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The effects of high stocking rates on milk production from dryland and irrigated Mediterranean pastures

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Abstract. An experiment using herds of ~20 cows (farmlets) assessed the effects of high stocking rates on production and profitability of feeding systems based on dryland and irrigated perennial ryegrass-based pastures in a Mediterranean environment in South Australia over 4 years. A target level of milk production of 7000 L/cow.year was set, based on predicted intakes of 2.7 t DM/cow.year as concentrates, pasture intakes from 1.5 to 2.7 t/cow.year and purchased fodder. In years 1 and 2, up to 1.5 t DM/cow.year of purchased fodder was used and in years 3 and 4 the amounts were increased if necessary to enable levels of milk production per cow to be maintained at target levels. Cows in dryland farmlets calved in March to May inclusive and were stocked at 2.5, 2.9, 3.3, 3.6 and 4.1 cows/ha, while those in irrigated farmlets calved in August to October inclusive and were stocked at 4.1, 5.2, 6.3 and 7.4 cows/ha.

In the first 2 years, when inputs of purchased fodder were limited, milk production per cow was reduced with higher stocking rates ($P < 0.01$), but in years 3 and 4 there were no differences. Mean production was 7149 kg/cow.year in years 1 and 2, and 8162 kg/cow.year in years 3 and 4. Production per hectare was very closely related to stocking rate in all years ($P < 0.01$), increasing from 18 to 34 t milk/ha.year for dryland farmlets (1300 to 2200 kg milk solids/ha) and from 30 to 60 t milk/ha.year for irrigated farmlets (2200 to 4100 kg milk solids/ha). Almost all of these increases were attributed to the increases in grain and purchased fodder inputs associated with the increases in stocking rate. Net pasture accumulation rates and pasture harvest were generally not altered with stocking rate, though as stocking rate increased there was a change to more of the pasture being grazed and less conserved in both dryland and irrigated farmlets. Total pasture harvest averaged ~8 and 14 t DM/ha.year for dryland and irrigated pastures, respectively. An exception was at the highest stocking rate under irrigation, where pugging during winter was associated with a 14% reduction in annual pasture growth.

There were several indications that these high stocking rates may not be sustainable without substantial changes in management practice. There were large and positive nutrient balances and associated increases in soil mineral content ($P < 0.01$), especially for phosphorus and nitrate nitrogen, with both stocking rate and succeeding years. Levels under irrigation were considerably higher (up to 90 and 240 mg/kg of soil for nitrate nitrogen and phosphorus, respectively) than under dryland pastures (60 and 140 mg/kg, respectively). Soil organic carbon levels did not change with stocking rate, indicating a high level of utilisation of forage grown. Weed ingress was also high (to 22% DM) in all treatments and especially in heavily stocked irrigated pastures during winter.

It was concluded the higher stocking rates used exceeded those that are feasible for Mediterranean pastures in this environment and upper levels of stocking are suggested to be 2.5 cows/ha for dryland pastures and 5.2 cows/ha for irrigated pastures. To sustain these suggested stocking rates will require further development of management practices to avoid large increases in soil minerals and weed invasion of pastures.

Introduction

There is strong interest by industry in increasing stocking rates on Australian dairy farms. A substantial increase in land prices has limited the potential for farmers to buy additional land but feed inputs, particularly grains, are readily available and have been shown to increase milk output when fed with grazed pasture (Walker *et al*. 2001). There is an acceptance that increasing dry matter harvested from pasture is associated with an increase in profitability and often this is achieved through increased stocking rates (Rogers 1973; Stockdale and King 1980). These factors have fostered interest in increasing production through higher stocking rates, but with associated inputs of grain and fodder to maintain production per cow.

Several farm surveys and research studies have shown that increasing pasture utilised per hectare on Australian dairy farms is a major objective in reducing the costs of milk production. In South Australia, gross margin per hectare has consistently increased with tonnage of pasture utilised per hectare (Mitchell and Chinner 1995), a result consistent with that in other Australian states (Busby *et al*. 2005). A previous experiment at the Flaxley Agricultural Centre, using dryland pastures, demonstrated a substantial increase in gross margin per hectare. This was due

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to the combination of an increase in stocking rate, from 1.2 to 2.0 cows/ha, and in grain input, from 1.0 to 2.5 t DM/cow.year (Valentine 1999). Pasture utilisation was maintained at 8 t DM/ha.year.

There is increasing interest in irrigation for dairy pastures. The net return on the capital invested in irrigation of dairy pastures has been shown to be at least equal to the return in purchasing more land for dairy production (Thomson 1998). The area under irrigation in the dairying regions in south-west Victoria and the south-east of South Australia has increased rapidly with the installation of centre-pivot and fixed sprinkler systems (Ward 1998). An advantage of irrigation is that the pasture grown under irrigation is available to increase milk production when the seasonal price for milk is relatively high, and there is the opportunity to increase stocking rate to improve production per hectare and profitability (Dickens and Fitzgerald 1997).

With deregulation of the dairy industry in 2000 and the consequent drive to reduce costs of production, there was increasing interest by dairy farmers in the levels of production achievable in intensive dairy systems, using high inputs of supplementary feeds and fertiliser under grazing regimes designed to maximise pasture use. These systems would need to go beyond current experience, using higher stocking rates, irrigation and sufficient supplementary feeds to maintain high milk production per cow. The information would also assist in understanding the issues in sustainability of such intensive systems. The current experiment aimed to quantify the effects of markedly increasing stocking rates on dryland and irrigated pastures, while at the same time maintaining production per cow through inputs of supplementary feeds, on the productivity and sustainability of pasture-based dairy farming systems in the low summer rainfall zone of southern Australia. A farmlet design, utilising herds of ~20 cows and running continuously for 4 years, was chosen to enable experimental conditions to resemble commercial practice.

Materials and methods

The experiment was conducted at the Flaxley Agriculture Centre, South Australia, at latitude 35.13S, longitude 138.82E and altitude 393 m. The climate is Mediterranean, with cool wet winters and hot dry summers. Average annual rainfall is 767 mm, with 80% falling from April to October inclusive. Rainfall totals were 685, 753, 711 and 782 for the 4 years of this experiment, with low rainfall during summer of year one being the main deviation from normal. Average maximum and minimum temperatures are 27 and 12°C in January and 13 and 4°C in July, respectively. Soils were a mix of Red and Brown Chromosols on the upper slopes and Brown Dermosols on the lower slopes (Fleming and Cox 1998). All soils had strong texture contrast between the A and B horizons. The A horizon had 11–15 cm sandy loam of 10–15% clay content overlaying 11–16 cm with a high (60%) ironstone gravel content. Below this, the B horizon was a medium to heavy clay with strong angular, blocky structure. Soils allowed relatively free water movement through both the A and B horizons.

Farmlet design

The experiment comprised five autumn calving, dryland farmlets with stocking rates of 2.5, 2.9, 3.3, 3.6 and 4.1 cows/ha, and four spring calving, irrigated farmlets with stocking rates of 4.1, 5.2, 6.3 and 7.4 cows/ha. The different calving times were to enable cow demand for pasture to be matched with pasture growth patterns. The dryland and irrigated farmlets were located on adjacent blocks of land and the irrigated area was watered using a centre pivot, overhead watering system. The dryland area was further subdivided into 47 paddocks of ~0.67 ha. The five farmlet treatments were allocated at random across these paddocks, with the number of paddocks allocated to each treatment restricted to 13, 10, 9, 8 and 7 respectively. The irrigated area was subdivided into 48 paddocks, each of 0.43 ha, and randomly allocated to treatments. There were 13, 10, 9 and 8 paddocks allocated to the four treatments. This allocation was intended to enable cow groups to be similar in size, though herd numbers ranged from 19 to 25 cows for individual treatments.

