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A comparison of stocking methods for beef production in northern Australia: pasture and soil surface condition responses

Trevor J. Hall[A,F], *John G. McIvor*[B], *David J. Reid*[C], *Paul Jones*[D], *Neil D. MacLeod*[B], *Cam K. McDonald*[B] *and David R. Smith*[E]

[A]Agri-Science Queensland, Department of Agriculture, Fisheries and Forestry, PO Box 102, Toowoomba, Qld 4350, Australia.
[B]CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, Qld 4001, Australia.
[C]Agri-Science Queensland, Department of Agriculture, Fisheries and Forestry, PO Box 6014, Red Hill, Rockhampton, Qld 4701, Australia.
[D]Agri-Science Queensland, Department of Agriculture, Fisheries and Forestry, Locked Mail Bag 6, Emerald, Qld 4720, Australia.
[E]Agri-Science Queensland, Department of Agriculture, Fisheries and Forestry, PO Box 976, Charters Towers, Qld 4820, Australia.
[F]Corresponding author. Email: trevor.hall@daff.qld.gov.au

Abstract. Historical stocking methods of continuous, season-long grazing of pastures with little account of growing conditions have caused some degradation within grazed landscapes in northern Australia. Alternative stocking methods have been implemented to address this degradation and raise the productivity and profitability of the principal livestock, cattle. Because information comparing stocking methods is limited, an evaluation was undertaken to quantify the effects of stocking methods on pastures, soils and grazing capacity. The approach was to monitor existing stocking methods on nine commercial beef properties in north and south Queensland. Environments included native and exotic pastures and eucalypt (lighter soil) and brigalow (heavier soil) land types. Breeding and growing cattle were grazed under each method. The owners/managers, formally trained in pasture and grazing management, made all management decisions affecting the study sites. Three stocking methods were compared: continuous (with rest), extensive rotation and intensive rotation (commonly referred to as 'cell grazing'). There were two or three stocking methods examined on each property: in total 21 methods (seven continuous, six extensive rotations and eight intensive rotations) were monitored over 74 paddocks, between 2006 and 2009. Pasture and soil surface measurements were made in the autumns of 2006, 2007 and 2009, while the paddock grazing was analysed from property records for the period from 2006 to 2009. The first 2 years had drought conditions (rainfall average 3.4 decile) but were followed by 2 years of above-average rainfall. There were no consistent differences between stocking methods across all sites over the 4 years for herbage mass, plant species composition, total and litter cover, or landscape function analysis (LFA) indices. There were large responses to rainfall in the last 2 years with mean herbage mass in the autumn increasing from 1970 kg DM ha^{-1} in 2006–07 to 3830 kg DM ha^{-1} in 2009. Over the same period, ground and litter cover and LFA indices increased. Across all sites and 4 years, mean grazing capacity was similar for the three stocking methods. There were, however, significant differences in grazing capacity between stocking methods at four sites but these differences were not consistent between stocking methods or sites. Both the continuous and intensive rotation methods supported the highest average annual grazing capacity at different sites. The results suggest that cattle producers can obtain similar ecological responses and carry similar numbers of livestock under any of the three stocking methods.

Additional keywords: cell grazing, continuous grazing, grazing methods, grazing systems, rotational grazing.

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Introduction

The grazing lands of northern Australia have supported cattle grazing for over 150 years. The traditional grazing or stocking method was continuous, year-long grazing of mostly large paddocks on properties where 'animals were harvested', before infrastructure development of waters and sub-division fencing allowed planned grazing management (Stewart 1996). Some deleterious changes have occurred in soils and pastures during this time and there are concerns that the land resources are declining and productivity is not being maintained. For example, Tothill and Gillies (1992) concluded that 12% of the northern grazing lands were in a degraded state (severe soil deterioration and a predominance of undesirable pasture species) and 32% were in a deteriorating state (slight soil deterioration and increased presence of undesirable pasture species and/or woody weeds). In a survey of 375 beef properties in northern Australia (Bortolussi *et al*. 2005*b*), 48% of producer respondents reported some form of land degradation problems (erosion, salinity and encroachment of weeds). Silcock *et al*. (2005) reported declining livestock production and carrying capacity on poplar box country in southern Queensland as pasture condition declined through continuous grazing (no annual rest periods) at above the local average stocking rates. However, only a minority of cattle producers in northern Australia have records of liveweight changes of cattle to assess their long-term production status (Bortolussi *et al*. 2005*a*).

Systems of control and management of grazing animals in northern Australia have been evolving and several grazing systems and stocking methods are currently practised. In this paper, we use the definitions of Allen *et al*. (2011) who defined stocking method as ‘a defined procedure or technique to manipulate animals in space and time to achieve a specific objective’ and this includes methods such as continuous stocking, rotational stocking, and deferred stocking. These methods are sometimes referred to as grazing systems but Allen *et al*. (2011) defined a grazing system as ‘a defined, integrated combination of soil, plant, animal, social and economic features, stocking methods and management objectives to achieve specific results or goals’ and hence the stocking method is simply a component of a larger grazing system.

Conventional grazing management has been to ‘continuously’ graze areas i.e. livestock are left in one paddock for long periods with little or no alteration in numbers in response to changes in forage supply or body condition. This enables livestock to selectively graze preferred pasture components, increasing diet quality and hence potential livestock production. However, it can also allow frequent, repeated defoliation of desirable species, which may lead to their loss if stocking rates are too high (Mott 1987; Gardener *et al*. 1990; McIvor and Orr 1991; Tothill and Gillies 1992). At low stocking rates, grazing can be uneven with both under- and over-used patches in the same paddock (McIvor *et al*. 2005). Any rest periods in these ‘continuous’ methods are of short duration relative to the grazing period.

Rotational grazing (recurring periods of grazing and rest) is often recommended, especially during the growing season (Ash *et al*. 2002) to give more control of defoliation to prevent selective over-grazing, allow seeding of desired species, and to enable livestock to harvest forage more efficiently. Rotation methods vary widely, from extensive rotations, where there are only a few more paddocks than there are herds and rest periods vary from weeks to months, to intensive rotations with typically 20–60 paddocks per herd and where grazing periods, from 1 to 3 days, are much shorter than the rest periods, which may be 30–90 days. Timing and duration of rest is usually determined by forage growth rates (McCosker 2000; Briske *et al*. 2008).

Stocking methods can be considered to lie along an intensity spectrum, based on infrastructure, paddock size, duration of grazing and rest periods, decision-making and record keeping, from continuous grazing, with or without rest periods, through extensive rotational grazing to intensive rotational grazing. The more intensive rotations are commonly referred to as cell systems. The definitions and on-property operation of these methods can overlap.

