops were simulated as 'Kale'. To extrapolate the results of this experiment to a Northland environment and to understand the growth of the various rotations, the treatments were simulated using the LUCI framework model (Zyskowski *et al.* 2007). Weather data from the Ruakura Meteorological Station (37.8°S, 175.3° E) and Whangarei (35.8°S, 174.4°E) were used. The key inputs into the model were crop type, sowing and harvest dates. In all simulations it was assumed that water and N did not limit crop yields.

Results

Field experiment

Total annual DM production was greatest on the MO sequence at 48.9 t DM/ha, while the KO and TRT sequences yielded 29.7 and 22.7 t DM per ha, respectively ($P<0.001$, SED=1854) (Fig. 1). Yields of the warm season crops were 33.0 t DM/ha from maize, compared to 14.2 and 14.6 for kale and turnips plus forage rape, respectively. There was no significant difference between

Figure 1 Total crop sequence yield (t DM/ha/yr), showing individual crop contribution, from sequences: maize-oats (MO), kale-oats (KO) and turnip-forage rape-triticale (TRT). Error bars represent SED.



the autumn sown oat crops on the MO and KO sequences at 15.9 vs. 15.6 t DM/ha, respectively (SED=408.2). Triticale yielded 8.1 t DM/ha.

Annual ME yield (weighted) was greatest on the MO sequence and least on the TRT sequence (Table 2). The TRT sequence showed the highest weighted ME concentration, representing a 0.93 and 1.45 unit advantage over the KO and MO sequences, respectively. Crude protein concentrations ranged from 7.3 – 21.2 %, with the TRT sequence containing the highest mean concentration. Levels of soluble sugars and starch were highest on the MO sequence (P<0.001). At final harvest, cob made up the largest amount of maize crop DM, while stem contributed the largest fraction to the kale, forage rape and cereal crops (Table 3).

Water and nitrogen use efficiencies were greatest for the maize crop at 85 kg DM/mm water applied and 210 kg DM/kg N applied, compared to the other warm season crops, kale and turnips, which each showed efficiencies of 37 kg DM/mm and 70 kg DM/kg N, and 53 kg DM/mm and 66 kg DM/kg N, respectively.

Table 2 Nutritive characteristics (g/100 g DM, unless otherwise stated) of the forage from crops at final harvest from the maize-oat (MO), kale-oat (KO) and turnip-forage rape- triticale (TRT) crop sequences.

Sequence	ME[1]	CP[2]	NDF[3]	SSS[4]
MO				
Maize	10.6	7.3	42.0	40.0
Oat	11.4	12.6	53.8	21.9
Weighted mean	10.9	9.1	45.8	34.1
GJ ME/ha/yr	532			
KO				
Kale	12.2	10.6	46.7	25.6
Oat	10.7	10.7	57.1	19.2
Weighted mean	11.4	10.7	52.2	22.3
GJ ME/ha/yr	340			
TRT				
Turnips	13.5	8.2	46.6	24.7
Forage rape	12.6	21.2	39.5	17.4
Triticale	10.8	14.9	54.2	10.7
Weighted mean	12.4	13.2	47.9	18.2
GJ ME/ha/yr	281			
SED (mean)	0.16	0.44	1.19	1.35
pval (mean)	***	***	**	***
SED (GJ/ha/yr)	23			
pval (GJ/ha/yr)	***			

NB: Mean and GJ ME/ha/yr are weighted for yield.

[1] ME, metabolisable energy MJ /kg DM; [2] CP, crude protein; [3] NDF, neutral detergent fibre; [4] SSS, soluble sugars and starch

Table 3 Crop component composition (% of total dry matter) at final harvest.