Ninety-eight Holstein–Friesian cows and heifers calving in March to May, inclusive, were allocated to the dryland areas. Ninety-three Holstein–Friesian cows and heifers calving in August to October, inclusive, were allocated to the irrigated areas. Twenty percent heifers were included in the initial groups placed on pasture in November 1999 and this ratio was maintained through annual replacements. Initially cattle were blocked on parity, previous production for cows and liveweight, and allocated at random to treatment. Mean liveweights of animals post calving in year 1 were 505 and 524 kg for dryland and irrigated treatments, respectively. Where replacement animals were required, in addition to the annual heifer intake, these were drawn from cows of similar age and production in the Flaxley herd.

The farmlets were stocked in November 1999, but the first 6 months of the program was used as an introductory period during which staff were trained in techniques and data collection procedures. Data collection commenced in March 2000 and was completed in July 2004, which enabled four lactations for both the dryland and irrigated farmlets to be completed. For convenience and to coincide with the beginning and end of lactation, data collection on the dryland farmlets for each lactation commenced on 1 March and finished on 28–29 February, and for the irrigated farmlets commenced on 1 August and finished on 31 July in each year.

Feeding management

As the intention was to maintain high milk production per cow, annual feed allocations, based upon anticipated pasture growth, were 2.7 tonne grain-based concentrate DM and initially 1.5 tonne purchased fodder DM (lucerne and cereal hays) per cow.

Grain and hay allocations were made using target dry matter intakes intended to allow for intake and wastage of fodder, set at an average of 24 kg/cow.day in early lactation, 22 kg/cow.day in mid lactation and 20 kg/cow.day in late lactation. In each month pasture growth was estimated, as described below, and a ration formulated for each treatment which would meet the targets for crude protein content and dry matter intake. Utilisation of pasture was given priority, with a target utilisation rate of 80%

DM grown, and quantities of hay and grain added to this to make up the ration. Fodder conserved from the experimental area was fed back to that treatment when required. In the first 2 years (2000–01 and 2001–02) cows were dried off if the purchased fodder limit was reached before the lactation was completed. However, in the next 2 years additional fodder was fed to complete the lactation if the purchased fodder limit was reached. Refusals of grain-based concentrates during milking were negligible. Hay was fed in the paddock and rejections not recorded.

The grain concentrate was based on rolled barley and lupin grains and the composition of the concentrate was adjusted to provide an estimated crude protein content in the total ration of 170–180 g/kg in early lactation, 160–170 g/kg in mid lactation and 150–160 g/kg in late lactation (National Research Council 1978). Each cow was fed a pelleted mineral supplement providing a daily intake of calcium 50 g, phosphorus (P) 25 g, salt 10 g, sodium bicarbonate 60 g, vitamin A 18 000 IU, vitamin D3 1500 IU, vitamin E 30 IU, cobalt 9 mg, iodine 4.5 mg, selenium 0.9 mg, iron 67 mg, magnesium oxide 50 mg, manganese 225 mg, zinc 250 mg, copper 75 mg, molybdenum 2.25 mg and rumensin 200 mg. The grain concentrate was fed in equal amounts twice daily during milking, through an automatic cow identification and concentrate feeding system, with the constraint that animals within a treatment were each fed the same amount.

Pasture management

Pastures were mixtures of perennial ryegrass (*Lolium perenne*) and subterranean clover (*Trifolium subterraneum*) for dryland, and perennial ryegrass and white clover (*Trifolium repens*) for irrigated pastures. These had been established at least 1 year before the start of the experiment. Nitrogen fertiliser was applied as urea at the rate of 50 kg N/ha in autumn and spring of each year on the dryland farmlets. On the irrigated farmlets, nitrogen was applied at 50 kg N/ha after each grazing, up to a maximum of 500 kg N/ha.year. All irrigated farmlet paddocks received this maximum in each year. Phosphorus and sulfur (S) were applied as double superphosphate at 15 kg P and 4 kg S/cow.year on each farmlet. Applications were in March, May and August on the dryland farmlets, and February, May, August, October and December on the irrigated farmlets. If the potassium (K) soil test fell below 120 mg/kg, K was applied as muriate of potash at the rate of 50 kg K/ha.year, but in fact the soil level did not go below this benchmark and none was applied. Irrigation water was applied at 25 mm when cumulative evaporation from the evaporation pan exceeded 100 mm.

Using electric fencing within paddocks, a fresh strip of pasture was provided after each milking. After the afternoon milking, cows were able to back graze pasture residue remaining from the morning allocation. Using the pasture sampling routine described below, the targets were a pasture yield on offer at the commencement of grazing of 2200 kg DM/ha, and a postgrazing residue of 1200 kg DM/ha. On all farmlets, during periods of rapid pasture growth the grazing rotation was slowed, and excess pasture was conserved as silage. Amounts made and fed back to the treatment herd were recorded. Excess pasture during autumn was measured as above and subsequently grazed by the Flaxley commercial herd or harvested with a forage harvester.

Reproductive management

A synchronised mating program was used for all farmlet herds, based on a double dose of prostaglandin. Tail paint and commercial mount detectors were used as aids in heat detection. AI only was used in the first year (up to three inseminations), and in latter years bulls were used after the initial 6-week mating period. Planned starting dates of calving were September 14 for the irrigated farmlets and April 1 for the dryland farmlets. Mean 21-week in-calf rate over the 3 years averaged 76% for dryland and 63% for irrigated farmlets. Overall conception rates to individual matings averaged 40% for all farmlets.

Data collection

Pasture

Pasture mass before and after grazing were measured daily with a rising plate pasture meter, taking 40 readings in each paddock and using calibration equations developed for each season in a previous project (Valentine 1999) and following procedures of Stockdale and King (1980) and Stockdale (1984). Pasture intake was calculated by differences without adjustment for growth during the grazing period. Pasture mass in all paddocks was measured in the same way with the rising plate meter once each month. Regression analyses of yield on time across paddocks within a treatment was used to estimate pasture net accumulation rates. Pasture botanical composition was measured on one occasion in summer, autumn, winter and spring each year, using the rod-point technique described by Little and Frensham (1993).

Pasture chemical composition was assessed by hand plucking pasture samples to simulate grazing in each month. Samples were dried at 60°C for 24 h, ground and analysed for *in vitro* digestible dry matter (DDM) and neutral detergent fibre (NDF) contents through commercial laboratories using NIR, and for nitrogen (Kjeldahl). ME was calculated from DDM using the equation: 0.17 DDM (%) – 2.0 (SCA 1990).

Milk production

Total milk production from each farmlet herd was measured at each milking with a flow rate sensor and data logger. Milk fat and protein contents and cell count were measured three times weekly, using an infrared milk analyser, on bulk milk sampled from each herd with an in-line drip sampler. Cows were weighed and condition scores assessed by two people (Earle 1976), monthly, following morning milking.

Feed composition measurements

Samples of pasture, hay, silage and grains were taken on one day each month and dried at 60°C for 24 h, then analysed for DDM and NDF by near infrared reflectance spectroscopy, and for nitrogen by the Kjeldahl method. The mean crude protein and NDF contents of the feed supplements across the 4 years were 12.5 and 57% respectively for silage, 19 and 44% for hay, and 31 and 26% for lupins. Barley averaged 10% crude protein.

Soil nutrients

Soil in each farmlet paddock was sampled in early March each year for 2000 to 2004, inclusive. Twenty-five 10-cm deep cores were taken from each paddock and bulked to form one sample for each paddock. Samples were dried at 40°C for 72 h and analysed for nitrate N, Colwell P, Colwell K, S, organic carbon, electrical conductivity and pH (water).

The differences between nitrogen, P and K inputs and outputs were calculated from annual inputs of grain mix (2.2% N, 0.4% P, 0.8% K), purchased fodder (3.0% N, 0.3% P, 1.5% K) and fertiliser, and outputs in milk (0.53% N, 0.09% P, 0.16% K), hay and silage made and not returned to the treatment (3.0% N, 0.3% P, 1.5% K) and liveweight change (0.5 kg N/cow.year).