There has been widespread interest in Australia in grazing management in recent years with debate over the merits of methods based on short grazing periods and long rest periods, e.g. short duration grazing, time-controlled grazing and cell grazing, compared with various forms of continuous stocking. Several producers have adopted these intensive grazing practices and report advantages in both financial performance and sustainability of resources (McCosker 1994, 2000; McArthur 1998; Gatenby 1999; Joyce 2000; Sparke 2000), while others have not observed positive results (e.g. Waugh 1997). Some reviews of grazing research have concluded that continuous stocking is no different ecologically from rotational stocking and may increase livestock production (Norton 1998). Several studies comparing stocking methods in the USA in the 1970s and 1980s showed little or no benefit from more intensive systems (Bryant *et al*. 1989; Hart *et al*. 1989; Taylor 1989). In a recent synthesis of research comparing continuous and rotational stocking, Briske *et al*. (2008) concluded that plant production was equal or greater in continuous compared with rotational grazing in 87% of the 23 experiments reviewed. Similarly, livestock production per head and per unit area was equal or greater in continuous compared with rotational grazing in 92 and 84% of the 38 and 32 experiments reviewed, respectively. This supports earlier studies in southern Africa where continuous and rotational stocking differed little in terms of their effects on livestock production or range condition (O’Reagain and Turner 1992). In contrast, Teague *et al*. (2011) found more intensive grazing management over 10 years, using a multi-paddock system, gave improved results for the maintenance of pasture and soil resources compared with continuous (full-year) stocking. Teague *et al*. (2013) have suggested reasons, such as management flexibility and paddock scale, for the differences between experimental results comparing continuous and rotational methods, and the perceptions of some multi-paddock operators.

Varying impacts of stocking methods on pastures and soil surfaces have been reported in Australian studies. Earl and Jones (1996) found a more favourable pasture composition for livestock and greater ground cover with cell grazing than continuous stocking on the Northern Tablelands of New South Wales. Dowling *et al*. (2005) used on-farm paired paddocks to compare continuous and time-controlled stocking with sheep and cattle in temperate Australia and concluded that there was no apparent medium-term benefit of time-controlled grazing over continuous stocking on pasture composition. Ground cover was greater and sediment losses less from time-controlled grazing than continuous stocking in traprock country in southern Queensland (Sanjari *et al*. 2009). Continuous grazing by sheep over 3 years in southern Australia was reported to decrease total soil macro-porosity and produce a smaller proportion of macro-pores in the topsoil compared with stable structural conditions under high-intensity and short-duration rotational grazing (Cattle and Southorn 2010). There have been limited empirical studies conducted in northern Australia but Alchin *et al*. (2008) found superior soil (surface condition and bulk density) and perennial grass density parameters from cell grazing compared with continuous stocking in a buffel grass [*Cenchrus ciliaris* L. or *Pennisetum ciliare* (L.)] pasture.

Intensive stocking methods are frequently promoted by management consultants and have been adopted by an increasing number of producers. This has attracted interest from other producers who are eager to improve livestock performance. They are interested in the concepts of intensive stocking methods but are unsure of the costs and benefits of such systems and whether they would be suited to their local environment, property infrastructure, management capacity and desired lifestyle. This interest from producers and their industry organisations prompted this research to investigate stocking methods in commercial practice in northern Australia in order to assist producers in deciding the most appropriate stocking methods for their purposes. This paper describes the project and presents the ecological results for pastures, soil surface conditions and grazing capacity.

Materials and methods

Research approach

Comparisons of stocking methods were made on commercial properties with established stocking methods in place. Conducting the comparisons on research stations would have ignored the fact that the owners/managers are the decision-makers and are the drivers of the management system on a property. In addition, our approach ensured that the comparisons were made under commercial conditions and enabled us to study established methods, to have a wide geographic spread of properties, and for comparisons to be made at an appropriate paddock scale. Since management (apart from stocking method) can have large impacts on performance, comparisons of stocking methods (continuous, extensive rotation and intensive rotation) were made on each property. In all cases the owners or managers made all management decisions, which were recorded on grazing charts, computer spreadsheets or occasionally in notebooks, and they conducted all the cattle management as part of their normal property operation. They were not influenced by the project team, whose on-property activity was limited to data collection and analysis. Since producers are continually responding to outside influences (e.g. growing seasons, forage availability, markets and labour supply), the actual stocking methods could vary over time. While this added to the commercial relevance of the work, it also meant that the ‘treatments’ were not fixed as they might be in a conventional experiment. The stocking methods were monitored over a 4-year period between 2005 and 2009 to cover a range of seasonal conditions (e.g. above- or below-average rainfall, which resulted in adjustments of stocking for a paddock).

Sites

Studies were conducted on nine established commercial beef properties (Fig. 1) with long-term owners. Details of these sites, including stocking methods, soil and vegetation type are shown in Table 1. The sites were selected to cover a range of annual rainfall in both northern and southern regions of Queensland, and to include both eucalypt (light textured soil) and brigalow (heavy textured soil) vegetation communities. All properties were beef cattle enterprises and eight included both breeding and growing cattle. One site (Condamine) grazed young growing cattle predominantly. All sites were managed by experienced owner-operators or on-site managers, all of whom possessed extensive local knowledge and had received some prior formal training in pasture management. Property owners or their intensive system (cell) managers on eight properties had received training with a minimum level of training being the Grazing for Profit course offered by Resource Consulting Services (RCS, Yeppoon, Qld, Australia). The owner-manager of the ninth property (Mundubbera) had received training through the Grazing Land Management course (Quirk and McIvor 2003) offered by the Queensland Government in conjunction with Meat and Livestock Australia. Both of these courses emphasise the importance of pasture management, carrying capacity and grazing pressure in all stocking methods and enterprises.

Daily rainfall on each property was recorded at the property homesteads with annual total rainfall reported in Table 2.

Stocking methods

Although stocking methods necessarily lie along a continuum, three broad categories can be identified: continuous grazing, extensive rotation and intensive rotation. On each property, at least two of these three stocking methods were already established and had been in operation for periods ranging between 1 and 12 years. Three properties were using all three of the stocking methods. A total of 21 individual methods were monitored. Within these methods, 74 paddocks (3–11 paddocks per site) were selected to be monitored. Paddock selection aimed to minimise differences in soil type, vegetation, topography, land condition and infrastructure between the stocking methods on a property. Only the selected paddocks within each method, were monitored, not the whole property. All paddocks, including the monitor paddocks, within a grazing method at all sites were managed similarly, with emphasis on pasture status and not on stocking rates.

For the seven continuously grazed pastures, one paddock only was monitored on each of the seven properties and cattle were present in the paddock for most of the time. Changes in stock numbers during the year were small but there were planned rest periods of a short duration every year. Only one continuous stocking method paddock at one site did not receive a rest period in 1 year during the 4-year study. Average size of the monitored paddocks was 551 ha (range 110–1304 ha) and average annual grazing duration was 311 days, including during drought years. Every paddock area was measured using GIS analysis after GPS marking of every fence line. This corrected some managers’ perceptions of the area of their paddocks. In the six properties with extensive rotations (6–18 rotation paddocks on a property), two or three rotation paddocks on each property (total number of paddocks, 13) were monitored. The average size of the monitored paddocks was 435 ha (range 38–1258 ha) and grazing periods were from 5 days to 12 months (in one paddock on one occasion), with an average annual grazing duration of 149 days. In each of the eight properties with intensive rotations (21–160 rotation paddocks on a property), 5–10 paddocks (total number of paddocks, 54) were monitored with an average size of 58 ha (range 6–172 ha), and grazing periods ranged from 1 to 37 days,

Fig. 1. Location of nine properties with different stocking methods in brigalow and eucalypt land types across Queensland.

with an average annual grazing duration of 12 days. A total area of 12 660 ha was monitored in the 74 paddocks.

