Producing over 40 t dry matter/ha per year through a complementary forage rotation system

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Abstract
A long-term field study is being conducted in New South Wales, Australia, to evaluate the feasibility of producing over 40 t DM/ha/year with a triple crop, complementary forage rotation (CFR) system. The CFR comprises a bulk crop (maize); a break crop (forage rape) and a legume crop capable of fixing atmospheric nitrogen (clover). The control is a well managed kikuyu-based pasture oversown with short rotation ryegrass each autumn. Treatments are replicated four times and data from the first 2 years are reported. Over 40 t DM/ha/year was either utilised by grazing or harvested mechanically from the CFR system in the first 2 years. This compares to almost 18 t DM/ha/year of utilised pasture for the control pasture system. In practice, these results indicate that dairy farmers in Australia can increase productivity by growing more forage on-farm with increased efficiency. The systems are designed to complement, rather than substitute, pasture-based systems.
Keywords: complementary forage rotation, pasture, crop, dairy

Introduction
In Australia, average pasture utilisation on dairy farms is less than 7 t dry matter (DM)/ha, despite evidence that we can produce over 25 t DM/ha/year when limitations to growth have been largely removed (Neal *et al.* 2005). High yielding crops such as maize (*Zea maize*), combined with high input, short rotation ryegrasses (*Lolium multiflorum*), can potentially produce over 30 t DM/ha/year (Pritchard 1987). However, these systems require large amounts of nitrogen (N) fertiliser and may not be environmentally sustainable. In FutureDairy, a national, multidisciplinary project, three technical modules (Forages, Feeding and Innovations) are being explored through an innovative approach that combines methodologies of social research ('People'), extension ('System') and technical research ('Science') (Kenny *et al.* 2006).

In the Forages component of the study, we are evaluating the feasibility of producing over 40 t DM/ha/year with a triple-crop Complementary Forage Rotation (CFR).

Methods
This paper reports results from the first 2 years (March 2004 to February 2006 of the Forages module). The study is ongoing and preliminary results from the first year have been reported by García *et al.* (2005).

The experiment is being conducted at Elizabeth Macarthur Agricultural Institute, located near Camden in New South Wales, Australia. The climate is warm temperate with an annual rainfall of 828 mm and a mean daily minimum and maximum air temperature of 10.2 and 23.6 ºC, respectively. The experimental design is a complete randomised block with four replicates (blocks) over two soil types (Black Vertisol and Brown Chromosol). All experimental sites were being used as kikuyu (*Pennisetum clandestinum*)-based pasture paddocks before the experiment started. Each block was split into halves and treatments were randomly assigned within each block to paddocks varying in size from 0.46 to 0.78 ha. The two treatments are:

- Control (existing pasture): Representing a typical pasture system with a C_4 (kikuyu) grass in summer, oversown with a C_3 grass (short-rotation ryegrass) and a legume (white clover, *Trifolium repens*) in early autumn. The pasture is fertilised, irrigated and managed to best practice.
- Complementary Forage Rotation (CFR) System: Representing a 'high-input, intensive' forage system with a rotation of forage 'crops' designed to complement the needs of the soil, plant and cows. The annual rotation being investigated is: maize (bulk crop); brassica (forage rape, *Brassica napus*, to aerate the soil as a root crop and also to provide some biofumigation from release of thiocyanates); and a legume (Persian clover, *Trifolium resupinatum*; to incorporate atmospheric N and reduce the need for fertiliser N input).

Establishment of crops
A brief description of crop establishment and management follows but more detail can be found in García *et al.* (2005). Maize was grown on all plots in the summer prior to treatment implementation. Forage rape (cv. 'Goliath') seed was then broadcast at 5 kg/ha immediately after the maize was harvested for silage in early March. A fertiliser mix (kg nutrients/ha) of 68 N, 47 phosphorus (P), 50 potassium (K), and 15 calcium (Ca) was applied immediately after sowing; 95 N, 14.5 P

and 52 K was applied after the first grazing (late April); and 67 N after the second grazing (June).

Persian clover (Shaftal type, cv. 'Maral') was broadcast at a rate of 10 kg seed/ha mixed with fertiliser (see above) after the first grazing of brassica in April. In Year 1, the clover did not establish uniformly and was replaced by maple peas (*Pisum sativum* cv. 'Secada'), which were direct drilled at a rate of 210 kg/ha immediately after the third grazing of the forage rape (late July-early August). In Year 2, each paddock (replicate) was subdivided into halves (subplots) and the two legume treatments (Persian clover, broadcast with the fertiliser in April; and maple peas, direct drilled in early August) were randomly assigned to subplots within blocks. Maple peas were harvested in a single cut for silage in early October (both Years 1 and 2) whilst Persian clover was rotationally grazed (Year 2 only).

In early October of both Years 1 and 2, the CFR paddocks were sprayed with glyphosate and maize (hybrid Pioneer 3527) was sown with a conventional drill in mid October at about 90 000 to 100 000 plants/ha. A mix of fertilisers was incorporated into the soil prior to sowing to provide (kg nutrients/ha): 162 N, 72 P and 200 K and an additional 145 units of N were broadcast as urea at V6 stage. In Year 1, germination was severely affected by excess water and the crop was resown in early November.