Earthworm populations

A survey of earthworm populations was carried out in the winters of 2000 and 2001. In 2000, the survey was conducted on two of the irrigated farmlets (4.1 and 7.4 cows/ha) and three dryland farmlets (2.5, 3.3 and 4.1 cows/ha). In 2001, only the two irrigated farmlets were surveyed. Earthworm numbers, species and biomass were measured in pasture sods measuring 0.16 m^2 in area, cut to a depth of 10 cm. In 2000, five sods were taken from each of five farmlet paddocks within a stocking rate treatment. In 2001, 10 sods were taken. Sods were immersed in water and teased apart to enable collection of earthworms.

Statistical analyses

Milk yield, feed intake and soil chemical analyses were analysed using the statistical package GENSTAT 6 (GENSTAT 6 Committee 2002). The experimental unit used in analyses was a group of cows in a farmlet, and the relationship between each variable of interest and stocking rate was tested by using grouped linear regression (with Year as the grouping factor) and an analysis of parallelism (GENSTAT 6) was performed. Initially, slopes were compared across years and if slopes were similar, intercepts were compared across years. Finally, if slopes and intercepts were similar, the significance of an overall regression line was assessed.

For pasture growth the effect of stocking rate was assessed by fitting an overall spline to the pasture growth data against month of the year for each stocking rate, then testing for differences between splines.

Results

Net pasture accumulation and composition

Net pasture accumulation rates were not different between stocking rates in any year for both dryland and irrigated pastures (Fig. 1). Irrigated pastures sustained high accumulation rates for much of the year, varying from 80 kg DM/ha.day in spring to 30 kg DM/ha.day in winter. By contrast, accumulation rates of dryland pastures showed a very short period of rapid accumulation (80 kg DM/ha.day) in spring, followed by rapid decline and no growth during summer (plant death). In 3 of the 4 years, autumn rain promoted a modest accumulation rate (40 kg DM/ha.day) from April to September inclusive. Rainfall was very late in autumn 2002 and very little growth occurred until spring.

Botanical composition of dryland pastures was not affected by stocking rate in any year. In year 1, dryland pastures averaged 42% grass, 41% clover and 17% weeds in the dry matter. Over the 4 years there was a reduction in clover and an increase in weed content to averages of 19 and 38%, respectively, in year 4 ($P < 0.05$), with no change in grass content. The primary weeds were barley grass (*Critesion murinum*), capeweed (*Artotheca calendula*) and geranium (*Erodium cicutarium*). Water couch (*Paspalum distichum*) was a substantial weed in the heavily stocked and irrigated pastures. By contrast, irrigated pastures had substantially higher grass content, averaging 82, 6 and 11% for grass, clover and weeds, respectively, in year 1. Grass content was reduced slightly in subsequent years ($P < 0.05$; 72% in year 4). Clover and weed content tended to increase slightly with years, averaging 12 and 16% respectively in year 4 ($P > 0.05$). Weed content at 7.4 cows/ha was higher than at the other stocking rates in the second to the fourth year, inclusive ($P < 0.05$), averaging 22% DM.

There were small but consistent increases in crude protein content of pasture with increases in stocking rate ($P < 0.05$), from a mean of 17% DM at 2.5 cows/ha to 18.5% DM at 4.1 cows/ha for dryland pastures, and from 21.0% DM at 4.1 cows/ha to 21.5% DM at 7.4 cows/ha on irrigated pastures, respectively. NDF content showed small but consistent decreases with increases in stocking rate ($P < 0.05$), from 52.2 to 50.7% DM for dryland pastures and from 49.5 to 48.8% DM for irrigated pastures, respectively. ME content was not altered with stocking rate for dryland pastures and averaged 10.0 MJ ME/kg DM. On irrigated pastures there was an increase from 11.5 to 11.7 MJ/kg DM at 4.1 and 7.4 cows/ha, respectively ($P < 0.05$).

Both crude protein and ME contents consistently increased with succeeding years of the experiment ($P < 0.05$), from 15.9 to 20.2% CP for dryland pastures and from 19.4 to 24.2% CP for irrigated pastures in years 1 and 4, respectively. ME content increased from 9.1 to 11.1 MJ/kg DM for dryland pastures and 11.0 to 12.1 MJ/kg DM for irrigated pastures in years 1 and 4, respectively. Within-year variations in CP and NDF contents were less for irrigated than dryland pastures and, during summer, NDF contents were maintained in the order of 55% DM for irrigated pastures compared with values from 60 to 75% DM for dryland pastures.

Feed intake

Cow intake

On both dryland and irrigated pastures, pasture intake per cow was reduced with increasing stocking rate in all 4 years. This was reflected in a reduction in total intake in years 1 and 2 (Table 1), but there were no differences in total intake between stocking rates for either dryland or irrigated pastures in years 3 and 4. In these years, purchased fodder intake was increased to compensate for the reduction in pasture intake. For dryland pastures, the additional purchased fodder inputs in years 3 and 4, compared with years 1 and 2, were nil at 2.5 cows/ha and 1 t DM/cow.year at 4.1 cows/ha ($P < 0.01$). Fodder conserved on the farmlet decreased with increased stocking rate ($P < 0.05$), and was 0.25 t DM/cow.year less at 4.1 compared with 2.5 cows/ha. Similarly, on irrigated pastures, purchased