Cattle numbers and grazing days

While it is desirable for grazing pressure to be similar for all stocking methods at any one property and in any one year, the actual management decisions that were employed meant this did not always occur. Systems were grazed by either growing cattle, mainly steers, or breeding animals with their progeny and bulls. No stocking methods were exclusive to any particular class of cattle. Grazing information (number and class of cattle, changes in numbers, reproductive status, liveweight, either by visual estimates or weighing, and periods of rest and grazing for each paddock) was provided by the owners and managers from their grazing records. Various methods were used to record this grazing information including grazing charts, notebooks or computer spreadsheets.

The grazing data were used to calculate the number of stock days ha^{-1} (SDH) for each year for each stocking method. The number of cattle in each class by liveweight range and reproductive status was converted to total livestock equivalents (AE) per paddock, using a standard AE conversion table (one AE is a dry cow of 450-kg liveweight at maintenance). The

Table 1. Site and stocking method information for nine sites in Queensland

Sites	Blackwater	Bowen	Clermont	Condamine	Injune	Mundubbera	Richmond	Rockhampton	Surat
Mean annual rainfall (mm)	570	990	570	540	710	690	500	690	540
Soil type (Isbell 1996)	Chromosol, Dermosol	Hydrosol, Rudosol	Vertosol, Dermosol	Chromosol, Dermosol	Chromosol, Sodosol	Dermosol, Chromosol	Kandosol	Chromosol, Dermosol	Red Chromosol
Land type (Whish 2011)	Brigalow/ Blackbutt	Poplar gum/ Melaleuca	Brigalow/ Gidgee	Poplar box	Brigalow/Poplar box	SLIB[A] on duplex	Sandy forest	SLIB on duplex	Poplar box/SLIB
Major grass	*Cenchrus ciliaris*[B]	*Urochloa mosambicensis*	*Cenchrus ciliaris*	*Cenchrus ciliaris*	*Cenchrus ciliaris*	*Heteropogon contortus*	*Aristida* spp.	*Bothriochloa ewartiana*	*Cenchrus ciliaris*
Stocking methods									
Continuous									
Paddock size (ha)	228	801	1304	608	110	247	–	561	–
Class of cattle	Breeders	Mixed classes	Breeders	Steers/heifers	Steers/bulls	Breeders	–	Breeders	–
Extensive rotation									
No. of paddocks	15	–	6	–	–	6	18	8	18
Paddock size (ha)[C]	121	–	909	–	–	383	809	161	43
Year commenced	1999	–	1994	–	–	2005	1994	2005	2002–03
Class of cattle	Steers	–	Breeders	–	–	Breeders	Steers/ heifers	Breeders	Breeders
Intensive rotation									
No. of paddocks	24	64	30	44	42	–	160	25	50
Paddock size (ha)[C]	28	21	142	35	89	–	98	41	25
Year commenced	1998–99	2002	1996	2004	2000	–	1994	2005	2002–03
Class of cattle	Steers	Breeders	Steers	Steers/heifers	Steers	–	Breeders	Breeders	Breeders

[A]SLIB = Silver-leafed ironbark.
[B]*Pennisetum ciliare* (L.) is a synonym for *C. ciliaris* (L.).
[C]Average of monitor paddocks.

Table 2. Annual rainfall (mm) during the experimental period and long-term mean rainfall at nine sites
n.a. – not applicable

Site	2005–06	2006–07	2007–08	2008–09	Long-term (>100 years)
Blackwater	332	534	576	636	573
Bowen	771	758	1232	1318	987
Clermont	532	548	682	600	572
Condamine	418	435	662	667	541
Injune	445	432	659	803	710
Mundubbera	460	564	559	606	693
Richmond	636	524	n.a.	n.a.	503
Rockhampton	590	488	898	692	690
Surat	495	301	586	617	537

AE calculations are adjusted for liveweight, seasonal feed demand and reproductive status. The annual sum of the AE for each graze period multiplied by the number of days the cattle grazed the paddock in each period, gave the annual total stock (AE) days. This was divided by the paddock area (ha) to give the annual SDH value for each paddock. The grazing method means were the average annual SDH for the monitored paddocks within each method at each site.

Pasture measurements

On each property, depending on the stocking methods in use, one paddock was selected to monitor the continuous stocking method, 2–3 paddocks were selected to monitor the extensive rotation stocking method, and 5–10 paddocks were selected to monitor the intensive rotation stocking method. Aerial photographs and on-ground, subjective visual surveys were used to identify the paddocks with similar land types, features and stages of development (especially in regard to distribution of water points, pasture communities, tree clearing and associated regrowth control) that were used to monitor the different stocking methods.

Pasture and soil surface measurements were made at the end of the growing season (April–May) in 2006, 2007 and 2009, except for the Richmond site, which was not sampled in 2009 due to cessation of the intensive stocking method. Pastures were not recorded in 2008 due to financial constraints. The data were collected from ~0.5 to 4 quadrats (50 × 50 cm) ha^{-1}, the total number depending on paddock size, on a grid system in each paddock along fixed transects that covered the entire paddock. The individual transects were ~100 m apart, and the quadrats along each transect were 50–100 m apart (depending on paddock size). Each quadrat was located each year by GPS reference so that samples taken in different years were within several metres of the same location. A total of 7930, 7420 and 6270 quadrats were sampled across all paddocks in 2006, 2007 and 2009, respectively.

Vegetation/pasture data were collected and analysed using the BOTANAL technique (Tothill *et al*. 1992), which involves visual estimation of pasture variables in quadrats. In each quadrat the following assessments were made of:

(i) Herbage mass, which was rated on a 0–99 scale and standardised for dry matter yield with 15 cut quadrats (of 0.25 m^2) at each site;

(ii) Species composition. There were 61 major pasture species (common, widespread and potential grazing pressure indicators) identified in addition to other minor (infrequent or only locally common) species and some unidentified species across the nine properties. A species photographic booklet was produced so identification by all recorders was consistent across sites and years. All species were allocated to four functional pasture groups: 3P (perennial, productive and preferred) native grasses, perennial sown exotic grasses, legumes (native and exotic), and other species (annual grasses, forbs, sedges and non-3P perennial grasses). Species frequency was calculated as a percentage of quadrats each species occurred in, within each paddock;

(iii) Diversity of plant species – measured as the number of species (native and exotic) per quadrat;

(iv) Ground cover – the proportion (%) of the soil covered by herbage, low shrubs (<3 m), stones, logs and litter;

(v) Litter cover – the proportion (%) of the soil covered by readily decomposable litter (detached leaves, stems, twigs, seeds, fruits and dung).