	Stem/Bulb	Green leaf	Ear/Seed
MO			
Maize	26.1	11.0	60.0
Oat	63.3	32.9	0.0
KO			
Kale	77.3	21.0	-
Oat	64.7	29.5	0.3
TRT			
Turnips	41.5	55.0	-
Forage rape	65.1	32.5	-
Triticale	57.7	39.1	0.0

Simulation study

The simulations showed small deviations from the observed data, but overall they tracked the trends of observed growth for each crop (Fig. 2). The 'Kale' model predicted crop emergence late for each of the three brassica crops and therefore simulated yield was initially low compared to that measured. However, after this it tracked crop growth closely.

The same simulations were run for Northland and indicated that the MO sequence was capable of yielding 43.6 t DM/ha, KO 32.4 t DM/ha and TRT 24.2 t DM/ha. The Northland and Waikato simulations showed similar trends (Fig. 3).

Discussion

Both the field experiment and simulation show that the MO sequence was the highest yielding sequence, likely due to the presence of the C_4 species, maize, in the rotation (Fig. 2a). Annual yield from the MO sequence was greater than that reported by Thom & Gillespie (1987) in a similar study (av. 26 t DM/ha/yr), and comparable to yields reported by Mason *et al.* (1987) of 46 t DM/ha/yr and by Shrestha *et al.* (2006) from other crop sequence studies in Australia that included maize as a warm season crop. In a summary of forage rotation studies in temperate climates of New Zealand and Australia, Garcia *et al.* (2007) showed that all those that exceeded an annual DM production of 30 t DM contained a C_4 species, which contributed the largest portion of total DM. C_4 species are highly efficient at converting solar radiation into crop biomass during warm summer temperatures (Sinclair & Muchow 1999), and in this study, maize was shown to be a more efficient user of other available resources (water and nutrients). In contrast, the KO and TRT sequences had brassicas as the warm season crops which proved to

Figure 2 Simulated (dotted lines) and observed (symbols) yields of individual crops of (a) maize-oat sequence (MO); (b) kale-oat sequence (KO) and (c) turnip-forage rape-triticale sequence (TRT) in Waikato.

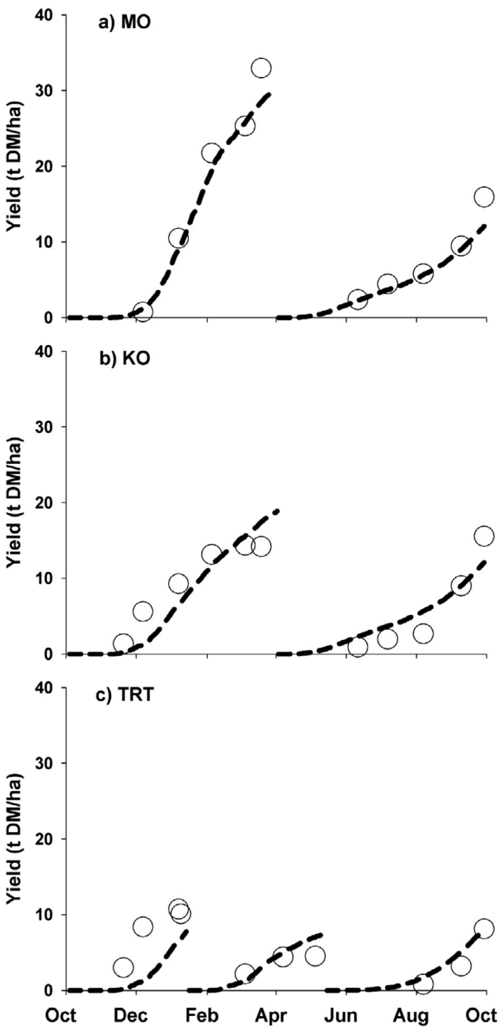
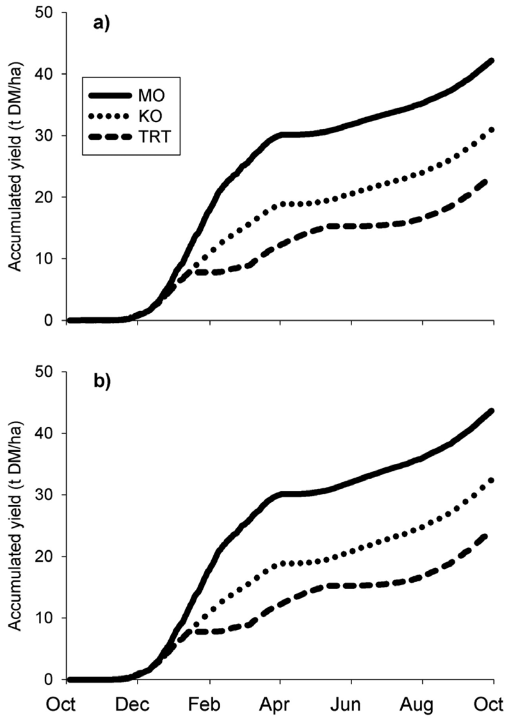