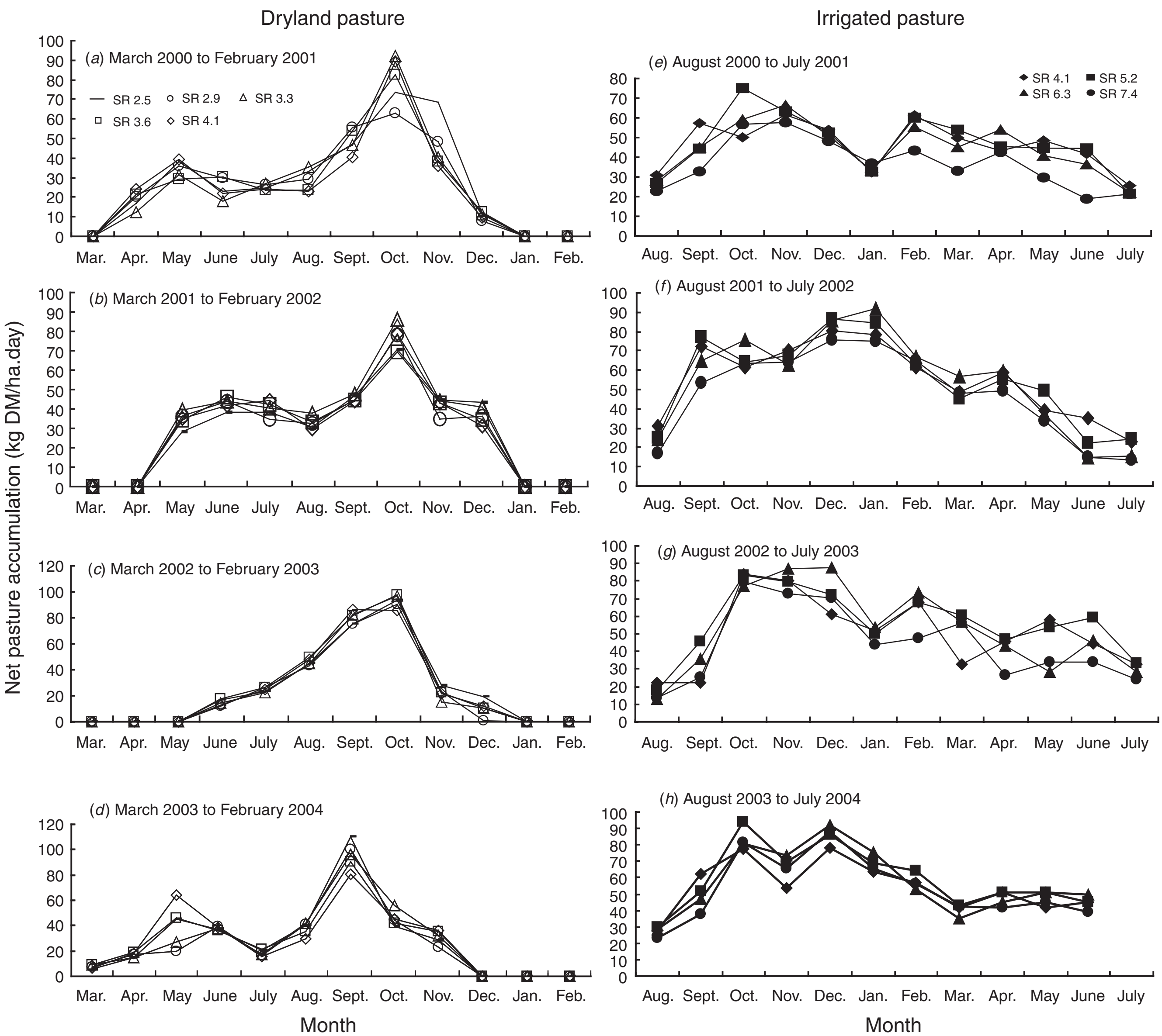

Fig. 1. Seasonal pattern of net pasture accumulation over 4 years for (*a–d*) dryland and (*e–h*) irrigated pastures at a range of stocking rates (cows/ha).

fodder inputs were increased at higher stocking rates in years 3 and 4, by up to an additional 1 t DM/cow.year at 7.1 cows/ha ($P < 0.01$). Amounts of fodder conserved off the farmlets were low, less than 200 kg/cow.year.

Intake per hectare

On dryland pastures, total feed intake increased from 17 to 30 t DM/ha.year (Fig. 2; $P < 0.01$). A significant part of the increase in feed input per hectare (40%) was due to increased concentrate inputs, but there were also increases ($P < 0.05$) in pasture harvest (12%) and purchased hay inputs (48%). The increase in purchased fodder input in years 3 and 4 compared with years 1 and 2 ranged from nil at 2.5 cows/ha to 4.5 t DM/ha.year at 4.1 cows/ha ($P < 0.01$).

Total feed intake on irrigated pastures increased linearly with stocking rate from 30 to 55 t DM/ha.year (Fig. 2; $P < 0.01$). These differences were almost entirely attributable to the increased inputs of concentrate (40%) and purchased fodder (60%). The increase in purchased fodder inputs in years 3 and 4 compared with years 1 and 2 ranged from nil at 4.1 cows/ha to 7 t DM/ha.year at 7.4 cows/ha ($P < 0.01$).

There was a close relationship between feed intake predicted before the experiment began and actual feed intake per hectare ($R^2 = 0.94$; regression coefficient 0.94), though this was in part due to the very close relationship between predicted and actual grain inputs ($R^2 = 0.96$). The separate relationship for purchased fodder was less precise ($R^2 = 0.73$) and the regression coefficient was 1.4, demonstrating the change in policy to purchasing fodder

Table 1. Effect of stocking rate on milk production, liveweight and feed intake of cows on dryland and irrigated farmlets in years 1 and 2 (short lactations)

**, $P < 0.01$; *, $P < 0.05$; n.s., not significant; –, slope not significant ($P > 0.05$)

Measurement						Slope (±s.e.)	Signif.
Dryland farmlets							
Stocking rate (cows/ha)	2.5	2.9	3.3	3.6	4.1		
Milk yield (kg/cow.lactation)	7232	7279	6903	6671	6968	–[A]	**
Fat (kg/cow.lactation)	272	270	254	262	243	–	n.s.
Protein (kg/cow.lactation)	225	225	218	210	214	–[A]	**
Liveweight (kg)	559	541	550	554	561	–	n.s.
Intake (kg DM/cow.year)							
Pasture	2390	2335	2234	2004	1885	–347 (± 28)	**
Fodder	1996	1904	1876	1813	1767	–134 (± 58)	*
Concentrate	2499	2486	2526	2577	2565	–	n.s.
Total	6885	6725	6636	6394	6217	–368 (± 62)	**
Irrigated farmlets							
Stocking rate (cows/ha)	4.1	5.2	6.3	7.4			
Milk yield (kg/cow.lactation)	7440	7108	6830	6130		–393 (± 72)	**
Fat (kg/cow.lactation)	288	272	258	229		–17 (± 3)	**
Protein (kg/cow.lactation)	232	18	208	185		–14 (± 2)	**
Liveweight (kg)	560	554	538	541		–10 (± 3.8)	*
Intake (kg DM/cow.year)							
Pasture	2832	2551	2414	1848		–318 (± 36)	**
Fodder	1493	1713	1572	1655		–	n.s.
Concentrate	2506	2511	2501	2486		–	n.s.
Total	6832	6775	6488	5989		–293 (± 51)	**

[A]The regression lines for the 2 years were different, with a highly significant effect in year 1 and a non significant effect in year 2 for both milk and protein yield.

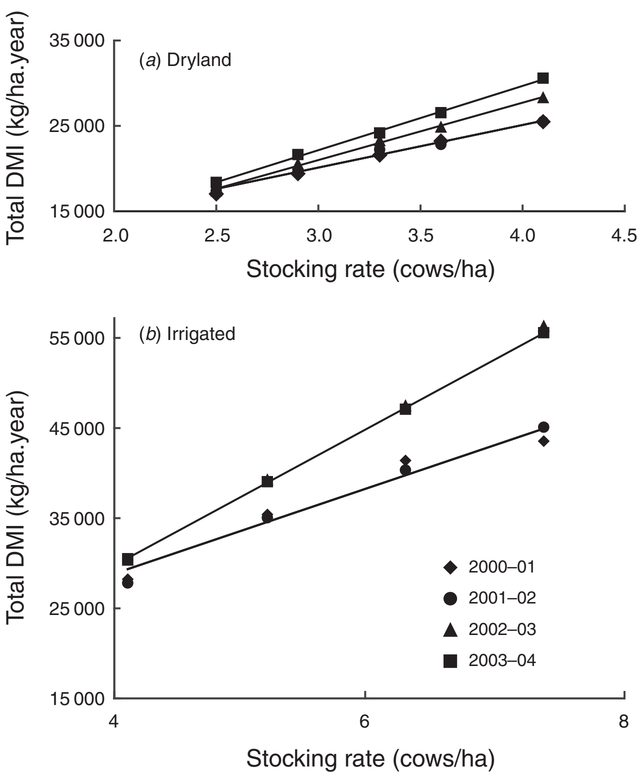

Fig. 2. The relationship between total feed intake by cows (t/ha.year) and stocking rate over 4 years for (*a*) dryland and (*b*) irrigated farmlets.

after 2 years. Predicted pasture intakes were not closely related to actual intakes ($R^2 = 0.25$), and there were consistent trends to underestimate pasture intake on dryland pastures (regression coefficient 1.5) and overestimate it on irrigated pastures (0.5). The amount of conserved fodder made showed no relationship to predictions ($R^2 = 0.01$).

Milk production

Lactation length

In year 1, lactation length of cows on the dryland farms was substantially reduced with increasing stocking rate (–57 days/unit change in stocking rate; $P < 0.01$) but it was not altered by stocking rate in other years and averaged 300 days. On irrigated farms, there were consistent reductions in lactation length with increasing stocking rate in years 1 and 2 (–17; $P < 0.01$) but no effects in years 3 and 4. Lactation length averaged 305 days at 4.1 cows/ha in years 1 and 2 and at all stocking rates in years 3 and 4.

Cow production in short lactations (years 1 and 2)

In years 1 and 2, when cows were dried off early if bought in feed resources were exhausted, milk production per cow was reduced at higher stocking rates on both dryland and irrigated farms (Table 1; $P < 0.01$). Milk fat and protein concentrations averaged 3.6 and 2.9% on dryland pastures and 3.7 and 2.9% for irrigated pastures, respectively, and were not altered with stocking rate. Fat and protein yields were reduced with increased stocking rate (Table 1). Liveweight of cows was reduced with stocking rate on irrigated farmlets, though not on dryland farmlets (Table 1). Condition score averaged 4.9 and was not altered with stocking rate.