Soil surface condition assessment

The soil surface condition parameters of the landscape function analysis (LFA) method (Tongway and Hindley 2005) were assessed in every BOTANAL pasture quadrat each year. The values for these indicators were then used to calculate indices of stability, infiltration/runoff and nutrient cycling status using the LFA methodology formulae for each index for every paddock in the years 2006, 2007 and 2009. Each index is the sum of the rating value for a range of pasture, soil surface and shrub cover parameters expressed as a percentage of the potential maximum value. These parameters are for stability index (maximum value 40): soil, litter and cryptogam cover, crust brokenness, erosion type and severity, deposited materials, surface hardness and slake test (scale value is average for the particular land type at each site); for infiltration/runoff index (maximum 57): perennial grass/shrub cover (<3 m high above each quadrat), litter cover, its origin and incorporation, surface roughness and hardness, soil texture and slake test; for nutrient cycling status index (maximum 43): perennial grass/shrub cover, litter cover, litter origin and incorporation, cryptogam cover and surface roughness. The LFA indices for each stocking method were then calculated from the mean of the monitored paddocks at each site. The mean indices for each grazing method for each site were then analysed statistically.

Land condition was assessed in every quadrat of the BOTANAL recording (in autumn 2006, 2007 and 2009) from the parameters: pasture composition (perennial grass species), soil surface condition ground cover and shrub cover (<3 m high within 10 m of the recording point), by the 'ABCD' framework method used in the Grazing Land Management Edge Network course (Quirk and McIvor 2003). A summary description of the four land condition classes is: A – condition has high 3P grass composition, ground cover >70%, few weeds, good soil condition, no erosion and negligible signs of woodland thickening; B – condition may have declining 3P grasses, ground cover 40–70%, signs of previous erosion and/or susceptibility to erosion, and some thickening of woody plants; C – condition has 3P grass decline with significant presence of less-favoured species, ground cover

<40%, obvious signs of past erosion and/or current susceptibility is high, and a general thickening of woody plants, and; D – condition has a lack of perennial grasses or forbs, severe erosion or scalding, and thickets of woody plants may occur. This hostile environment for plant growth requires disturbance or mechanical intervention to rehabilitate to C condition or higher. Land condition for paddocks, stocking methods and sites was calculated from individual quadrat assessments and these means were statistically analysed separately for each land condition class.

Statistical analyses

The research approach using commercial properties adopted here limited the capacity for statistical analysis. There was no replication of stocking methods within sites and the location of the different stocking methods was usually not random. Measurements, however, were repeated over a 4-year period and at multiple sites and permitted some statistical treatment of the transformed data. Analyses across sites within years and also across years were conducted, bearing in mind the limitations of these analyses. Although this allows for broader inferences, variation is likely to be much greater and hence statistical differences less likely to be observed. Multiple paddocks in the extensive and intensive rotations at all sites allowed within-site variation to be estimated.

Many factors will contribute to between-site variability. The levels of the stocking method treatment (intensive and extensive rotations and continuously grazed) were not definitive (‘fixed’) but rather a broad categorisation. Sites are confounded with both management and environment (soil, climate and seasonal weather), although some environmental variability was accounted for by having sites from two regions and two vegetation communities. Due to this confounding, it is not possible to meaningfully separate the environmental and managerial sources of variation. Similarly, stocking rate and stocking method are confounded and so it cannot be determined if an effect is due to stocking method or stocking rate.

The three stocking methods, two vegetation communities (eucalypt and brigalow) and two regions (north and south Queensland) across the nine properties were statistically compared for each year (3 years in total for pasture, soil surface and land condition parameters and 4 years for grazing data) using the method of residual maximum likelihood (REML) (Payne *et al*. 2011). The REML method was chosen because it provides efficient estimates of treatment effects in linear models with more than one source of error (linear mixed models) and is appropriate for unbalanced datasets. Analyses of the pasture and soil surface data included the fixed effects of stocking method, region and vegetation community, and the random effects of paddocks within stocking methods within properties (sites). An analysis across years was performed by including the fixed effect of year. Analyses of grazing SDH across time and properties included the fixed effects of stocking method, region, vegetation community, and years (4), and the random effects of time within paddocks, stocking methods and sites. This analysis is based on an assumption of independence between years given that the herds differed in numbers, times of grazing and occasionally in classes over time. Significance test for cattle parameters was at the 5% level ($P = 0.05$) and for pasture parameters was at the 10% level ($P = 0.10$).

Results

Rainfall and growing conditions

Annual rainfall at the homestead of each study site and the long-term average annual rainfall (>100 years) of the nearest Bureau of Meteorology site are shown in Table 2. The study commenced during an abnormally dry period with the first 2 years being characterised by drought conditions at all sites (average annual decile was 3.4, with three sites at decile 1 in 1 of these 2 years). However, annual rainfall over the final 2 years of the monitoring was average to above average at all sites (average annual decile was 6.3, with three sites in decile 9 over the 2 years). Across all sites, average annual rainfall over the first 2 years was 515 mm (range 398–765 mm) compared with 720 mm over the final 2 years (range 602–1275 mm).

Pasture growing conditions were limited by the drought in 2006 and 2007, while conditions were good for pasture growth at all sites in the latter 2 years, with all of the northern sites having above-average rainfall, and above-average summer and winter rainfall at the Rockhampton site.

Cattle numbers and grazing days

The differences in SDH between the three stocking methods were not consistent and, over the 21 methods at the nine sites, there were no significant differences between the three stocking methods; continuous with rest periods, extensive rotations and intensive rotations (Table 3). However, at four sites, there were differences ($P < 0.05$) between the methods in SDH: the continuous stocking method was superior at Mundubbera, the continuous and extensive rotation at Clermont supported the highest SDH, and the intensive rotation method had the highest SDH at Richmond and Surat.

Table 3. Annual SDH grazing use (AE livestock days ha^{-1}) for three stocking methods at nine sites

Data were log-transformed before analysis. Means within sites are back-transformed predicted means from an analysis across years within sites. Stocking method means are back-transformed predicted means from an analysis across years and sites. Stocking method means followed by a common letter are not significantly different ($P = 0.05$)

Site	Stocking method: Continuous	Extensive rotation	Intensive rotation
Blackwater	87	96	83
Bowen	91	–	146
Clermont[A]	175a	148a	81b
Condamine	103	–	107
Injune	138	–	146
Mundubbera[A]	92a	66b	–
Richmond[A]	–	12b	23a
Rockhampton	85	99	107
Surat[A]	–	36b	87a
Method mean	95a	77a	97a

[A]Significant difference between stocking methods within site. Means within a site not followed by a common letter are significantly different ($P = 0.05$).

