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HRM and cell grazing: A review of the evidence base

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Abstract

Debate continues over the relative merits of continuous grazing and forms of rotational grazing, especially Cell Grazing. A review was conducted of comparisons of continuous grazing and Cell Grazing published in peer-reviewed journals in which measurements were made of animal performance and pasture and soil characteristics. The review confirmed the conclusion of Briske *et al*. (2008) that plant and animal production are equal or greater in continuous grazing compared to rotational grazing. In those trials where various plant and soil measurements other than plant production were considered, the results for continuous and Cell Grazing were the same in the majority of cases with only 35% of the cases showing some benefit of Cell Grazing. This suggests that cell grazing can affect some soil and plant measures, relative to continuous stocking, but such effects are not consistent and were not reflected in superior plant and animal production during the period of the trials. There is growing recognition of the need to improve grazing management, in particular management of stocking rate, but the experimental evidence indicates that adoption of cell grazing is not superior to alternative approaches for improving grazing management.

Executive summary

There is widespread interest in Cell Grazing and debate over the relative merits of Cell Grazing, other rotational methods and continuous grazing. In this review we examine comparisons of stocking methods that include continuous grazing and intensive rotational methods described as Cell Grazing or something similar. We first examined previous reviews of continuous and rotational grazing and then conducted a computer-based survey of peer-reviewed scientific papers that compared grazing methods. For this study, we included reports which compared continuous grazing and a rotational method that mentioned cell grazing, short duration grazing, time-controlled grazing, high intensity; had many paddocks; or had short grazing periods and long rest periods. The focus was on rotational systems involving one group of stock moving between many paddocks. Both Australian and overseas studies were included. Summaries of the papers are provided in the appendix. Tables were prepared showing where results for different stocking methods were the same or different for various measurements. For these comparisons the studies were divided into groups where both methods used the same stocking rate, and those studies where the stocking rate used was higher for Cell Grazing.

Previous reviews (including Wheeler 1962; O'Reagain and Turner 1992; Briske *et al*. 2008) of continuous stocking with various forms of rotational stocking have concluded that animal production from continuously grazed pasture is similar or greater than that achieved with rotational stocking.

In this current review, a total of 29 papers were assessed, 6 from Australia and 23 from overseas.

Only one of the 11 studies that reported animal production found LWG/head was higher for Cell Grazing when stocking methods were compared at the same stocking rate. For measures of diet quality and intake, stocking methods were similar or continuous grazing was superior.

Three studies compared animal production when the Cell Grazing was grazed at a higher stocking rate. In two short term studies, LWG/head was the same for both methods; in the other study (Pitts and Bryant 1987) LWG/head was the same for both methods in two years but lower for Cell Grazing in another year. The combination of similar LWG/head and higher stocking rates gave higher LWG/ha for Cell Grazing. However, as there was no continuously grazed treatment at the higher stocking rate, any impact of Cell Grazing per se is uncertain. For comparisons of diet quality and intake, Cell Grazing was better in three studies, poorer in one, and there were no differences in the other four.

There were 17 comparisons of herbage mass (12 at the same stocking rate and 5 with a higher stocking rate for cell Grazing); for two of these yields were higher for Cell Grazing with no difference for the other 15. There was also a total of 80 cases where additional measures of soil and pasture were recorded and compared (but confined to a relatively small of studies; most cases were at the same stocking rate). While 47 of these 80 comparisons found no difference between grazing methods, Cell Grazing performed better for 28 measurements and was poorer for five measurements. The 28 cases where Cell Grazing gave a better performance occurred in seven studies with 13 of the 28 cases in one study, Teague *et al* (2011). There was often only one comparison for a particular measurement but, where there were multiple comparisons, the better (and poorer) performance occurred across the range of measurements with Cell Grazing showing no consistent benefit for any measurement.

This review of experiments comparing continuous grazing with Cell Grazing confirms the conclusions of Briske *et al*. (2008) that, in terms of plant and animal production, the experimental evidence does not show that Cell Grazing is superior to continuous grazing. Briske *et al*. (2008) showed 80-90% of studies found plant and animal production were equal or greater in continuous compared to rotational grazing and the result was similar in this comparison.

When plant and soil measures other than herbage mass are considered, the majority of recorded measures did not differ between Cell Grazing and continuous grazing. Cell grazing was better for 35% of cases where additional measures were recorded, while continuous grazing was better than Cell Grazing for 6% of the cases. This suggests there may be benefits from Cell Grazing in aspects of pasture composition, cover or soil characteristics and health, but these benefits were far from consistent and were not reflected in plant and animal production during the period of the trials.

Some issues relating to the experimental comparisons that influence the relevance of the results to commercial practice are discussed. These include experimental treatments only representing a small part of the variation in commercial continuous and Cell Grazing systems, limited temporal and spatial scale of experiments, the impact of the manager on results, and the fixed animal numbers used in many experiments.

There is considerable anecdotal information of positive results with Cell Grazing that is not mirrored in the scientific literature. Cell Grazing is usually adopted as part of a broad philosophy or package of which Cell Grazing is only part. Where this leads to superior management (clearer goals, improved financial systems, better decision making, greater monitoring, forage budgeting), the new system may indeed outperform the previous system using continuous grazing (especially if stocking rate had previously been consistently higher than carrying capacity) but this is likely not due to the Cell Grazing per se.

There is growing recognition of the need to improve grazing management to maintain and improve the pasture base but the question of what management will lead to optimal productivity and long-term pasture health is likely to remain a topic of some debate. However, experimental evidence clearly shows that important components of improved grazing management will include:

- paddocks adequately fenced and watered to help manage animal distribution,
- stocking rate varied around the long-term carrying capacity,
- growing season rest practised, and
- stock numbers reduced in response to poor growing seasons.

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1 Background

Systems of control and management of grazing animals in northern Australia have been evolving in recent decades and a number of 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. Grazing system is a much broader term, defined by Allen *et al*. (2011) as “a defined, integrated combination of soil, plant, animal, social and economic features, stocking methods and management objectives designed to achieve specific results or goals.” Unfortunately, these terms have sometimes been used interchangeably. This can lead to confusion when stocking methods are being compared but different stocking rates are used on different methods; differences associated with stocking method may be more likely associated with different stocking rates.

Conventional grazing management has been to ‘continuously’ graze areas i.e. animals are left in one paddock for long periods although animal numbers may change in response to changes in forage supply or animal condition. This enables animals to selectively graze preferred pasture components increasing diet quality and hence animal 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. It is important to note that this is not set stocking as commonly practised in experiments where animal numbers remain constant over time. Within continuously grazed systems there can be a wide range of stocking rates and many of the deleterious changes ascribed to continuous stocking are more appropriately ascribed to the heavy stocking rates used rather than the continuous grazing *per se*.