Cow production in complete lactations (years 3 and 4)

Where extra purchased fodder was used to maintain lactations, stocking rate had no effect on milk yield on dryland or irrigated farmlets ($P > 0.05$). Mean milk yield averaged 8096 and 8227 kg/cow.year for dryland and irrigated farmlets, respectively. Both yields and concentrations of fat and protein were unaffected by stocking rate and averaged 3.4 and 3.1% for dryland farmlets and 3.6 and 3.1% on irrigated farmlets, respectively. In all years there were temporary reductions in fat percentage in milk during winter when ~10 kg DM concentrates was being fed daily with high quality pasture, and NDF content of the diet was calculated to be less than 25% DM (data not shown).

Liveweight and condition score were not altered by stocking rate on dryland farmlets. On irrigated farmlets there was a reduction of 30 kg liveweight and –0.15 condition score with increasing stocking rate ($P < 0.05$).

Milk yield per hectare

On dryland farmlets, yields of milk, fat and protein per hectare increased substantially with stocking rate for both short and complete lactations (Fig. 3). The response rate for milk yield (mean ± s.e.) varied between years ($P < 0.01$), being 3554 (±955) and 9241 (±1351) in years 1 and 2 respectively and 7614 (±602) kg/ha.unit change in stocking rate for years 3 and 4. Total milk output from dryland farms ranged from 18 000 kg/ha at 2.5 cows/ha to 34 000 kg/ha at 4.1 cows/ha ($P < 0.01$). Yields of fat (mean ± s.e.) increased with stocking rate in years 1 and 2 (200 ± 34 kg/ha.unit change in stocking rate) and in years 3 and 4 (258 ± 22 kg/ha.unit change in stocking rate).

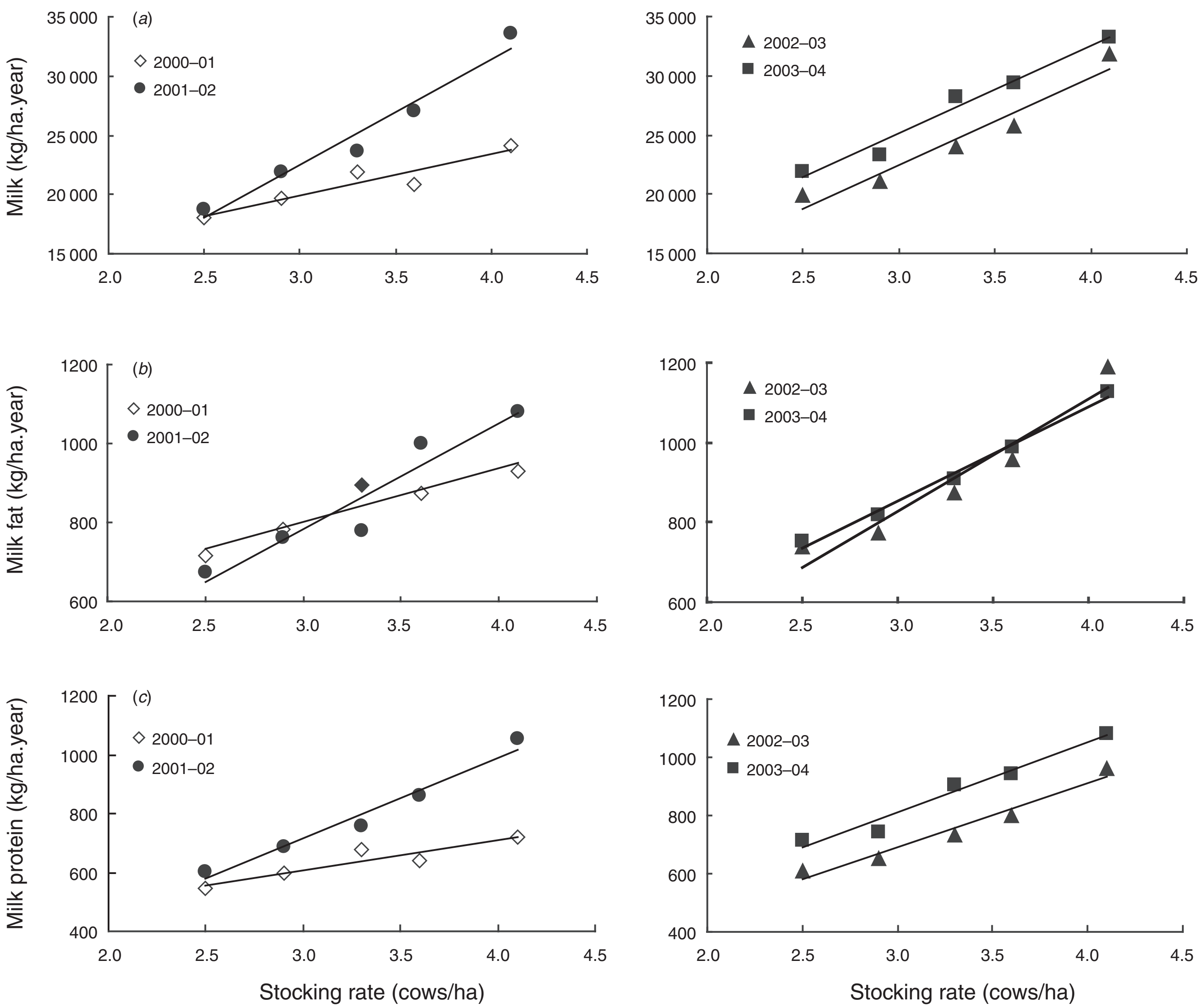

Fig. 3. The relationship of stocking rate with (*a*) milk, (*b*) fat and (*c*) protein production per hectare for dryland farmlets over short (years 1 and 2) and complete lactations (years 3 and 4).

Protein yield (mean ± s.e.) increased by 103 (±26) ($P < 0.05$) and 275 (±37) ($P < 0.01$) kg per unit increase in stocking rate in years 1 and 2 ($P < 0.01$), and by 229 (±18) kg in years 3 and 4 ($P < 0.01$).

On irrigated farms there were no differences between years in either short or complete lactations (Fig. 4). Milk, fat and protein yields (mean ± s.e.) increased ($P < 0.01$) by 4965 (±894), 167 (±25) and 138 (±31) kg per unit increase in stocking rate in short lactations, and by 8685 (±492), 316 (±23) and 265 (±16) respectively in complete lactations. Total milk output ranged from 30 000 to 60 000 kg/ha.year (Fig. 4).

There was a close relationship between total feed intake and milk solids production (R^2 = 0.98; Fig. 5), and this was not different between treatments.

Soil nutrient content

The effects of stocking rate on soil nutrient levels were consistent across years and mean values are shown in Table 2. On dryland pastures there were increases in nitrate nitrogen, P, K, S, conductivity and pH. Soil carbon was not altered with stocking rate. Treatment effects were similar for irrigated pastures, though levels of all nutrients except nitrate nitrogen were higher for irrigated than dryland pastures (Table 2).