Pasture characteristics

Mean values for herbage mass, species diversity and ground cover (total and litter) are presented in Tables 4 and 6. An example of the results of these pasture measurements from one site, operating three grazing methods (Rockhampton), is presented in Fig. 2. Similar stocking method and annual trends were observed at all sites (data from other sites are not presented).

There were no significant differences in herbage mass in April/May at the end of the summer growing season for the different stocking methods across sites within any year (Table 4). All paddocks were measured at the same time (autumn) irrespective of their recent grazing history in their rotation cycle. Mean herbage mass over all sites and years was 2420 kg DM ha^{-1}. Herbage mass was greater ($P < 0.05$) in 2009 (3830 kg DM ha^{-1} over all sites and stocking methods) than in 2006 and 2007 (average 1970 kg DM ha^{-1}).

Pasture diversity, measured as number of species per quadrat (native and exotic), was higher ($P < 0.10$) in the extensive rotation than in the intensive rotation stocking method (Table 4). Pasture diversity was less at the three sites where buffel grass was strongly dominant compared with the sites where native grasses were dominant (1.1 versus 2.5 species per quadrat). The highest number of species recorded in each quadrat was five and this number occurred infrequently in any stocking method at any site.

The pastures at all sites were dominated by perennial grasses with no consistent differences between stocking methods. Buffel grass was particularly dominant, >93% of the herbage mass, in all stocking methods at the Blackwater, Injune and Surat sites. Using the information on the composition, frequency and dry matter yield of the most dominant preferred (palatable) grass species at each site within each stocking method for the 3 years recorded showed that four grasses were dominant (Table 5). These were the exotic sown buffel grass, which was the dominant preferred grass at six sites, and the naturalised Indian bluegrass [*Bothriochloa pertusa* (L.) A. Camus], and the native 3P grasses [black speargrass [*Heteropogon contortus* (L.) P. Beauv. ex Roem. and Schult] and desert bluegrass [*Bothriochloa ewartiana* (*Domin*) C.E. Hubbard] ,which were dominant at the other three sites (Table 5). At the Bowen site in 2009, the exotic sown Sabi grass [*Urochloa mosambicensis* (Hack.) Dandy] was more common in the intensive rotation method, with a herbage mass of 1340 kg DM ha^{-1} compared with 450 kg DM ha^{-1} in the continuous stocking method. Within sites and stocking methods, the dominant species and their contribution to the total pasture remained consistent over time, but their herbage mass increased on average by 67% (range 8–201%) between the first and the fourth year of the study over the eight sites recorded in 2009.

Over all sites and stocking methods, there was little difference between 2006 and 2007 in the dominant pasture grass species composition, frequency or herbage mass. However, all three of these pasture attributes were higher in 2009, particularly for herbage mass (mean 1280 kg DM ha^{-1} for 2006 and 2007 compared with 2480 kg DM ha^{-1} in 2009). Within all sites and stocking methods, there was a wide range of contribution from the four dominant grasses. For example, buffel grass composition ranged from 1 to 99%, frequency from 1 to 99% and yield from 10 to 5440 kg DM ha^{-1}. Sites and stocking methods with a dominance of exotic grass species had a greater contribution to the pasture from a single species. For example, over the 3 monitoring years (2006, 2007 and 2009), the average of grazing methods for buffel grass (six sites) and the dominant native grass (three sites) was: composition 79 and 17%, frequency 77 and 26%, and herbage mass 2220 kg DM ha^{-1} and 400 kg DM ha^{-1}, respectively.

Average pasture composition over the 3 years, 2006, 2007 and 2009, with the desirable species divided into three functional groups [3P native grasses, sown exotic grasses and legumes (native and sown exotic)] and a fourth group of other less desirable species, is shown in Fig. 3. At no site was there a significant effect of grazing method on these four species groups, although there were large inherent differences between sites. At sites cleared of trees and sown to exotic pastures (e.g. Blackwater, Clermont, Condamine, Injune and Surat), buffel grass was dominant and there was little contribution from other species groups in all stocking methods. At the native pasture sites (Bowen, Mundubbera, Richmond and Rockhampton) species functional group composition was similar between stocking methods within a site, and there was a contribution from each of the four functional groups.

Table 4. Herbage mass (kg ha^{-1}) and species diversity (number per quadrat) for three stocking methods at nine sites

Site values are back-transformed means of estimates made in 2006, 2007 and 2009 accounting for unequal numbers contributing to the means. Herbage mass data were log-transformed before analysis. The year and overall means are predicted means from a statistical analysis across sites and years. Stocking method means followed by a common letter are not significantly different ($P = 0.10$)

Site/Year	Stocking method: Continuous	Extensive rotation	Intensive rotation
	Herbage mass (kg DM ha^{-1})		
Blackwater	2270	3130	3720
Bowen	3330	–	3640
Clermont	3060	2840	2370
Condamine	1290	–	1900
Injune	2530	–	2460
Mundubbera	2290	2210	–
Richmond	–	1540	1550
Rockhampton	2490	2830	2260
Surat	–	1670	2400
2006	1990a	2370a	2480a
2007	1780a	1490a	1730a
2009	3630a	4040a	3810a
Method mean	2340a	2400a	2520a
	Plant species diversity (no. of species per quadrat)		
Blackwater	1.1	1.2	1.1
Bowen	3.2	–	3.1
Clermont	1.7	2.0	1.7
Condamine	1.8	–	1.5
Injune	1.1	–	1.2
Mundubbera	3.1	3.2	–
Richmond	–	2.4	1.9
Rockhampton	2.9	2.8	2.7
Surat	–	1.4	1.4
2006	1.8a	1.9a	1.8a
2007	1.8ab	1.9a	1.6b
2009	2.0a	2.1a	2.0a
Method mean	1.9ab	2.0a	1.8b