Rotational grazing [a method that utilises recurring periods of grazing and rest among three or more paddocks (Allen *et al*. 2011)] is often recommended, especially during the growing season (Ash *et al.* 2002) to give more control of defoliation to prevent overgrazing, allow seeding of desired species, and to enable animals to harvest available forage more efficiently. Rotations vary widely from low intensity with only one or a few more paddocks than there are herds and where rest periods vary from weeks to months, to intensive rotations with typically 20 to 60 paddocks per herd and grazing periods are from 1-3 days and these grazing periods are much shorter than the rest periods, which may be 30-90 days. Timing and duration of rest is usually determined by plant growth rate (McCosker 2000; Briske *et al*. 2008).

Cell Grazing and holistic management were introduced into Australia in 1989 (McCosker 2000) and are strongly based on the theories and practice of Alan Savory (Savory and Butterfield 1999). Cell Grazing is based on a set of broadly based principles that have been evolving through time in response to practical experience McCosker 2000). The principles are:

1. Control rest to suit the growth rate of the plant.
2. Adjust stocking rate to match carrying capacity.
3. Plan, monitor and manage grazing.

4. Use short graze periods to increase animal performance.
5. Use maximum stock density for the minimum time.
6. Use diversity of plants and animals to improve ecological health.
7. Use large mob size to encourage herding.

The principles and the words used for Cell Grazing have changed over time and continue to do so.

McCosker (2000) stressed the importance of clear definitions. Cell Grazing and the Savory Grazing method are high level, time-control stocking methods with >7 paddocks per herd and usually 20-40. Movement of herds between paddocks is based on the growth rate of the pasture and its physiological requirement for rest (i.e. movement is not calendar-based). Cell Grazing requires high stock density. According to McCosker (2000) nobody can claim to be Cell Grazing unless the first five principles are followed strictly and in priority order.

There has been and remains a widespread interest in Cell Grazing and debate over the relative merits of Cell Grazing, other rotational methods and continuous grazing. In this review we examine comparisons of stocking methods that include continuous grazing and intensive rotational methods described as Cell Grazing or something similar.

2 Methodology

We first examined previous reviews of continuous and rotational grazing. We then conducted a computer-based survey of peer-reviewed scientific papers that compared stocking methods. For this study, we included reports which compared continuous grazing and a rotational method that

- Mentioned cell grazing, short duration grazing, time-controlled grazing, high intensity
- Had many paddocks
- Had short grazing periods and long rest periods

Our focus was on rotational systems involving one group of stock moving between many paddocks. Both Australian and overseas studies were included. Summaries of the papers are provided in the appendix. Tables were prepared showing where results for different methods were the same or different for various measurements. For these comparisons the studies were divided into groups where both methods used the same stocking rate, and those where the stocking rate was higher for Cell Grazing.

3 Results

Previous reviews

There have been many comparisons of continuous stocking with various forms of rotational stocking over many years and the majority of these have shown that animal production from continuously grazed pasture is similar or greater than that achieved with rotational stocking.

Wheeler (1962) reviewed the literature to that time noting that for more than 350 years there have been records of the rotational grazing of pastures. He concluded that “the majority of experiments conducted at equal stocking rates show negligible differences in annual production of meat or milk per acre between these two systems.”

O’Reagain and Turner (1992) evaluated the basis for grazing management recommendations for rangelands in southern Africa. They concluded:

- Stocking rate has a major impact on range condition and animal production
- Relative to stocking rate, the grazing system employed is of minor importance
- Little apparent difference between continuous and rotational grazing systems
- Pauci-camps (<8 paddocks) appear to be equal to multi-camp (8 or more) systems and there appears to be little ecological or economic justification for applying latter systems
- Regular seeding or vigour rests or rests to accumulate fodder appear essential
- Simple grazing systems using adaptive or opportunistic management are recommended

In a more recent major review, Briske *et al*. (2008) concluded:

- Plant production was equal or greater in continuous compared to rotational grazing in 87% (20 of 23) of the experiments
- Animal production per head and per area were equal or greater in continuous compared to rotational grazing in 92% (35 of 38) and 84% (27 of 32) of the experiments respectively.

It seems clear that the experimental literature shows little difference between continuous and rotational grazing for both plant and animal production.

Current review

In this section we look at experimental results where comparisons were made with methods that aimed to reproduce Cell Grazing. While some of these reports may not meet strict definitions of Cell Grazing, many observers would regard them as Cell Grazing (see Discussion). We consider both animal and plant production, and also a number of resource/environmental measures.

A total of 29 papers were reviewed (see Appendix), 6 from Australia and 23 from overseas (mainly USA but also Canada, Argentina and China). The results of the comparisons for various measures of animal performance are presented in Table 1 and for pasture and soil measurements in Table 2. These have been summarised in Table 3 (animal measures) and Table 4 (pasture and soil measurements) where the number of times Cell Grazing performed better than, worse than, or was similar to continuous grazing for different measurements are presented.

When stocking methods were compared at the same stocking rate, only one of the 11 studies that reported animal production found LWG/head was higher for Cell Grazing. For measures of diet quality and intake, stocking methods were similar or continuous grazing was superior.

Three studies compared animal production when the Cell Grazing was grazed at a higher stocking rate. In two short term studies, LWG/head was the same for both methods; in the other study (Pitts and Bryant 1987) LWG/head was the same for both methods in two years but lower for Cell Grazing in another year. The combination of similar LWG/head and higher stocking rates gave higher LWG/ha for Cell Grazing. For diet quality and intake, Cell Grazing was better in three comparisons, poorer in one, and there were no differences in the other four.

There were 17 comparisons of herbage mass (12 at the same stocking rate and 5 with a higher stocking rate for cell Grazing); for two of these yields were higher for Cell Grazing with no difference for the other 15. However a different picture emerges for other pasture and soil measurements. A total of 80 such comparisons were made (58 at the same stocking rate). While 47 of these 80 comparisons found no difference between stocking methods, Cell Grazing performed better for 28 measurements and was poorer for five measurements. The 28 cases where Cell Grazing gave a better performance occurred in seven studies with 13 of the 28 cases in Teague *et al* (2011). There was often only one comparison for a particular measurement but where there were multiple comparisons, the better (and poorer) performance occurred across the range of measurements with Cell Grazing showing no consistent benefit for any measurement.