Figure 3 Simulated accumulated yields for Waikato (a) and Northland (b) from sequences: maize-oats (MO), kale-oats (KO) and turnip-forage rape-triticale (TRT).



be less efficient at converting resources into biomass. Hence the differences in total annual yield between the cropping sequences were largely due to differences between the warm season crops within each sequence, as there was no difference in the cool season crops in the MO and KO sequences. Yield would have also been compromised on the TRT sequence as it contained two crop transitions (Fig. 3c) whereas the MO and KO sequences had only one. Each transition means that solar radiation is not intercepted by a crop and therefore represents lost potential yield. Furthermore, the first transition from turnips to forage rape occurred during mid-summer. This is when both incident solar radiation and air temperatures are optimal for rapid crop growth. And the second transition from forage rape to triticale occurred in May when soil temperatures were likely to have been below optimal for establishing the cereal. While yield from the maize crop was high (Fig. 1), similar yields of 30 to 35 t DM/ha (Densley *et al.* 2001; Densley *et al.* 2006; Pritchard 1987) have been reported for other late maturing hybrids. Irrigation and higher average temperatures and solar radiation (Table 1) are likely to be contributing factors to the high yield of the maize crop in this study. Yields from the kale were below the desired target of 24 t DM/ha and of those reported (Brown *et al.* 2007) of 15 t DM/ha over a similar growing period in Canterbury; though within the range reported by Chakwizira (2008) of 10-11.4 t DM/ha, highlighting the variable nature of the crop. Similarly, the turnip and forage rape crops fell short of their expected yields of 15 and 8 t DM/ha, respectively. Low rainfall during summer is likely to have contributed to poor performance of the brassica crops. In the 2007/08 season the Waikato region experienced the worst drought on record and driest year since records began in 1906 (MAF 2008). While the experiment was irrigated, this was restricted and it is likely that the brassica crops experienced some moisture stress as wilting of foliage was observed, limiting crop production and resilience to pests.