The changes in N, P and K content of soil reflected the increasing disparity between amounts of those nutrients applied as fertiliser and through feed supplements and amounts removed as milk and silage or hay. This difference increased linearly with stocking rate and was greater on irrigated than dryland pastures (Fig. 6). At the lowest stocking rate there was a positive difference of 200 kg N/ha.year, and this increased to 400 kg N/ha.year under dryland pastures and 1000 kg N/ha.year under irrigation. At the common stocking rate of 4.1 cows/ha, the greater difference for irrigated pastures reflects the higher inputs of N fertiliser. The P difference ranged from 40 to 150 kg/ha.year for dryland pastures and from 150 to 410 kg/ha.year for irrigated pastures. Potassium differences increased similarly, from 50 to 180 kg/ha.year for

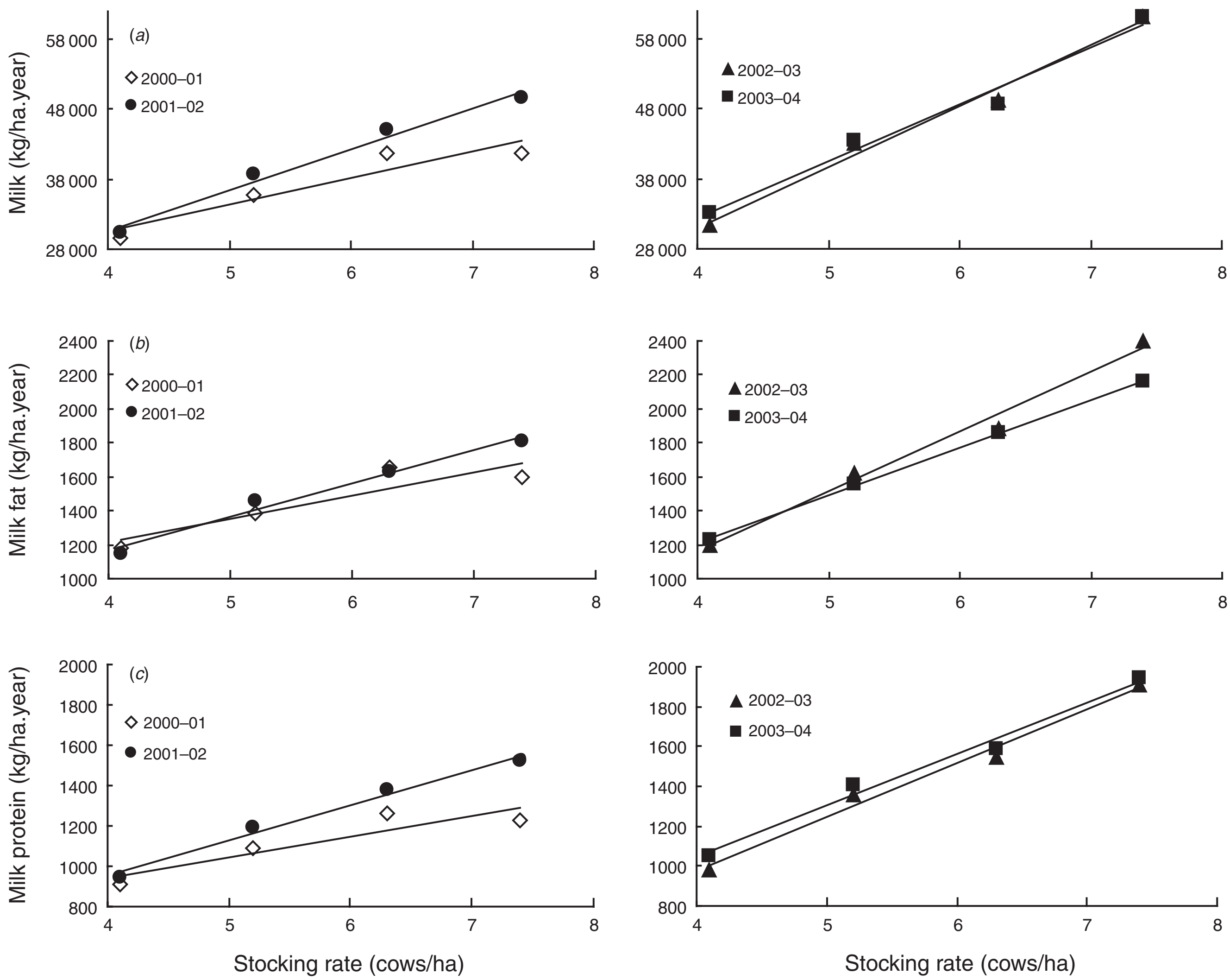

Fig. 4. The relationship of stocking rate with (*a*) milk, (*b*) fat and (*c*) protein production per hectare for irrigated farmlets over short (years 1 and 2) and complete lactations (years 3 and 4).

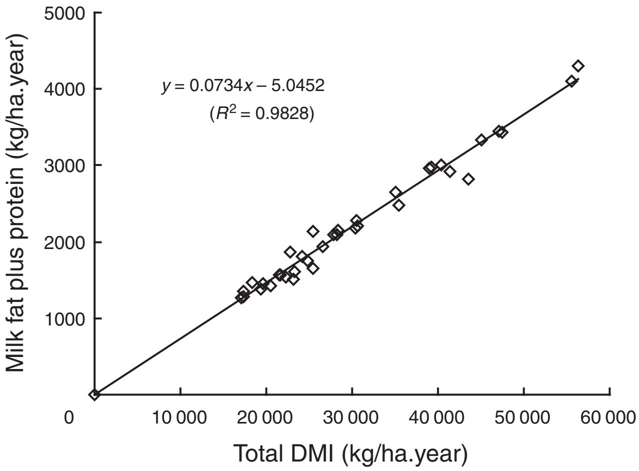

Fig. 5. The mean (for all treatments) relationship over 4 years between total feed intake and milk production per hectare for cows at different stocking rates on dryland and irrigated pastures.

dryland pastures and from 100 to 300 kg/ha.year for irrigated pastures.

Inputs of N to the positive nutrient balance were equally distributed among grain mix, purchased fodder and fertiliser, whereas fertiliser accounted for 50% of P inputs. K inputs were primarily through purchased fodder and the grain mix, with a similar quantity from each.

Worm numbers and biomass

For dryland farms, there was no relationship between worm numbers or biomass and stocking rate. With irrigated farms, numbers and biomass at 4.1 cows/ha averaged 90 worms and 13 kg/ha, respectively, and there were declines in both numbers (–15 ± 2.2; $P < 0.05$) and biomass (–1.8 ± 0.25, $P < 0.05$) with increasing stocking rate. In the population of earthworms positively identified in 2001, 70% were *Aporrectodea rosea*, 24% *A. caliginosa* and 6% *Microscolex dubius*.

Discussion

This experiment used stocking rates which were well above those used in commercial practice and in previous farmlet trials in South Australia (Valentine 1999), and milk and milk solids output per hectare showed a strong and positive linear association with stocking rate to the highest levels used. This was achieved through the use of a feeding system which enabled each cow to have a successful lactation, independent of the stocking rate. Even in years 1 and 2, when the budgeted amounts of purchased fodder were shown to be inadequate, the relatively high inputs of grain and fodder ensured a sound lactation, though this was shortened by a lack of fodder towards the end of lactation. This was in keeping with the expressed industry objective of utilising very high stocking rates, without the risk of cow failure, to ensure a high utilisation of grass (Wales *et al*. 2006). Such an experimental design avoided the risk of reaching a break point where output per hectare might be reduced at high stocking rates due to large reductions in production per animal (King and Stockdale 1980), and most effects of stocking rate would be evident through changes in pasture utilisation (Stockdale and King 1980).