Simple financial analyses of continuous and rotational grazing were made by Hart *et al*. (1988) and McCollum *et al*. (1999). Hart *et al*. (1988) found there was no benefit from the rotational system over the continuous system while McCollum *et al*. (1999) showed variable costs of the rotational system would need to decrease by 24-34% to equalize the net returns with continuous grazing.

Table 1. **Comparisons of continuous and Cell Grazing: animal measurements**

Cell Grazing methods have many paddocks, short grazing periods and much longer rest periods. Years refers to the number of years the grazing systems were in place; in some cases measurements were not made in all years. Where available, details of cell system (number of paddocks, durations of grazing (days) and rest periods (days)) are presented.

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
(a) Comparisons made at the same or similar stocking rates for both methods						
LWG/head	9	7			No difference	Derner and Hart (2007)
	4	4	10	30	Lower in cells	Hao *et al*. (2013)
	5	8	2-11		No difference	Hart *et al*. (1988)
	24	8			Lower in cells	Derner *et al*. (2008)
	13	8	2-11		No difference	Manley *et al*. (1997)
	1	8	2-4	17-19	No difference	Jung *et al*. (1985)
	3	10	1-3		No difference	Olson and Malechek (1988)
	1	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	6		2-8	30-45	Lower in cells	McCollum *et al*. (1999)
	5	8			No difference	Hart *et al*. (1993)
	5	8			Higher in cells	Hart *et al*. (1993)
LWG/ha	9	7			No difference	Derner and Hart (2007)
	1	8	2-4	17-19	No difference	Jung *et al*. (1985)
	1	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	6		2-8	30-45	Lower in cells	McCollum *et al*. (1999)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Diet crude protein	3	10	1-3		No difference	Olson and Malechek (1988)
	1	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	2	8	4	28	No difference	Ortega *et al*. (1997)
	8		3-7	21-49	Lower in cells	McCollum and Gillen (1998)
	3	10	2-7	18-63	No difference	Popp *et al*. (1997)
Diet digestibility	4	4	10	30	Lower in cells	Hao *et al*. (2013)
	3	10	1-3		No difference	Olson and Malechek (1988)
	1	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	2	8	4	28	No difference	Ortega *et al*. (1997)
	3	10	2-7	18-63	No difference	Popp *et al*. (1997)
Forage intake	4	4	10	30	Lower in cells	Hao *et al*. (2013)
	8		3-7	21-49	Lower in cells	McCollum and Gillen (1998)
(b) Comparisons made with a higher stocking rate for Cell Grazing						
LWG/head	2	10			No difference	Heitschmidt *et al*. (1982)
	1	8	2-4	17-9	No difference	Jung *et al*. (1985)
	4	16	2-7	30-60	No difference	Pitts and Bryant (1987)
LWG/ha	2	10			Higher in cells	Heitschmidt *et al*. (1982)
	1	8	2-4	17-19	Higher in Cells	Jung *et al*. (1985)
	4	16	2-7	30-60	Higher in Cells	Pitts and Bryant (1987)
Diet crude protein		14/42	1-5	30-65	Minor differences	Walker *et al*. (1989)
	2	8	3-7+	18-7+	Higher for cell	Hirschfeld *et al*. (1996)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Diet digestibility	4	16	2-7	30-60	No difference	Pitts and Bryant (1987)
		14/42	1-5	30-65	Only minor differences	Walker *et al*. (1989)
	2	8	3-7+	18-7+	Higher for cell	Hirschfeld *et al*. (1996)
Forage intake	4	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	2	8	3-7+	18-7+	Higher in cells	Hirschfeld *et al*. (1996)
		14/42	1-5	30-65	Lower in cells	McKown *et al*. (1991)

Table 2. Comparisons of continuous and Cell Grazing: pasture and soil measurements

Cell Grazing methods have many paddocks, short grazing periods and much longer rest periods. Years refers to the number of years the grazing systems were in place; in some cases measurements were not made in all years. Where available, details of cell system (number of paddocks, durations of grazing (days) and rest periods (days)) are presented.