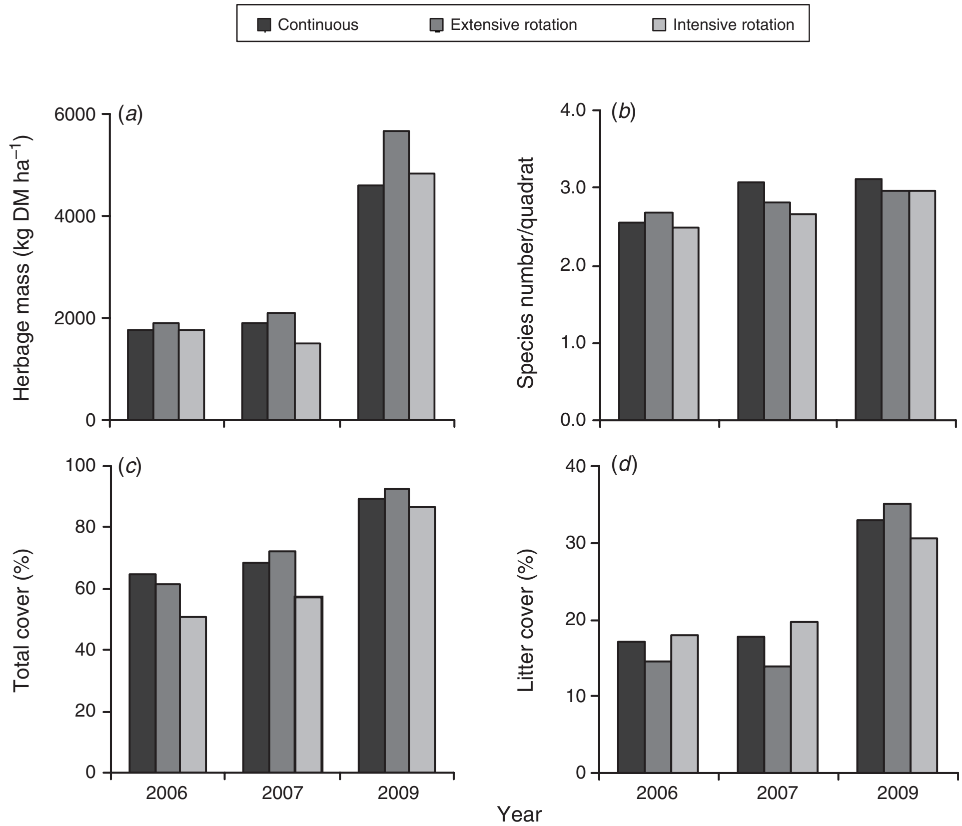

Fig. 2. (*a*) Herbage mass, (*b*) plant species diversity, (*c*) total plant cover, and (*d*) total litter cover for three stocking methods (continuous, extensive rotation and intensive rotation) in 2006, 2007 and 2009 at the Rockhampton site.

Apart from 2009, when the mean ground cover in the extensive rotation (77%) was greater ($P < 0.10$) than that in the continuous grazing and intensive rotation (average 71%), there were no significant differences between stocking methods for ground cover (average all sites and years 61%) or litter cover (average over sites and years 20%) (Table 6). Both ground cover and litter cover were greater in 2009 (73 and 26%, respectively), than in 2006 and 2007 (average 57 and 18%, respectively).

Soil surface condition

Apart from the stability index, which was lower in the continuous stocking method in 2009 than for the other two stocking methods (62.7 versus 64.7, respectively), there were no significant differences between stocking methods in any of the 3 years for the three LFA indices (Table 7). The average stability, infiltration and nutrient cycling indices for all sites and years were 60.6, 39.1 and 31.3, respectively.

The three LFA indices all increased from 2006 to 2009. Over all stocking methods, the average stability index increased from 60 to 64; infiltration index increased from 37 to 41, and nutrient cycling index increased from 29 to 34.

Land condition for the three stocking methods across all paddocks of the eight sites monitored in the final year increased from 59, 69 and 71% in A or B condition (good land condition) in 2006 to 79, 83 and 82% in A or B condition in 2009 for the continuous, extensive rotation and intensive rotation methods, respectively. There were no significant differences in any land condition class between grazing methods in 2009.

Discussion

There were no consistent significant differences in pasture variables or soil surface characteristics between the three stocking methods across the eight sites monitored over 3 of the 4 years of the study. Similarly there were no differences between the methods at the Richmond site for the 2 years it was monitored. Any differences that were detected were small and varied between years and across the sites. These results support the findings from a review of experimental data by Briske *et al.* (2008) who reported that there was no conclusive experimental evidence of pasture production or livestock production advantages from rotational grazing compared with continuous grazing.

This research approach of evaluating stocking methods at multiple sites under commercial beef production conditions was selected due to site-specific and scale limitations associated with running a large-scale grazing experiment at one site. Also we recognised that the owner/managers are an important part of any stocking method and that we needed an appropriate commercial paddock scale, and the ability to monitor stocking methods that had been in operation for some years across a range of environments. This commercial-scale research approach, accounting for the owners' ecological, financial and social goals,

Table 5. Composition (%) of dominant perennial preferred grass species [*C. cil.* – *Cenchrus ciliaris* (buffel grass); *B. per.* – *Bothriochloa pertusa* (Indian bluegrass); *H. con.* – *Heteropogon contortus* (black speargrass); *B. ewa.* – *Bothriochloa ewartiana* (desert bluegrass)], frequency (%) and herbage mass (kg ha^{-1}) in three stocking methods (continuous, Con; extensive rotation, ER; intensive rotation; IR) at nine sites in 2006, 2007 and 2009

	Site[A]	Bla	Bow	Cle	Con	Inj	Mun	Ric	Roc	Sur	
		Dominant preferred grass species									
Year	Stocking method	*C. cil.*	*B. per.*	*C. cil.*	*C. cil.*	*C. cil.*	*H. con.*	*C. cil.*	*B. ewa.*	*C. cil.*	Method mean
					Composition (%)						
2006	Con	98	5	86	55	97	18	–	38	–	57
	ER	94	–	78	–	–	26	9	29	96	55
	IR	99	6	84	94	97	–	28	7	95	64
2007	Con	99	6	89	70	97	12	–	36	–	59
	ER	93	–	69	–	–	24	24	31	92	55
	IR	98	4	63	95	97	–	18	13	96	60
2009	Con	99	13	90	70	94	12	–	9	–	55
	ER	96	–	80	–	–	20	–	15	98	62
	IR	99	16	68	95	95	–	–	7	98	68
					Frequency (%)						
2006	Con	97	12	83	59	91	31	–	36	–	59
	ER	91	–	67	–	–	44	6	31	98	56
	IR	97	19	68	97	95	–	15	9	97	62
2007	Con	97	22	85	76	93	27	–	31	–	62
	ER	95	–	69	–	–	37	9	34	98	57
	IR	96	14	57	98	92	–	12	17	97	60
2009	Con	97	31	86	84	88	26	–	15	–	61
	ER	96	–	76	–	–	37	–	21	99	66
	IR	96	38	61	98	94	–	–	10	99	71
					Dry matter yield (kg ha^{-1})						
2006	Con	1660	260	1560	500	3163	510	–	680	–	1190
	ER	3010	–	1810	–	–	610	150	550	1850	1330
	IR	3430	190	1290	1640	3184	–	500	110	2480	1600
2007	Con	1330	200	2340	841	1410	190	–	680	–	1000
	ER	1820	–	1270	–	–	360	320	650	910	890
	IR	2980	90	1510	1730	1150	–	290	170	1670	1200
2009	Con	5070	530	5440	1230	3210	330	–	430	–	2320
	ER	4850	–	4670	–	–	600	–	840	2660	2720
	IR	5000	690	2860	2050	3740	–	–	330	3090	2540

[A]Site code: Bla – Blackwater; Bow – Bowen; Cle – Clermont; Con – Condamine; Inj – Injune; Mun – Mundubbera; Ric – Richmond; Roc – Rockhampton; Sur – Surat.

is supported in the paper by Teague *et al*. (2013). The results from these wide-spread commercial sites have more direct application to beef producers, but this approach also suffers from having less ability to control sources of variability. This inherent variability between sites, seasons, environments and managers, means larger consistent differences are required for statistical significance. In contrast to a controlled experimental research approach, there were no replicates of stocking methods on individual properties and no long-term 'fixed treatments' across the stocking methods for the 4 years. The actual management (number and class of livestock, rest and grazing periods) in any stocking method changed as owners and managers took an adaptive management approach responding to the numerous external influences on their operations, including seasonal weather conditions, pasture growth, business interests and lifestyle requirements.