However, net pasture accumulation and utilisation were unaffected by stocking rate in both the dryland and irrigated farmlets. All treatments showed weed invasion and the total pasture harvests, as grazed pasture and conserved fodder, were similar for treatments within the dryland and irrigated farmlets. As stocking rate increased more pasture was grazed directly and less pasture was conserved and fed back to cows. Though not statistically significant, the highest stocking rate on irrigated

Table 2. Mean nutrient contents of soil sampled in March each year, from 2000 to 2004 inclusive, at a range of stocking rates for both dryland and irrigated pastures

**, $P < 0.01$; *, $P < 0.05$; n.s., not significant; –, slope not significant ($P > 0.05$)

Measurement						Slope (± s.e.)	Signif.
			Dryland farmlets				
Stocking rate (cows/ha)	2.5	2.9	3.3	3.6	4.1		
Nitrate N (mg/kg)	31	39	39	43	52	11.4 (± 1.2)	**
P (mg/kg)	90	101	88	99	117	13.1 (± 3.6)	*
K (mg/kg)	219	283	249	288	346	67 (± 11)	**
S (mg/kg)	16.4	16.6	18.1	20.6	23.3	4.5 (± 0.5)	**
Organic C (%)	3.9	3.7	4.3	4.0	3.83	–	n.s.
Conductivity (dS/m)	0.175	0.157	0.208	0.226	0.259	0.051 (± 0.005)	**
pH (water)	5.7	5.8	5.8	5.7	5.9	0.068 (± 0.033)	*
			Irrigated farmlets				
Stocking rate (cows/ha)		4.1	5.2	6.3	7.4		
Nitrate N (mg/kg)		46	61	58	60	3.5 (± 1.4)	*
P (mg/kg)		142	150	171	190	18.8 (± 4.4)	*
K (mg/kg)		325	398	413	443	33 (± 6)	**
S (mg/kg)		32.7	36.2	34.2	39.5	1.7 (± 0.6)	*
Organic C (%)		4.53	4.42	4.46	4.55	–	n.s.
Conductivity (dS/m)		0.898	0.934	0.904	0.955	–	n.s.
pH (water)		6.7	6.7	6.7	6.8	0.02 (± 0.01)	*

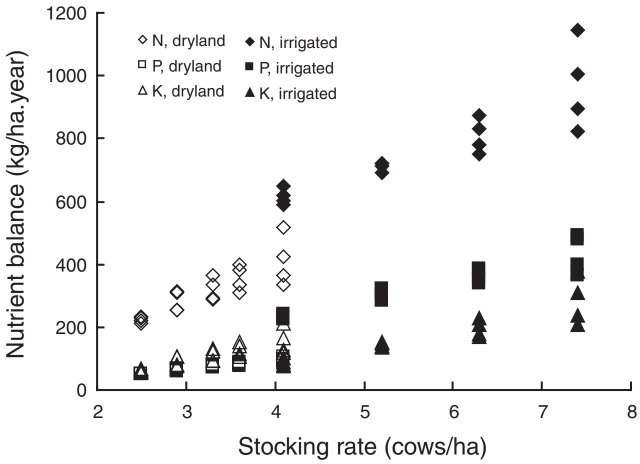

Fig. 6. The excess of inputs over outputs of N, P and K for dryland and irrigated pastures under intensive management and a range of stocking rates.

farmlets (7.4 cows/ha) may have been an exception to this conclusion, as empirical evidence suggested severe pugging during the wet winters and invasion of summer active weeds, notably water couch (*Paspalum distichum*). Mean pasture harvest was on average 1 t/ha less for this treatment. Horne (1987) has shown that compaction and pugging of soil by grazing cows can reduce pasture use by 20–40%. Otherwise the robust pasture growth under high stocking rates was unexpected, as other experiments have shown that, at high stocking rates with sheep on dryland pastures (Cayley *et al*. 1998) or cows on irrigated pastures (Stockdale and King 1980), pasture growth can be suppressed. However, in the markedly Mediterranean environment of south-western Australia van Houtert (2002) reported similar pasture utilisation for pastures grazed at 1.2 to 2.4 cows/ha. The short, but rapid period of high pasture growth rates for these pastures, particularly dryland, may limit the impact of grazing on pasture regrowth, as Stockdale and King (1998) showed any reduction in pasture growth is associated with reductions in residual pasture after grazing and subsequent effects on regrowth.

The data also show that all pasture was utilised at each of the stocking rates used. This indicates that the lowest stocking rates used in both dryland and irrigated farmlets, and the maintenance of cows in a productive state through supplementation, were effective in achieving an aim of the study of ensuring full utilisation of pasture, and so avoid the substitution often encountered with grazing studies (Stockdale 2000). There was a change in the amounts of pasture conserved during spring and, as this was reduced with higher stocking rates, there was an increased need to purchase fodder to maintain the cows' targeted intake. Previous research indicates that an increase in pasture harvest occurs with increased stocking rate to relatively high levels of pressure on the biological system, and an increase in stocking rate will often increase the percentage utilisation of pasture grown (Stockdale and King 1998). At high stocking rates there is often a reduction in pasture growth rate. Initially, this may be compensated by an increase in pasture quality but, beyond a certain point, total energy harvested declines (Stockdale and King 1998). There were modest changes in pasture quality in the present experiment, but effects on yields were not seen, perhaps because the lowest stocking rates were sufficiently high to ensure full utilisation of pasture. The levels of pasture utilisation measured were similar to those measured for the highest percentile of dairy farmers in the region, which is 7 t DM/ha for dryland pastures and 14 t DM/ha for irrigated pastures (S. Scown, pers. comm.). Average pasture utilisation on dairy farms is approximately half these levels.

The lack of change in pasture utilisation meant that all the increases in milk and milk solids output per hectare were due to the increased inputs of grain and purchased fodder, and these drove the relationship between stocking rate and milk output per hectare (ratio of milk output to total feed input of 0.94 L/kg DM). More cows were supported on the same area, provided purchased feed resources were increased to totally account for the additional feed intake requirements. This suggests a robust system of production, where the benefits are based entirely on the ratio of milk price to cow, grain and hay prices. In other environments, and particularly where the level of supplementary feeding is modest, changes in both animal and pasture production with increases in stocking rate make such calculations more complicated.

The effects of irrigation, and the associated fertiliser inputs, on pasture growth were outstanding. Pasture harvest averaged 14 t DM/ha on irrigated pastures compared with 6.5 t DM/ha on dryland pastures, and maintained growth rates over 60 kg DM/ha.day for 6 months, compared with 2 months on dryland pastures. It has been well demonstrated in other localities in the Mediterranean zone of Australia that irrigation can markedly increase the production of pasture, particularly during the hot, clear and dry summers (King and Stockdale 1998), and is an effective means of increasing feed resources for cows. At the common stocking rate of 4.1 cows/ha for dryland and irrigated pastures, the primary benefit was for irrigation to provide pasture in place of conserved and purchased fodder, and the measured difference in milk output per hectare was in the order of 3 t milk/ha.year. However, irrigated pastures were able to support stocking rates up to the order of 6.3 cows/ha and, at this level, total milk production per hectare was ~20 t/ha more than on dryland pastures. Similar maximum stocking rates for irrigated pastures have been reported from northern Victoria (King and Stockdale 1998). The results demonstrate the potential of irrigated pasture systems to maintain highly intensive milk production systems.

The current data raise some substantial questions as to the sustainability of these intensive systems of production. The build-up of soil minerals was very high, related to both the fertiliser inputs and the large amounts of supplementary feed inputs. In many cases levels were well above those recommended as optimum for this environment. Nutrient balances on the current farmlets showed large positive differences of N, P and K between inputs and outputs. On the irrigated farmlets up to 1000 kg N/ha.year was applied in excess of that removed from the pasture. Intense dairy production is associated with a greater import of nutrients onto the farm through fertilisers and supplementary feeds and, as a consequence, the potential for transfer of soil P to surface and groundwater is increased (Haygarth 1997). Phosphorus input was approximately equally split between fertiliser and feed, though fertiliser was likely to have had the greater impact on P loads in nutrient runoff (Nash and Halliwell 1999). High soil nitrate nitrogen levels have been shown to lead to high rates of nitrate leaching (Eckard *et al*. 2004). Phosphorus is generally considered to be relatively immobile in most soils while nitrogen is considered to be very mobile with losses through leaching or vaporisation (Young *et al*. 1996). It appears that the mobility of N in soil was greater on the irrigated farmlets than the dryland farmlets and this could be related to greater leaching under irrigation (Pakrou *et al*. 1997). Organic carbon levels did not alter with stocking rate, perhaps because the high pasture utilisation did not enable a substantial incorporation of pasture organic matter back into the soil. Other studies have shown an increase in soil organic matter content with years of irrigated pasture at lighter stocking rates (Barley 1953). The ingress of weeds occurred at all stocking rates and may indicate a potential problem with pasture production over a longer time frame. If earthworm concentration and species richness in soil can be used as an indicator of soil health and potential grazing system sustainability (Baker 1998), then the highest stocking rate on the irrigated farmlets would be deemed to be at risk.