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
(a) Comparisons made at the same or similar stocking rates for both methods						
Herbage mass	2				No difference	Weltz and Wood (1986)
	5				Little difference	Sanjari *et al*. (2008)
	4		2-8	30-45	No difference	Gillen *et al*. (1998)
	4	4	10	30	No difference	Hao *et al*. (2013)
	5	8	2-11		No difference	Hart *et al*. (1988)
	13	8	2-11		No difference	Manley *et al*. (1997)
	6	15	3	42	No difference	Vermeire *et al*. (2008)
	1	8	2-4	17-19	No difference	Jung *et al*. (1985)
	1	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	3	10	2-7	18-63	No difference	Popp *et al*. (1997)
	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
	4-14	21-166			No difference	Hall *et al*. (2013)
Root biomass	13	8	2-11		Little difference	Manley *et al*. (1997)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Botanical composition	4-6	18-31			Few consistent differences	Dowling *et al*. (2005)
	2-3	26-28			Better in cells	Earl and Jones (1996)
	4		2-8	30-45	No difference	Gillen *et al*. (1998)
	5	8	2-11		No difference	Hart *et al*. (1988)
	13	8	2-11		No difference	Manley *et al*. (1997)
	6	15	3	42	No difference	Vermeire *et al*. (2008)
	7	10-12	3-15	25-90	Better in cells	Jacobo *et al*. (2006)
	9	10-41	1-3	30-90	Better in cells	Teague *et al.* (2011)
	4-14	21-166			No difference	Hall *et al*. (2013)
Pasture species diversity	7	10-12	3-15	25-90	No difference	Jacobo *et al*. (2006)
	4-14	21-166			No difference	Hall *et al*. (2013)
Ground cover	5				Higher in cells	Sanjari *et al*. (2009)
	9	7			No difference	Derner and Hart (2007)
	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
	4-14	21-166			No difference	Hall *et al*. (2013)
Litter cover	2				No difference	Weltz and Wood (1986)
	4		2.5-3	54-82	Higher in cells	Tom *et al*. (2006)
	13	8	2-11		Higher in cells	Manley *et al*. (1997)
	5				Higher in cells	Sanjari *et al*. (2008)
	7	10-12	3-15	25-90	Higher in cells	Jacobo *et al*. (2006)
	9	7			No difference	Derner and Hart (2007)
	4-14	21-166			No difference	Hall *et al*. (2013)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Basal area	2-3	26-28			Higher in cells	Earl and Jones (1996)
	9	7			No difference	Derner and Hart (2007)
	5	8	2-11		No difference	Hart *et al*. (1988)
	13	8	2-11		No difference	Manley *et al*. (1997)
	7	10-12	3-15	25-90	No difference	Jacobo *et al*. (2006)
Crude protein	4	4	10	30	Lower in cells	Hao *et al*. (2013)
	1	8	2-4	17-19	No difference	Jung *et al*. (1985)
Digestibility	4	4	10	30	Lower in cells	Hao *et al*. (2013)
	1	8	2-4	17-19	No difference	Jung *et al*. (1985)
Soil bulk density	4		2.5-3	54-82	No difference	Tom *et al*. (2006)
	5				No difference	Sanjari *et al*. (2008)
	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
	2	8			No difference	Abdel-Magid *et al*. (1987)
Soil microbial biomass	4		2.5-3	54-82	No difference	Tom *et al*. (2006)
Soil fungal/bacteria ratio	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
Soil respiration	4		2.5-3	54-82	No difference	Tom *et al*. (2006)
Earthworms	4		2.5-3	54-82	No difference	Tom *et al*. (2006)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Micro-arthropods	4		2.5-3	54-82	Higher in cell	Tom *et al*. (2006)
Soil organic matter	5				No difference	Sanjari *et al*. (2008)
	9	10-41	1-3	0-90	Higher in cells	Teague *et al.* (2011)
Soil total nitrogen	5				No difference	Sanjari *et al*. (2008)
	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Soil extractable phosphorus	5				No difference	Sanjari *et al*. (2008)
Soil CEC	9	10-41	1-3	30-90	Higher in cell	Teague *et al.* (2011)
Soil aggregate stability	9	10-41	1-3	30-90	Higher in cell	Teague *et al.* (2011)
Soil hydraulic conductivity	9	10-41	1-3	30-90	Higher in cell	Teague *et al.* (2011)
Penetration resistance	9	10-41	1-3	30-90	Lower in cell	Teague *et al.* (2011)
Infiltration rate	2				Lower in cells	Weltz and Wood (1986)
	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
	2	8			Higher in cells	Abdel-Magid *et al*. (1987)
Runoff	5				Lower in cells	Sanjari *et al*. (2009)
	4		7		No difference	Naeth and Chanasyk (1996)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Sediment loss	5				Lower in cells	Sanjari *et al*. (2009)
	4		7		No difference	Naeth and Chanasyk (1996)
	9	10-41	1-3	30-90	Lower in cells	Teague *et al.* (2011)
(b) Comparisons made with a higher stocking rate for Cell Grazing						
Herbage mass	3				No difference	Weltz and Wood (1986)
	1	8	2-4	17-19	No difference	Jung *et al*. (1985)
	5	9			No difference	White *et al*. (1991)
	4	16	2-7	30-60	No difference	Pitts and Bryant (1987)
	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
Botanical composition	3	35			Better in cells	Earl and Jones (1996)
	9	10-41	1-3	30-90	Similar	Teague *et al.* (2011)
Ground cover	9	10-41	1-3	30-90	Similar	Teague *et al.* (2011)
Litter	3				No difference	Weltz and Wood (1986)
Basal area	3	35			Higher in cells	Earl and Jones (1996)
	5	9			No difference	White *et al*. (1991)
Crude protein	1	8	2	17-19	No difference	Jung *et al*. (1985)
Digestibility	1	8	2-4	17-19	No difference	Jung *et al*. (1985)

Measurement	Years	Pdks	Grazing	Rest	Result of comparison of	Reference
Soil bulk density	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Soil fungal/bacteria ratio	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
Soil organic matter	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
Soil total nitrogen	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Soil CEC	9	10-41	1-3	30-90	Higher in cells	Teague *et al.* (2011)
Soil aggregate stability	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Soil hydraulic conductivity	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Penetration resistance	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Infiltration rate	3				Higher in cell	Weltz and Wood (1986)
		14	4	50	Lower in cell	McCalla *et al*. (1984a)
	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)
Runoff	9	10-41	1-3	30-90	Lower in cell	Teague *et al.* (2011)
Sediment loss		14	4	50	Higher in cell	McCalla *et al*. (1984b)
	9	10-41	1-3	30-90	No difference	Teague *et al.* (2011)

Table 3. Number of comparisons where Cell Grazing performed better or poorer than continuous grazing or there was no difference for measures of animal performance.

Measurement	N =	Better	Poorer	No difference
(a) Comparisons made at the same or similar stocking rates for both methods				
LWG/head	11	1	3	7
LWG/ha	4		1	3
Diet crude protein	5		1	4
Diet digestibility	5		1	4
Forage intake	2		2	
Total	**27**	**1**	**8**	**18**
(b) Comparisons made with a higher stocking rate for Cell Grazing				
LWG/head	3			3
LWG/ha	3	3		
Diet crude protein	2	1		1
Diet digestibility	3	1		2
Forage intake	3	1	1	1
Total	**14**	**6**	**1**	**7**

Table 4. Number of comparisons where Cell Grazing performed better or poorer than continuous grazing, or there was no difference, for pasture and soil measurements.

Measurement	N =	Better	Poorer	No difference
(a) Comparisons made at the same or similar stocking rates for both methods				
Herbage mass	12	1		11
Root biomass	1			1
Botanical composition	9	3		6
Pasture species diversity	2			2
Ground cover	4	2		2
Litter cover	7	4		3
Basal area	5	1		4
Crude protein	2		1	1
Digestibility	2		1	1
Soil bulk density	4			4
Soil microbial biomass	1			1
Soil fungal/bacteria ratio	1	1		
Soil respiration	1			1
Earthworms	1			1
Micro-arthropods	1	1		
Soil organic matter	2	1		1
Soil total nitrogen	2			2
Soil extractable phosphorus	1			1

Soil CEC	1	1		
Soil aggregate stability	1	1		
Soil hydraulic conductivity	1	1		
Penetration resistance	1	1		
Infiltration rate	3	1	1	1
Runoff	2	1		1
Sediment loss	3	2		1
Total	**70**	**22**	**3**	**45**
(b) Comparisons made with a higher stocking rate for Cell Grazing				
Herbage mass	5	1		4
Botanical composition	2	1		1
Ground cover	1			1
Litter cover	1			1
Basal area	2	1		1
Crude protein	1			1
Digestibility	1			1
Soil bulk density	1			1
Soil fungal/bacteria ratio	1	1		
Soil organic matter	1	1		
Soil total nitrogen	1			1
Soil CEC	1	1		
Soil aggregate stability	1			1
Soil hydraulic conductivity	1			1
Penetration resistance	1			1
Infiltration rate	3	1	1	1
Runoff	1	1		
Sediment loss	2		1	1
Total	**27**	**8**	**2**	**17**

4 Discussion/conclusions

This review of experiments comparing continuous grazing with Cell Grazing confirms the conclusions of Briske *et al*. (2008) that in terms of plant and animal production the experimental evidence does not show Cell Grazing is superior to continuous grazing. Briske *et al*. (2008) showed 80-90% of studies found plant and animal production were equal or greater in continuous compared to rotational grazing and the result was similar in this comparison.