Although the average grazing pressure over nine sites, measured as SDH, was similar under the continuous grazing and intensive rotation methods, grazing pressures on the various stocking methods at a particular site were not always the same. There were four sites with significant ($P < 0.05$) differences between stocking methods, but these were not consistent. All three stocking methods supported the highest SDH at some sites. The average lower SDH in the extensive rotation method can be explained by the destocking of the monitor paddocks, and the unmonitored paddocks, after stick-raking regrowth at one site (Surat), and changed grazing management strategies during drought at two sites (Clermont and Surat). Pasture growth and subsequent grazing of the extensive rotation method after the stick-raking treatment was restricted by a continuing drought.

The eight intensive rotations were all established and managed as 'cell systems' by the owners and managers, even though they have not always strictly adhered to all of the formal principles of cell grazing as advanced by McCosker (2000). The pasture management considerations of all owners meant the 'continuously grazed' paddocks also had some annual rest periods although of a shorter duration than in the two rotational methods.

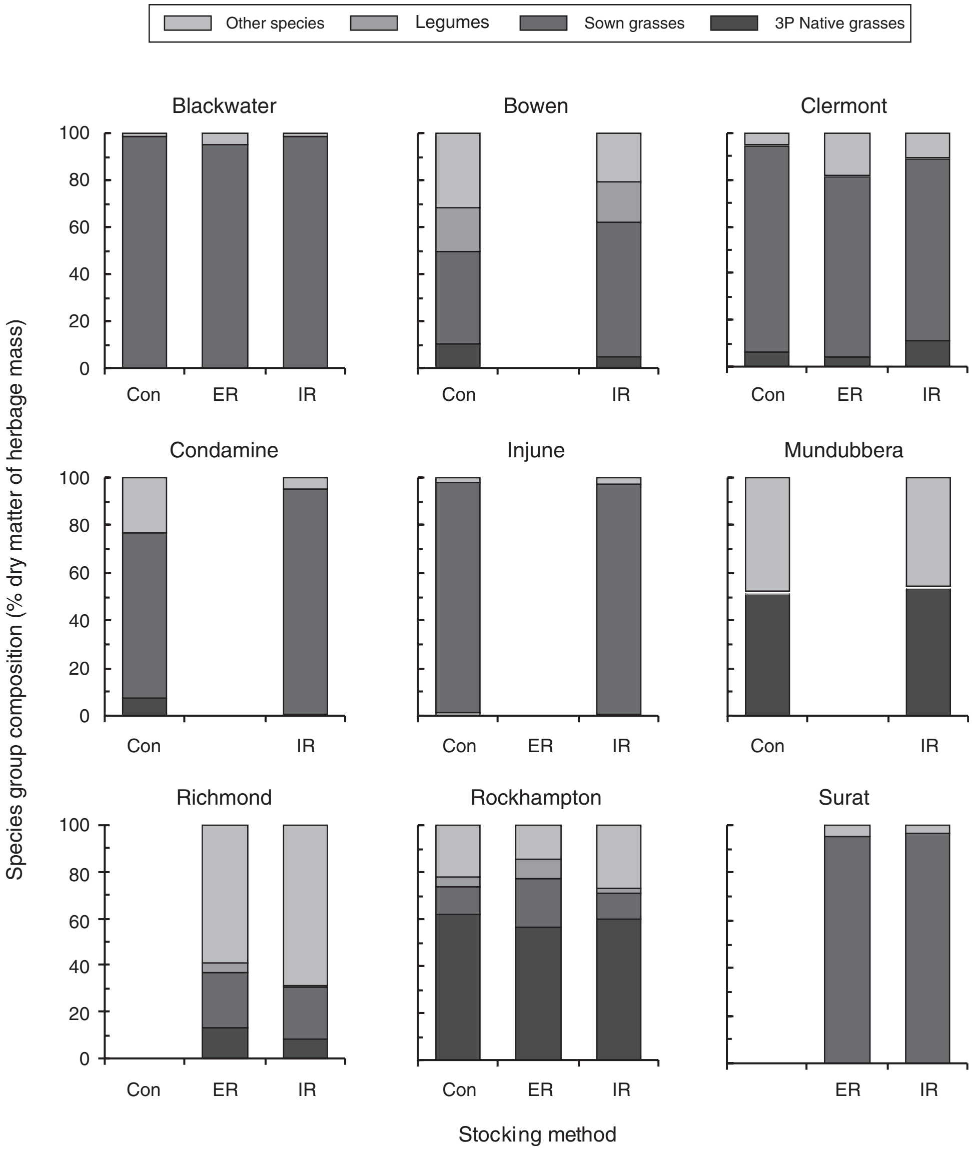

Fig. 3. Pasture composition (% of DM of herbage mass) of four pasture species groups (sown exotic grasses, 3P native grasses, legumes and other species) in three stocking methods (continuous, Con; extensive rotation, ER; and intensive rotation, IR) at nine sites (Blackwater, Bowen, Clermont, Condamine, Injune, Mundubbera, Richmond, Rockhampton and Surat) averaged over 2006, 2007 and 2009.

Another consequence of monitoring commercial operations, which may have led to similar pasture responses between methods, was that the different stocking methods within a property were not always managed independently of each other. They were operated as components of an integrated whole property management and beef production system. This meant that the pastures were managed similarly for grazing pressure over the longer-term beyond single grazing events, and also that individual livestock classes may spend time grazing in different stocking methods during a year. This occurred at some sites especially during drought periods, e.g. a calf could be born in an intensive rotation, grown in an extensive rotation, and finished under a continuous stocking method. All properties had cattle weighing scales but weighing of breeders or regular weighing within a stocking method was not practised. The combination of different livestock classes between stocking methods at some sites, and a lack of specific liveweight data within a method, precluded attempts to directly assess the impact of stocking method on individual livestock productivity or to ascribe production impacts to one particular stocking method.