Forage harvesting and measurements

Pastures, brassicas and clovers were grazed with Holstein-Friesian lactating cows. Utilised pasture was calculated as the difference between pre- and post-grazing measurements with a rising plate meter calibrated to that pasture during the first year of the experiment. Grazing management for the pasture component of the study was based on decision rules which consider both the number of live leaves/tiller (ryegrass: between 2 and 3; kikuyu: between 3 and 4.5) and biomass (target pre- and post-grazing pasture cover = 2400-2600 and 1300-1400 kg DM/ha, respectively). On average (± sd), pastures were grazed 19.3 ± 0.9 times/year with an instantaneous stocking rate of 164 ± 58 lactating dairy cows/ha/day.

Brassicas were grazed after the canopy had closed completely (approximately 60 cm height), and Persian clover was grazed when senescence of oldest leaves commenced. Utilised forage yield of brassicas and Persian clover (at every grazing) and maple peas (at harvest) were estimated by cutting 10 x 0.25 m^2 quadrats diagonally across two grazing strips (about 0.06 ha each). Cutting height was based on the average residual height left by the cows in the strip grazed the previous day, varying for the brassicas from 15 to 20 cm above ground level.

Maize was harvested for silage when the crop had achieved physiological maturity (milk line >2/3). On each replicate, between 10 and 12 sampling areas (each sampling area = 2 x 4 m linear rows) were selected, resulting in a total of > 3000 individual plants being cut to approximately 15-20 cm from ground level (to simulate 'harvestable' maize) and weighed.

Hand-plucked pasture samples, simulating grazing, were taken prior to each grazing from the pasture plots. Similarly, composite samples of brassicas and legumes were taken at each grazing and at harvest time for maple peas and maize. All forage and pasture samples were later analysed for neutral detergent fibre (NDF) and acid detergent fibre (ADF) (Van Soest *et al*. 1991), water soluble carbohydrates (WSC) (Smith 1969), *in vitro* digestibility of DM and OM (Clark *et al*. 1982) and nitrogen (N) by combustion using a Leco® FP-428 Nitrogen Determinator (Leco® Corporation St. Joseph, Michigan, U.S.A). The metabolisable energy (ME) content was calculated from DM digestibility (SCA 1990).

Application of fertiliser was based on expected nutrient removal for each crop whilst irrigation was based on monitoring soil moisture (thrice weekly) using a capacitance-based meter (*Diviner2000*, Sentek PTY LTD). A refill point was determined for each access tube (2/paddock) as the total amount of water (mm) in the first 50 cm of soil at field capacity minus 30 mm.

Data were analysed by year using one-way ANOVA in GenStat and significance was declared when $P < 0.05$.

Results

In 2 consecutive years, the CFR treatment achieved a mean forage yield of 41.2 t DM/ha/year (Table 1). This figure is utilised (brassicas, clover) or harvested (maize, maple peas) and does not include losses due to conservation and/or feeding out silage. Pasture utilisation in the control paddocks averaged 17.6 t DM/ha over the same period. The brassica crop averaged 11.05 t utilised DM/ha in three grazing periods, Persian clover or maple peas averaged 4.04 t utilised or harvested DM/ha and the maize produced an average of 26.4 t harvested DM/ha.

On a seasonal basis, the CFR produced 2.2 times more DM during the spring-summer period (maize for silage) than the well managed pasture. This figure increased to 2.6 times more forage DM in favour of the CFR during the autumn-winter period (grazed brassica and legume).

On average, the amount of irrigation water applied was 20% higher for the CFR than for the pasture system although this difference was only significant in Year 2 (Table 2). Nitrogen input was only significantly higher for the CFR than pasture in Year 1, but the opposite was true in Year 2, resulting in a similar total input for both treatments on average over the 2 years. Inputs of both P

Table 1 Seasonal (autumn-winter and spring-summer) and total annual forage yield (t DM utilised/harvested per ha) for the Complementary Forage Rotation (CFR) and control (pasture) systems.

Forage yield (t DM/ha)	Year	CFR	Pasture	SED	P<
Autumn-Winter	1	15.5	5.5	0.3	<0.001
	2	14.6	6.1	1.0	0.01
	Average	15.1	5.8		
Spring-Summer	1	26.6	11.7	0.9	<0.001
	2	26.2	11.9	1.1	<0.001
	Average	26.4	11.8		
Total forage yield	1	42.2	17.3	0.9	<0.001
	2	40.2	18.0	1.4	0.004
	Average	41.2	17.6		

SED = standard error of the difference; P< = probability

Table 2 Nutrients (kg/ha) and irrigation water applied (mm) to the Complementary Forage Rotation (CFR) and control (Pasture) systems in Year 1 and 2.