When plant and soil measurements other than herbage mass are considered, there were 80 comparisons (58 at the same stocking rate and 22 where the stocking rate was higher for Cell Grazing). The results for continuous grazing were the same as those for Cell Grazing in the majority of studies (47 comparisons). However, Cell Grazing was better for 28 of the 80 measurements (35%) while continuous grazing was better than Cell Grazing for only five measurements (6%). This suggests that Cell Grazing can improve some soil and plant measures, relative to continuous stocking, but such effects are not consistent and were not reflected in superior plant and animal production during the period of the trials. These differences might be associated with providing rest at critical stages of vegetative growth (Teague *et al*. 2011) and be just as readily achieved through simpler and less costly forms of rotational spelling (Ash *et al*. 2011).

This review has highlighted a number of issues relating to the comparison of Cell Grazing with other stocking methods:

(1) Comparisons are often made of grazing systems rather than stocking methods (see definition in the earlier background section). While stocking methods cover a wide range of possibilities (time and duration of grazing), grazing systems cover both this variation and also the other components of the system (e.g. stocking rate, animal type, manager and managerial performance) which can have more impact on outcomes than stocking methods *per se*. To keep experiments within resource limits, usually only a few of the possible systems involving continuous or Cell Grazing are studied. This provides a restricted base for extrapolation to commercial conditions and the wide variety of systems used and the conditions experienced in practice.

(2) The definition of Cell Grazing is not static but changes as new information becomes available and more experience is gained. For experimental comparisons, treatments are fixed for the duration of the experiment and this can lead to the situation where a treatment considered to be Cell Grazing at the start of a trial is no longer considered to represent Cell Grazing by the end of the trial. This is particularly so for trials than are conducted for long periods to cover a range of seasons and allow time for botanical changes.

(3) Limited resources can make it difficult to make comparisons at appropriate temporal and spatial scales. Large scale long-term experiments are most desirable but they are expensive. Experiments frequently do not reach this ideal and this limits the value of the experimental results.

(a) Duration - animal production responds to current conditions but botanical changes can take years and may not occur during short-term trials.

(b) Many of the experiments reviewed had small numbers of paddocks (less than 10 and much fewer than the 20+ often used in Cell Grazing) in the rotation and this raises issues of how the results relate to Cell Grazing under commercial conditions.

(c) Small plot experiments are not suited to landscape scale processes and may bias comparisons. In some studies the size of the paddocks was much smaller than under commercial conditions. This was particularly so for some continuous grazing treatments (Teague *et al*. 2013). In an analysis of the merits of Cell Grazing, Norton (1998) concluded that the small size of continuously grazed paddocks limited the selective and uneven grazing and pasture degeneration that is common in large continuous paddocks with their greater heterogeneity.

(d) Despite the importance of stocking rate in determining pasture and animal performance, most studies used only one stocking rate for each stocking method. In most cases this was the same for both methods but in some cases different stocking rates were used on different stocking methods confounding the comparisons.

(e) Limited resources were accommodated for in some studies by having no replication restricting the possibilities for statistical analysis.

(f) In studies on commercial properties where Cell Grazing had been in place prior to experimental measurements commencing, grazing treatments were often not replicated and their location was not allocated at random.

(4) Where comparisons are made with different stocking methods on different properties, differences between managers may have more impact on the results than differences between stocking methods.

(5) In most experiments, the number of animals is held constant (set stocking) to enable comparisons to be made without changing animal numbers confounding the results. However, constant animal numbers rarely if ever occur in commercial practice over a period of time e.g. in their study of continuous grazing on nine properties, Hall *et al*. (2013) found animal numbers changed and all ‘continuous’ paddocks had some rest over the four years of the trial.

While the experimental evidence does not show that Cell Grazing performs better than continuous grazing, it is possible that some producers will get better results by changing to a grazing system (Allen *et al*. 2011) which incorporates Cell Grazing than they did from previous systems using continuous grazing. Indeed, managers have found that rotational grazing can work for diverse management purposes (Briske *et al*. 2011) and there is considerable anecdotal information of positive results with Cell Grazing (McCosker 2000; Teague *et al*. 2013) that is not mirrored in the scientific literature. Cell Grazing is usually adopted as part of a broad philosophy (Richards and Lawrence 2009) or package of which Cell Grazing is only part. Where this leads to superior management (clearer goals, improved financial systems, better decision making, greater monitoring, forage budgeting) or other advantages (e.g. quieter, more easily handled cattle) the new system may indeed outperform the previous system using continuous grazing but this is likely not due to the Cell Grazing per se.

There is growing recognition of the need to improve grazing management to maintain and improve the pasture base but the question of what management will lead to optimal productivity and long-term pasture health is likely to remain a topic of debate. However, important components of this management will include:

- paddocks are adequately fenced and watered to help manage animal distribution,
- stocking rates vary around the long-term carrying capacity,
- growing season rest is practised, and

- stock numbers are reduced in response to poor growing seasons.

If these components are included in a grazing system then a number of stocking methods, including ones that include periods of continuous grazing, will give productive and sustainable results.

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6 Appendix: Summaries of peer reviewed scientific articles comparing continuous grazing and rotational grazing

Australian reports

Dowling *et al*. (2005) used a paired-paddock design at 5 locations in south-eastern Australia to compare continuous grazing with time-control grazing (TCG) (18-31 paddocks) by cattle and sheep. All managers had completed a time-control grazing course and the cells were managed according to the rules for time-control grazing. Managers attempted to maintain similar stocking rates on both continuous and TCG paddocks by adjusting stock numbers. Overall, the numbers of grazing days/ha were similar for the two treatments but for some individual years they varied with both higher and lower stocking rates in different years. Over all five sites there were few consistent differences between continuous and TCG and they concluded that there was no apparent medium-term benefit of a multi-paddock rotational (time-control) grazing system over continuous grazing for encouraging and maintaining favourable botanical composition.