In contrast to the similar grazing capacity results from the different stocking methods, there were large and consistent differences in pasture responses between years due to the higher rainfall in the last 2 years compared with the first 2 years of the study. This increased pasture production, doubling on average, and increased ground cover for each of the three stocking methods across all sites indicated that rainfall was the main driver of observed ecological changes in pastures rather than the

Table 6. Ground and litter cover levels (%) for three stocking methods at nine sites

Site values are back-transformed means of estimates made in 2006, 2007 and 2009 accounting for unequal numbers contributing to the means. Data were arcsine-transformed before analysis. The year and overall means are predicted means from a statistical analysis across sites and years. Stocking method means followed by a common letter are not significantly different ($P = 0.10$)

Site/Year	Stocking method		
	Continuous	Extensive rotation	Intensive rotation
	Ground cover (%)		
Blackwater	57	67	68
Bowen	76	–	82
Clermont	54	65	47
Condamine	50	–	58
Injune	55	–	59
Mundubbera	74	70	–
Richmond	–	42	37
Rockhampton	75	77	66
Surat	–	53	61
2006	59a	63a	58a
2007	52a	53a	54a
2009	70b	77a	72b
Method mean	59a	64a	61a
	Litter cover (%)		
Blackwater	16	23	20
Bowen	30	–	35
Clermont	11	22	17
Condamine	18	–	17
Injune	18	–	20
Mundubbera	25	24	–
Richmond	–	20	17
Rockhampton	22	20	22
Surat	–	17	20
2006	18a	19a	16a
2007	16a	19a	19a
2009	22a	28a	28a
Method mean	18a	22a	21a

Table 7. Landscape function analysis indices for three stocking methods at nine sites

Site values are means of estimates made in 2006, 2007 and 2009 accounting for unequal numbers contributing to the means. The year and overall means are predicted means from a statistical analysis across sites and years. Stocking method means followed by a common letter are not significantly different ($P = 0.10$)

Site/Year	Stocking method		
	Continuous	Extensive rotation	Intensive rotation
	Stability index		
Blackwater	59.0	62.0	62.3
Bowen	67.9	–	70.1
Clermont	52.4	54.3	56.3
Condamine	59.1	–	61.3
Injune	60.5	–	59.1
Mundubbera	65.8	67.3	
Richmond	–	52.0	50.3
Rockhampton	65.0	67.0	65.3
Surat	–	60.9	61.5
2006	59.6a	60.9a	60.3a
2007	56.9a	58.8a	59.1a
2009	62.7b	64.7a	64.7a
Method mean	59.4a	61.2a	61.1a
	Infiltration index		
Blackwater	37.6	41.3	37.9
Bowen	41.2	–	44.0
Clermont	40.5	41.9	36.2
Condamine	39.3	–	36.8
Injune	36.6		38.4
Mundubbera	40.9	37.8	–
Richmond	–	41.4	40.8
Rockhampton	36.7	37.6	38.0
Surat	–	39.2	39.3
2006	37.5a	37.7a	36.1a
2007	39.1a	40.1a	39.0a
2009	40.0a	41.9a	40.8a
Method mean	38.9a	39.8a	38.7a
	Nutrient cycling index		
Blackwater	29.3	33.2	30.9
Bowen	35.2	–	36.6
Clermont	28.7	33.2	30.2
Condamine	29.2	–	29.3
Injune	30.1	–	31.2
Mundubbera	33.4	32.7	–
Richmond	–	30.0	27.3
Rockhampton	31.5	30.5	30.7
Surat	–	30.6	31.0
2006	28.7a	29.5a	27.9a
2007	30.8a	31.8a	31.0a
2009	32.8a	35.6a	34.7a
Method mean	30.6a	32.3a	31.1a

stocking method. All of the properties were well managed with respect to seasonal pasture growth, with grazing pressure and rest periods periodically adjusted across their two or three stocking methods.

There are no direct means of separating the stocking method management from seasonal effects across these sites. The long-term ground cover trends, 1987–2009, of the 74 paddocks, assessed by remote sensing (VegMachine) (Beutel *et al*. 2010, data not presented), showed a strong consistency between the average historical ground cover and ground cover recorded in this study, across all areas of the stocking methods within each property. Ground cover of paddocks in each stocking method, as assessed by VegMachine, declined significantly in the two drought periods, 1992–95 and 2005–07. The similar cover trends between stocking methods indicate that the management of grazing pressure and pastures has varied similarly within each site following seasonal pasture growth patterns irrespective of the stocking method. On a regional scale, Bastin *et al*. (2012) suggested that remote sensing-based analysis of ground cover dynamics in dry years may be able to help differentiate management effects from seasonal effects on pastures. The method works where management affects ground cover, but it does not account for changes in species composition. This method may be useful in stocking method comparisons in the future, but it cannot be used on our datasets as the required cover reference points were not established in the dry years, e.g. 2005–06, before monitoring commenced.

There was an improvement in land condition, using the ABCD land condition framework of the Grazing Land Management program (Whish 2011), over the monitoring period in all stocking methods at all sites. Paddocks that had been assessed to be in poor land condition in 2006, i.e. a high proportion in C condition (including bare patches), had higher ground cover dominated by perennial grasses, both exotic sown cultivars and native 3P species, and were assessed to be good condition (A or B) under all three stocking methods in 2009. This was after two above-average summer rainfall seasons.

This study has reported on pasture and soil surface condition responses under three commonly employed stocking methods. Other factors can also be important; for example responses in diet quality to stocking method. Also, the potential effects of the different stocking methods on vertebrate fauna populations and diversity were not monitored. In north Queensland over a 5-year period from 1999 to 2004, Kutt *et al*. (2012) found a similar effect on fauna to our pasture responses, where seasons had a greater effect than did grazing pressure. Where vertebrate fauna assemblages changed, it was attributable to the interplay between stocking rates, vegetation types, burning and a decrease in rainfall over the survey period. In the monitor paddocks at the seven sites of this study sampled for total soil organic carbon (Richmond and Surat sites were not sampled), there were no consistent effects of stocking method on the stock of soil organic carbon. However, it was strongly (and non-linearly) affected by the amount and variability of surface vegetation, local slope, annual rainfall and average stocking rate measured in SDH (Allen *et al*. 2013).

Cell grazing is based on a set of principles of which three relate to resting pastures; adjusting stocking rate to match carrying capacity; and planning, monitoring and managing grazing (McCosker 2000). The owners and managers at all nine sites applied these principles to all their respective stocking methods and not just the intensive rotations. The ‘continuous with rest’ method of grazing used by the producers in this study was not the traditional ‘continuous’ grazing or annual set stocking that is often associated with these terms, and can have connotations of over-grazing and associated degradation. Our results suggest that beef producers can obtain similar ecological responses and carry similar numbers of cattle with any of the three stocking methods examined here, provided that these three principles are followed and paddock size and property water infrastructure are sufficiently developed to allow utilisation of the full paddock. The absolute responses recorded were strongly affected by above-average rainfall irrespective of the particular stocking method. All classes of stock were successfully managed under the three stocking methods, from weaners to growing cattle to breeders with calves. Although there were no advantages to the pastures of rotational grazing in these comparisons on well managed properties, other benefits of the different stocking methods may influence a producers’ choice of stocking method. For example, the ease of stock handling and supplementation in intensive systems are benefits cited by some producers, while their high establishment costs and timeliness of labour requirements are of concern to others.

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