The high yield achieved from the MO sequence would complement a pasture-based system by balancing fluctuating pasture supply. While increasing the amount of feed produced on farm is beneficial, the nutritive value of the supplementary forage and the time of year when it is available are also important. Based on ME values, the forages were all of moderate to high quality (Kolver 2000) and similar to those reported elsewhere (Clark *et al.* 1997; Nichol *et al.* 2003; Burke *et al.* 2000) (Table 2). Greatest ME yield was achieved with the MO sequence as it achieved the highest DM yield. Assuming a 30 % loss in ME yield through wastage, ME yields in this study ranged from 196 to 372 GJ ME/ha/yr, meeting the levels suggested by Luxton (2005) of 180 GJ ME/ha/yr as necessary to achieve the industry feed production target. However, the greatest ME concentration was obtained from the TRT sequence, due to the presence of the two high quality brassica crops (turnips and forage rape) that contained the highest levels of CP. Though weighted CP content from all three sequences was low and would be insufficient to meet the minimum requirement (18 %) of a lactating dairy cow (Kolver 2000) if fed as whole diet. Forage rape was the only crop that demonstrated CP concentrations sufficient to support lactation, and therefore is suitable as a supplementary feed in late summer/autumn when perennial ryegrass-based pastures may be lacking in protein. Crude protein levels in the kale and turnip forages were lower than expected and lower than levels reported by Nichol *et al.* (2003) of 15 % for kale and Thom (1996) of 13 % CP for turnips. Fibre levels (NDF %), however, were greater than reported elsewhere (46.7 cf. 25.0 for kale (NRC 2001) and 46.6 cf. 23.0 for turnips (Nichol *et al.* 2003)). The low CP and high fibre levels are likely to result from a low leaf to stem ratio of those crops at final harvest (Table 3), as the leaf fraction of kale and turnip crops is typically higher in CP content than that found in the stem fraction (Brown *et al.* 2007, Nichol *et al.* 2003). The low proportions of leaf material in the kale and turnip crops observed on this study are likely to be due to water stress and plant pest damage. Soluble sugar concentration was greatest on the MO sequence as a result of the high concentration in the maize forage, making the supplementary feed from this sequence suitable for balancing the nutrient requirements for dairy cows in early to mid lactation (Kolver *et al.* 2001).

Conclusions

The field experiment simulations both confirm that annual yields of forage crops of around 45 t DM/ha with an average metabolisable energy value of 11 MJ/kg DM are possible in the Waikato and Northland, provided that water and nitrogen are plentiful and that the crop rotation is carefully designed to maximise solar radiation capture and utilisation. In Northern regions rotations that include maize as the summer crop are likely to yield the highest annual DM due to their high resource use efficiency during the warm season (Sinclair & Muchow 1999). However, as stated previously, this paper reports findings from year one of a 2 year study, further investigation including simulation studies over several years will be undertaken.

Implications

A MO system on 100% of the farm area would maximise energy yield but would not provide sufficient CP to support lactating cow demands. Here we calculate the areas of crop and pasture required to meet the energy and CP demands of lactating cows to determine the maximum milksolids yield per ha that might be obtained from an integrated crop-pasture system. Our assumptions are given in Table 4.

A simple calculation (details not presented) shows that energy eaten per ha is optimised within the constraint of providing 18% CP by a combination of 60% pasture + 40% crop. This combination provides 137.5 and 150 GJ ME/ha/yr from pasture and crop, respectively, to give a total of 287.5 GJ ME/ha/yr with

Table 4 Assumptions used in calculating maximum milksolids yields obtainable from a maize-oats crop combined with perennial ryegrass pasture (1 GJ ME = 1000 MJ ME).

	Yield (GJ ME/ha/yr)	Waste (%)	Eaten (GJ ME/ha/yr)	ME (MJ/kg DM)	CP (g/100 g DM)	Source
MO (maize-oats)	532	30	372	10.9	9.1	This paper
Pasture (non-limiting nutrients & water)	288	20	230	12.0	24.0	Clark *et al.* (2001)

- Crop + pasture area = 100% of farm
- Lactating cow CP requirement = 18% of diet
- Feed conversion efficiency = 90 kg MS/t DM eaten (Glassey 2007)

an ME content of 11.5 MJ/kg DM, or 24.9 t DM/ha/yr. A conversion factor of 90 kg MS/t DM gives 2240 kg MS/ha/yr which is approximately 50% greater than the current maximum MS yield (1500 kg MS/ha/yr) from commercial and research farms once bought in feed and grazing off have been accounted for (Glassey 2007).

This brief analysis outlines the potential MS that might be achieved from an integrated pasture-crop system based on 'best' plot yields of crops and pasture. It takes no account of the difficulties of achieving these yields in commercial practice, the profitability of such a system or the environmental consequences of widespread adoption.

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