The current farmlet design enabled the core question, whether there are benefits in high stocking rates if cows are fed to requirements, to be tested in a realistic framework over an extended period of time. It is unlikely this could have been done with small numbers of cows or more limited treatments, and continuous measurements over 4 years allowed some conclusions as to longer-term effects. Thus, they were more applicable to a commercial farm than shorter, more refined studies. However, some restrictions were still apparent which had the potential to alter the conclusions. The high expense of treating each herd separately may have precluded some management activities which could not be made common to all farmlets. For example, during winter the highest stocking rates on irrigated pastures caused substantial pugging but it was not possible to provide 'sacrifice' paddocks to these animals. The present design did enable an applied question to be addressed in a more relevant way than previous experiments using small numbers of animals over shorter periods, though future farming system experiments may require even greater flexibility in management procedures.

Conclusions

The high stocking rates tested in this study exceed those commercially used in milk production systems in southern Australia and provide an insight to the productivity and sustainability of such systems ahead of industry uptake. There were no advantages in pasture harvest to large increases in stocking rate, and the increases in milk production were entirely dependent on purchased feeds. Pastures were able to sustain these high stocking rates without a reduction in pasture growth rates and, as a consequence, there were large increases in milk output per hectare. Irrigation was a very effective means of increasing feed supply to cows. However, the current experiment also raises some serious questions as to the environmental sustainability of such systems, with large excesses of nutrients accumulating in the soil and elsewhere. The success of such systems will largely depend on the ability to moderate these effects and the cost of the large amounts of purchased feedstuffs required to maintain them.

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References

Baker GH (1998) The ecology, management, and benefits of earthworms in Agricultural soils with particular reference to southern Australia. In 'Earthworm ecology'. (Ed. CA Edwards) (St. Lucie Press: Washington, DC)

Barley KP (1953) The root growth of irrigated perennial pastures and its effect on soil structure. *Australian Journal of Agricultural Research* **4**, 283–291. doi: 10.1071/AR9530283

Busby G, Hetherington G, Itzstein R, Murphy R (2005) 'Balancing dairy production and profits in northern Australia.' (Department of Primary Industries and Fisheries: Brisbane)

Cayley JWD, Hannah MC, Kearney GA, Clark SG (1998) Effects of phosphorus fertiliser and rate of stocking on the seasonal pasture production of perennial ryegrass-subterranean clover pasture. *Australian Journal of Agricultural Research* **49**, 233–248. doi: 10.1071/A97113

Dickens A, Fitzgerald B (1997) The economics of high feed inputs and irrigation. In 'Proceedings of the large herds Australia conference, Warrnambool'. pp. 22–37.

Earle D (1976) A guide to scoring dairy cow condition. *Journal of Agriculture, Victoria* **37**, 147–150.

Eckard RJ, White RE, Edis R, Smith A, Chapman DF (2004) Nitrate leaching from temperate perennial pastures grazed by dairy cows in south-eastern Australia. *Australian Journal of Agricultural Research* **55**, 911–920. doi: 10.1071/AR04042

Fleming NK, Cox JW (1998) Chemical losses off dairy catchments located on a texture contrast soil: carbon, phosphorus, sulphur, and other chemicals. *Australian Journal of Soil Research* **36**, 979–995. doi: 10.1071/S98013

GENSTAT 6 Committee (2002) 'GenStat 6 reference manual.' (VSN International: Oxford, UK)

Haygarth P (1997) Agriculture as a source of phosphorus transfer to water: sources and pathways. Scientific Committee on Phosphates in Europe, Scope Newsletter No. 21.

Horne DJ (1987) Soil and unsafe grazing days on the Tokomaru silt loam in the winter of 1986. In 'Massey University Dairy Farming Annual'. pp. 131–133. (Massey University: Palmerston North, NZ)

King KR, Stockdale CR (1980) The effects of stocking rate and nitrogen fertiliser on the productivity of irrigated perennial pasture grazed by dairy cows. 2. Animal production. *Australian Journal of Experimental Agriculture and Animal Husbandry* **20**, 537–542. doi: 10.1071/EA9800537

Little DL, Frensham AB (1993) A rod-point technique for estimating botanical composition of pastures. *Australian Journal of Experimental Agriculture* **33**, 871–875. doi: 10.1071/EA9930871

Mitchell GJ, Chinner SR (1995) Pasture utilisation on dairy farms in the Mount Lofty Ranges 1992–94. In 'Dairy pasture systems: dairy farm studies in the Mount Lofty Ranges of SA, Technical Report No. 232'. (Eds GJ Mitchell, SR Chinner) pp. 51–60 (Primary Industries South Australia and the South Australian Research and Development Institute: Adelaide)

Nash DM, Halliwell DJ (1999) Fertilisers and phosphorus loss from productive grazing systems. *Australian Journal of Soil Research* **37**, 403–429. doi: 10.1071/S98087

National Research Council (1978) 'Nutrient requirements of dairy cattle.' 5th edn. (National Academy Press: Washington, DC)

Pakrou N, Dillon P, Stranger G (1997) Impact of pastoral land use on ground water quality. Centre for Groundwater Studies, Final Report LWRRDC Project No. CWW9, SA.

Rogers G (1973) A study of the effects of high stocking rates on the production of perennial pasture and its utilisation by dairy cattle. MAgricSci Thesis, University of Melbourne, Melbourne, Australia.

SCA (1990) 'Feeding standards for Australian livestock: ruminants.' (CSIRO Publishing: Melbourne)

Stockdale CR (1984) Evaluation of techniques for estimating the yield of irrigated pastures intensively grazed by dairy cows. 2. The rising plate meter. *Australian Journal of Experimental Agriculture and Animal Husbandry* **24**, 305–311. doi: 10.1071/EA9840305

Stockdale CR (2000) Levels of pasture substitution when concentrates are fed to grazing dairy cows in northern Victoria. *Australian Journal of Experimental Agriculture* **40**, 913–921. doi: 10.1071/EA00034

Stockdale CR, King KR (1980) The effects of stocking rate and nitrogen fertiliser on the productivity of irrigated perennial pasture grazed by dairy cows. 1. Pasture production, utilisation and composition. *Australian Journal of Experimental Agriculture and Animal Husbandry* **20**, 529–536. doi: 10.1071/EA9800529

Thomson T (1998) Six steps to improve irrigation for fodder production. In 'Proceedings of the large herds Australia conference, Tanunda'. pp. 97–123.

Valentine SC (1999) FLAXLEY FARMLETS – Cost effective pasture-based dairy farming systems in the low summer rainfall zone. Final Report to the Dairy Research and Development Corporation.

van Houtert M (2002) Productivity, profitability and sustainability of intensive Western Australian dairy farming systems (phase 2). Department of Agriculture, DAW041 – Milestone report 7, Vasse milk farmlets, Western Australia.

Wales WJ, Heard JW, Ho CKM, Leddin CM, Stockdale CR, Walker GP, Doyle PT (2006) Profitable feeding of dairy cows on irrigated dairy farms in northern Victoria. *Australian Journal of Experimental Agriculture* **46**, 743–752. doi: 10.1071/EA05357

Walker GP, Stockdale CR, Wales WJ, Doyle PT, Dellow DW (2001) Effect of level of grain supplementation on milk production responses of dairy cows in mid to late lactation when grazing irrigated pastures high in paspalum (*Paspalum dilatatum* Poir). *Australian Journal of Experimental Agriculture* **41**, 1–11. doi: 10.1071/EA00076

Ward G (1998) Success depends upon knowing when to water. In 'Proceedings of the large herds Australia conference, Tanunda'. pp. 124–130.

Young WJ, Marston FM, Davis JR (1996) Nutrient exports and land use in Australian catchments. *Journal of Environmental Management* **47**, 165–183. doi: 10.1006/jema.1996.0043

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