Tom *et al*. (2006) measured populations of soil organisms after 4 years (January 2000 to February 2004) of continuous or short-duration (SD) grazing. In the SD treatment grazing and rest periods were 2.5 and 54 days during the growing seasons, and 3 and 82 days during the non-growing seasons. Stock were on the plots for 45 days over 4 years giving a “stocking rate” of 9 DSE/ha. The continuous plots were grazed at 9 DSE/ha initially and the numbers increased to 15 DSE/ha within a year and then maintained in response to favourable seasonal conditions. Soil samples were taken in May and August-September 2004. Bulk density was not affected by grazing but litter levels were higher with short-duration grazing. Earthworm numbers were unaffected by grazing regime but micro-arthropod abundance in the surface soil (0-10 cm) was significantly higher in the SD regime than in the continuously grazed plots. Microbial biomass and respiration did not differ across treatments.

The effects of continuous and time-controlled (TC) grazing on soil characteristics (Sanjari *et al*. 2008), runoff and sediment loss (Sanjari *et al*. 2009) were compared on a commercial grazing property 40 km west of Stanthorpe. In the continuous grazing, a stocking rate of *c*1.6 DSE/ha was applied for the whole year. In the TC plots stocking rate, grazing duration and rest periods were adjusted according to the feed on offer and grass growth rate. Overall, grazing days were similar for the two treatments (3608 and 3529 days/ha). Two paddocks were used, one for each grazing treatment. Each paddock was divided two sections – one with deeper soil (40-42 cm) and lower slope (10%), and one with shallower soil (27-28 cm) and steeper slope (15%). Measurements were made from May 2001 to May 2006.

Sanjari *et al*. (2008) reported litter levels increased in both sections of the TC paddock but only on deeper, less sloping part of the continuous paddock. There was no difference in change in bulk density between the first and final years for either grazing treatment, although the value increased slightly (1.19 to 1.28 g/cm^3) on the shallow, steep part of the continuous paddock. There were no significant changes for either grazing method from 2001 to 2006 for soil organic carbon and nitrogen but extractable phosphorus levels declined in both treatments over this period. Herbage mass increased slightly over time in both treatments; the TC plots had slightly higher yields in the first year and the rate of increase was slightly higher in the TC plots but the differences were not statistically analysed.

Sanjari *et al*. (2009) reported results for three catchments – two for TC (C1 of 8 ha with 11% slope and C2 of 3.4 ha with 16% slope) and one for continuous (C3 of 7.5 ha with 11.5% slope). Flumes and samplers were used to measure runoff and sediment loss. Rainfall over 2001-2006 was similar for C1 and C3 (1383 and 1341 mm) but higher in C2 (1943 mm). Runoff, runoff coefficient (runoff/rainfall) and sediment loss were higher for C3 (continuous) than C1, but lower than those for C2 (both TC). When results were compared for the first 3 years and the last 3 years (when the TC grazing had been in place for longer), total rainfall was similar for the two periods but runoff, runoff coefficient and sediment loss were lower for the two TC catchments but higher for the continuous grazing. Ground cover was 60-70% in all catchments in 2001 but declined in 2003, then increased in all plots to approximately 90% in the two TC catchments but only 65% in the continuous catchment.

Earl and Jones (1996) compared the effects cell grazing and continuous grazing on pasture composition on three properties on the northern Tablelands of NSW. Cell grazing commenced in 1993 or 1994 and measurements were made until 1996 in a paddock in the cell system (26, 28 and 35 paddocks) and an adjacent paddock grazed continuously at the same stocking rate on two properties but at about half the stocking rate on the other as the owner considered it was not possible to maintain the same stocking rate under continuous grazing. At all three sites, basal area was significantly higher after two years cell grazing than under continuous grazing. The most desirable species at each site remained constant or increased under cell grazing while declining under continuous stocking. The least palatable components declined under cell grazing but changed little under continuous grazing.

Hall *et al*. (2013) compared continuous and cell systems on eight properties in Queensland. Over all properties stocking rates were similar for the two systems but they varied between systems on some individual properties. Cell systems had 21 to 166 paddocks on the different properties. Pasture and soil characteristics were measured in 2006, 2008 and 2009. There were no differences in pasture biomass, botanical composition, species diversity, ground cover or litter cover between grazing treatments.

Overseas reports

Derner and Hart (2007) in north central Colorado compared effects between 1995 and 2003 of time-controlled, short-duration rotational grazing against season-long continuous grazing, at a moderate stocking rate, on livestock gains and on foliar and basal cover in short-grass steppe. The grazing season was from mid-May to mid-October. The grazing periods in the 7 rotation paddocks were 6-7 days with three cycles per grazing season. Livestock average daily gains (1.05 kg/head for the continuous and 1.03 for the rotation) and grazing-season gains (144 and 143 kg), and beef production did not differ between grazing systems. Basal and foliar cover of all plant functional groups (C_3 annual grasses, C_3 perennial grasses and grass-likes, C_4 perennial grasses, cactus, annual forbs, perennial forbs, and shrubs/subshrubs) did not differ between grazing systems. Litter and bare ground were also unaffected by grazing system, with litter increasing and bare ground decreasing over the duration of this experiment.

Gillen *et al*. (1998) evaluated grazing system (either a short duration rotation or continuous grazing system) and stocking rate (ranging from 52 AUD/ha to 90 AUD/ha) effects on standing crop and species composition of tall-grass prairies in north-central Oklahoma from 1989 to 1993. Yearling steers grazed the pastures from late April to late September. Grazing schedules in the rotation units (8 paddocks) were originally designed to allow an average of 45 days of rest for each pasture between grazing periods. The rest and grazing periods were later shortened in the early portion of the growing season (to 2-5 days and 30-35 days) and lengthened as the growing season progressed. Continuous and rotational grazing affected the major herbage components similarly over time. Rotation grazing had no positive impact on the standing crop or relative contribution of any major vegetation component over the study period compared to continuous grazing. From the same experiment **McCollum *et al*. (1999)** reported live weight gain per head was higher under continuous stocking than rotational stocking at all stocking rates. At 52 AUD/ha, individual gains under rotational stocking were 11% less than under continuous stocking. At 90 AUD/ha, individual gains under rotational stocking were decreased by 20%. Measurements of steer diets and forage standing crop suggested the reduction in weight gain was due to reduced forage intake under rotational stocking. Live weight gain per hectare increased with stocking rate and was higher with continuous stocking at all stocking rates. Net returns per hectare increased as stocking rate increased for both stocking methods but were lower for rotational stocking at all stocking rates. Variable costs per head would have to decrease by 24 to 34% under rotational stocking to equalize net returns between the two grazing methods.