Inputs	Year	CFR	Pasture	SED	P<
Irrigation (mm)	1	843.0	723.0	87.6	0.26
	2	961.0	774.0	54.4	0.04
	Average	902.0	748.5		
Nitrogen (kg/ha)	1	632.0	536.0	23.6	0.03
	2	535.0	667.0	15.9	0.004
	Average	583.5	601.5		
Phosphorus (kg/ha)	1	217.0	90.0	2.2	<0.001
	2	158.5	71.4	0.0	<0.001
	Average	187.8	80.7		
Potassium (kg/ha)	1	324.8	247.0	4.5	<0.001
	2	347.0	164.0	14.4	0.001
	Average	335.9	205.5		

SED = standard error of the difference; P< = probability

and K were significantly higher for the CFR than for the pasture (Table 2).

Compared to pasture, the two grazing components of the CFR system (brassicas and Persian clover) were higher in crude protein (CP, >25%), lower in NDF (< 30%) and ADF (<22%), and higher in total ME (>11 MJ/kg DM) (Table 3).

On average, the apparent 'nutrient use efficiency' (defined as kg of DM produced/unit of input applied) of N was more than double for the CFR than for the pasture treatment whilst the apparent water use efficiency was 2.4 times higher for CFR than for pasture system (Table 4). Phosphorus and K use efficiencies were usually similar for the two forage systems.

Discussion

These results demonstrate that complementary forages can be combined in a rotational way to produce in excess of 40 t DM/ha/year. This figure is 4 to 5 times greater than the estimated average utilised pasture in Australia (García & Fulkerson 2005). Previous work in northern Victoria (Pritchard 1987) has shown that combinations of maize grown for silage followed by short rotation ryegrass pasture can produce over 30 t DM/ha/year. However, such combinations require larger N fertiliser inputs and hence may not be sustainable.

Pasture utilisation in the control pasture was nearly 18 t DM/ha, which is 2.5 times more than the national average. Such a production level was achieved in the first year of the experiment, indicating the potential to rapidly increase the amount of high quality pasture when nutrients, irrigation and management are adequate. However, this high-yielding pasture was unable to produce more than 5 or 6 t DM/ha during the critical months of autumn and winter, in comparison to the CFR where about 15 t DM could be utilised by grazing over the same period. This has important practical implication on dairy farms, particularly those that produce milk in winter, as high quality grazed forage can partially replace more expensive supplements.

Although an economic analysis is beyond the scope of this paper, the increase in forage yield for the CFR in comparison with the pasture was much larger than the relative increase in inputs. At present input prices, this indicates that the forage yield of the CFR would need to decrease (due to lower yields, climate contingencies –

Table 3 Mean neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP) and metabolisable energy (ME) of forage crops and pasture.

	Year	Brassica	Persian clover[1]	Maple pea	Maize[2]	Pasture
NDF (%)	1	19.3		38.7	52.9	56.0
	2	23.4	28.6	32.8		55.1
	Average	21.4		35.7	52.9	55.5
ADF (%)	1	16.0		33.7	28.3	26.4
	2	19.4	21.9	29.0		23.7
	Average	17.7		31.4	28.3	25.1
CP (%)	1	24.8		20.8	6.8	23.2
	2	28.4	26.5	25.7		26.2
	Average	26.6		23.3	6.8	24.7
ME (MJ/kg DM)	1	11.3		9.5	8.8	9.6
	2	11.5	11.0	10.0		10.8
	Average	11.4		9.7	8.8	10.2

[1] Persian clover: Year 2 only;
[2] Maize chemical composition data for Year 2 not yet available

Table 4 Apparent nutrient efficiency (kg DM/unit input) for Complementary Forage Rotation (CFR) and control (pasture) systems.

Nutrient	Year	Apparent use efficiency (kg DM/unit input)		SED	P<
		CFR	Pasture		
Nitrogen	1	67.0	32.0	0.8	<0.001
	2	74.5	26.9	2.5	0.003
	Average	70.8	29.5		
Phosphorus	1	194.0	190.0	11.9	0.8
	2	254	251.7	17	0.9
	Average	224.0	220.9		
Potassium	1	130.0	69.0	4.8	0.001
	2	114.1	109.7	5.5	0.5
	Average	122.1	89.4		
Water (irrigation only)	1	52.0	24.0	5.9	0.017
	2	41.2	23.4	0.5	<0.001
	Average	46.6	23.7		

SED = standard error of the difference; P< = probability

flooding, drought- and/or losses due to conservation and feeding out of silage) by 40% (i.e. from 42 to about 25 t DM/ha/year) before the pasture treatment were more economically viable than the CFR.

In practice, these results indicate that dairy farmers in Australia can increase productivity by growing more forage on farm with increased efficiency. The systems are designed to complement, rather than substitute, pasture-based systems. As key questions to be explored are in relation to CFR implementation on farm, we are working in partnership with farmers who are implementing these systems (see companion paper by Kenny *et al.* 2006 in this volume).

In conclusion, after 2 years we have demonstrated that the target of 40 t DM/ha/year is achievable through a CFR system and that this system is more (apparent) nutrient efficient than a well managed pasture. The CFR system also produced more quality forage during the critical autumn-winter period than a well managed pasture.

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