Hao *et al*. (2013) determined the effects of rotational (RG) and continuous (CG) grazing on herbage mass, diet digestibility, organic matter intake and live weight gain of sheep in the Inner Mongolian steppe, China. During June–September 2005– 2008, two 2-ha plots were used for each grazing system with grazing seasons of 90-98 days. In RG, plots were divided into four 0.5-ha paddocks that were grazed for 10 days each at a moderate stocking rate and rested for 30 days. CG sheep grazed the whole plots throughout the entire grazing season at a similar stocking rate. Across the years, herbage mass did not differ between systems ($p = 0.820$). However crude protein, digestibility, intake and LWG (80 vs 104 g/day) were lower in RG than in CG.

Hart *et al*. (1988) compared continuous and 8-paddock short-duration (SD) rotation grazing on mixed-grass range near Cheyenne, Wyoming from 1982 through 1987. Grazing pressures ranged from 19 to 81 steer-days per tonne of forage dry matter produced with a grazing season from June to October. In the SD system in 1982 and 1983 the steers on short-duration rotation grazed each paddock for 3 days at the beginning of the grazing season; the length of the grazing period was increased gradually to 7 days by the end of the season. In 1984 through 1987 each grazing period on each paddock was determined by growth rate and forage supply; grazing periods ranged from 2 to 11 days. There were no differences in peak standing crop or its botanical composition between grazing systems. Utilisation did not differ between systems. Basal cover of vegetation was affected only by years. Steer average daily gain decreased as grazing pressure increased ($r^2 = 0.66$); systems had no significant effect. With a change in the rotation plan of the short-duration rotation systems in 1984 through 1987, all differences among systems at the same stocking rates disappeared. In a simple economic analysis of the results there was no benefit from the rotational system over the continuous system. The lower performance of the short-duration rotation steers in 1982 and 1983 was caused by rotation according to a fixed schedule rather than according to forage supply and plant growth rate (Savory 1983), resulting in overgrazing of some paddocks and undergrazing of others. The length of grazing in short-duration systems must be short to minimize forced grazing which could limit intake and/or increase consumption of lower quality forage.

Hepworth *et al*. (1991) observed grazing behaviour during on this trial in 1983, 1984, and 1985. Steers travelled farther under continuous than under short-duration rotation grazing at both stocking rates in 1984, but only at the high stocking rate in 1985. Steers had to travel farther to water in the continuous pastures, and may have had to cover a greater area in an effort to select a more desirable diet, particularly under heavy stocking. Grazing system affected grazing and rest time only in 1985 at the heavy stocking rate, when steers spent more time grazing and less time resting under continuous than under short-duration rotation grazing. These differences were not reflected in differences in gain among stocking rates or grazing systems.

Manley *et al*. (1997) reported results from 1982 through 1994 on above- and below-ground biomass, botanical composition and basal cover. Grazing strategy had no effect on above-ground biomass or basal area, and little effect on botanical composition and root biomass. Litter levels were higher in SDG than continuous grazing. Grazing strategies had no significant effect on steer average daily gain.

Derner *et al*. (2008) reported the results of this trial for the final 16 years (1991-2006). Cattle LWGs were 6% lower in SDG (0.84 vs 0.89 kg/head/day) than continuous over the whole period but differences only occurred in years with average rainfall; there were no differences in dry or wet years.

Heitschmidt *et al*. (1982) compared continuous and short duration grazing (SDG) on the northern rolling plains of Texas. The grazing season was from early April to early October. The duration of the grazing period in the SDG pastures ranged from 3 days during periods of rapid vegetative growth to 7 days during summer dormancy. This resulted in deferment periods ranging from 35 to 42 days. Total and average daily gains of Hereford/Angus crossbred growing heifers were contrasted between a continuously grazed (CG) treatment and a 10-pasture, 1-herd rapidly rotated short duration grazing (SDG) treatment. Stocking rate in the CG was 0.48 ha/AUM, a moderate rate, while stocking rate in the SDG treatment was 0.24 ha/AUM. Trials were conducted during the 1978 and 1979 growing seasons. Both total and average daily gains were similar in both treatments in both years. Because of the two-fold difference in stocking rate, production/ha was approximately double in the SDG to that in the CG treatment. It was tentatively concluded from the results of this and previous studies that a properly managed SDG system may satisfactorily support live-stock at rates of stocking appreciably greater than that normally expected from conventional grazing schemes.

Vermeire *et al*. (2008) compared seven simulated grazing treatments (including continuous and SDG) on the northern Great Plains in south-eastern Montana for 6 years from 1997-2002. The continuous and SDG treatments were both grazed at the same moderate stocking rate. The SDG treatment had 15 paddocks with a 3-day grazing period and 42 day rest period. There were no differences in standing crop or botanical composition between grazing treatments.

Jacobo *et al*. (2006) compared the two main plant communities in the Flooding Pampa region of Argentina under rotational and continuous grazing over 4 years (1993-1996). The experiment had four pairs of farms, one managed under rotational grazing (implemented in 1989) and an adjacent one managed under continuous grazing at a similar stocking rate (1 AU/ha). The rotationally grazed farms had 10-12 paddocks and paddocks were grazed for 3-15 days with rest periods of 25-90 days. Basal cover, litter, and bare soil were monitored in midslope and lowland grassland communities on each farm. Total plant basal cover remained unchanged under both grazing methods. Under rotational grazing, litter cover was higher in both communities while the amount of bare soil showed a significant reduction in lowlands and a tendency to be lower in midslope. Basal cover of legumes, C_3 annual and C_3 perennial grasses was higher, while cover of C_4 prostrate grasses was lower under rotational grazing in the midslope community. In the lowland community, rotational grazing effects were evident only in the drier years, when higher cover of hydrophytic grasses and legumes and lower cover of forbs occurred. Plant species diversity did not change in response to grazing. In conclusion, rotational grazing promoted functional groups composed of high forage value species and reduced bare soil through the accumulation of litter. These changes indicate an improvement in rangeland condition.

Jung *et al*. (1985) studied forage quality and performance of post-weaning heifer calves under continuous and short-duration grazing (SDG) systems on smooth bromegrass (*Bromus inermis*) pasture in Nebraska for 2 years. There were 8 paddocks for each SDG cell. The animals were on pasture from early May through the middle of August in both years. Heifers grazed the SDG system for 2-4 days and paddocks were rested for 17-19 days. In 1982, the grazing treatments were stocked at equal levels (2.9 animals/ha). The stocking rate was increased to 3.8 animals/ha on the SDG treatment in 1983, while the continuous system remained at 2.9 animals/ha. Average daily gain (ADG) was similar on both systems (continuous 0.48 kg/d vs. SDG 0.47 kg/d, P>0.05 in 1982; 0.56 and 0.52 kg/d, P>0.05 in 1983). Available forage in 1982 tended to be greater under the SDG system (3141 vs. 3786 kg/ha), but this difference was not significant. Forage quality did not differ (P>0.05) between the grazing systems overall but crude protein content of the forage was higher for the SDG system on some sampling dates. In 1983 available forage was similar for both systems (2551 vs. 2159 kg/ha). The SDG system increased available forage when stocking rates were equal for the grazing systems, and this forage was effectively utilized at a higher stocking rate for the SDG system to produce more gain per ha (166 vs. 206 kg) without sacrificing individual performance.

McCalla *et al*. (1984a) The influence of short duration grazing (SDG), moderate continuous grazing (MCG), heavy continuous grazing (HCG), and grazing exclusion on infiltration rates of midgrass and shortgrass dominated communities was evaluated over a 20-month period on the Texas Agricultural Research Station, located near Sonora in the Edwards Plateau, Texas. A combination of cattle, sheep, and goats were used in each grazing treatment. The SDG pasture simulated one pasture of a 14-pasture, 1-herd grazing system, with approximately a 4-day and 50-day graze/rest cycle. Stocking rates varied from 3.2 ha/ AU/yr to 4.9 ha/AU/yr because of destocking during the 1980 drought. The MCG pasture was historically grazed at 8.1 ha/AU/yr. The HCG pasture stocking rate ranged from 0.3 ha/AU/yr to 12 ha/AU/yr. This pasture has been extremely heavily grazed since March 1978. Infiltration rates were consistently less in the midgrass (bunchgrass) than in the shortgrass (sodgrass) community. The HCG pasture was severely overgrazed and infiltration rates were reduced to about one-half those in the MCG pasture. The midgrasses in this pasture were destroyed after 26 months of overgrazing. Infiltration rates in the SDG pasture, stocked at double the recommended rate, decreased during the study period. Infiltration rates in the SDG pasture shortgrass community, near the end of the study, approached those in the HCG pasture. The greatest infiltration rates for both communities were maintained in the MCG pasture. Infiltration rates for the midgrass community remained relatively stable during the study when the general trend in the SDG and HCG pastures was toward reduced infiltration rates. The nongrazed pasture subsequent to the 1980 drought had a general increase in infiltration rates.

McCalla *et al*. (1984b) reported sediment production from the SDG pasture stocked at double the recommended rate increased during the study period. The SDG pasture, by the end of the study, had lost more sediment from both the midgrass- and shortgrass-dominated communities than the MCG pasture. Sediment loss from the midgrass community in the MCG pasture was consistently low during the study; however, sediment production from the shortgrass community decreased in the MCG pasture. Sediment production from the midgrass community in the non-grazed pasture remained consistently low throughout the study, but the shortgrass community showed a strong decrease in sediment loss during the study.

Naeth and Chanasyk (1996) quantified the effects of grazing systems on runoff and sediment yield from fescue grasslands in Alberta, Canada. The effects of two grazing intensities (heavy and very heavy) for two durations (short duration [grazed for I week in mid-June] and continuous grazed from May to October) were compared to an ungrazed control between June 1988 and April 1991. Runoff from rainfall varied with year and landscape position but was similar overall for grazing systems although both systems had higher values for particular year-position combinations. Sediment levels were similar for both systems, and low as there was no overland flow and soil loss was only that initiated by rainfall.

White *et al*. (1991) studied the vegetation response of a nine-paddock, short-duration grazing cell compared to that of a continuous pasture for a 5-year period in south-central New Mexico. Stocking rates in the short-duration cell ranged from a low of 1.1 times that of the continuously grazed pasture in 1981 and 1982 to a high of 2 times greater in 1985. In fall 1982, both grazing treatments were destocked of all cows due to drought conditions, and only the heifer calves were left until the following year. Differences in vegetation between grazing systems were small. Both basal area and end-of-season standing crop were similar for both systems. Blue grama aboveground productivity and basal cover were higher for the short-duration pastures than for the continuously-grazed pasture.

Weltz and Wood (1986) determined the influence of short duration grazing (SDG), continuous grazing, and grazing exclusion on infiltration rates on two range sites in south-central and east-central New Mexico. At Fort Stanton, continuous grazing was compared with SDG at a similar stocking rate. At Fort Sumner, continuous grazing was compared with SDG at twice the stocking rate. Measurements were made in 1982, two and three years respectively after grazing treatments commenced. Short duration grazing had no beneficial effect on the hydrology of the two sites. The terminal infiltration rates of both SDG systems, after the cattle had grazed the area, were about one-half the terminal infiltration rate of the same area before the cattle grazed the area. When the continuous grazed plots were compared with the SDG plots before grazing, terminal infiltration rate of the continuous grazed plot was higher at Fort Stanton and lower at Fort Sumner, than the SDG plots. Total standing crop and litter levels were similar for the two systems at both sites. Moderate continuous grazing was superior to heavy continuous grazing and short duration grazing, based on the hydrologic variables evaluated.

Olson and Malechek (1988) compared season-long grazing and short duration grazing (SDG) over three years (1983-1985) in west-central Utah. The SDG system consisted of 10 paddocks grazed for 1-3 days periods. The stocking rate was the same for both systems. Over three years there was no difference in daily LWG (1.02 vs 0.97 for continuous and SDG) with each system higher in one year and no difference in the other. There were no differences in diet crude protein and digestibility.

Pitts and Bryant (1987) compared 1-herd, 16-pasture short duration grazing (SDG) and continuous grazing (CG) on the Texas High Plains over a 4-year period. Animal performance, vegetation response, and diet quality were evaluated. Stocking rate on SDG was equal to that on CG the first year (13.3 ha/AU), double that on CG in the second year, and 1.5 times that on CG the third and fourth years. Average daily gain (ADG) of steers was the same (0.33 kg/day) between SDG and CG the first year. When stocking was doubled on SDG the second year, steers on SDG gained 0.15 kg/day compared to 0.25 kg/day under CG. In the third and fourth years, with stocking under SDG at 1.5 times that on CG, gains were similar. Standing crop biomass on SDG fell below that on CG after 1 year of grazing. In the second year standing crop was greater ($P<0.05$) on SDG than on CG, but in years 3 and 4, standing crop on the SDG was less than on CG. Changes in species composition were the same on both CG and SDG. Steer diet composition and quality were evaluated during the growing season (May to October) of year 4. Steers on SDG consumed 15% more forbs (39% vs 24%) than steers on CG. No differences ($P>0.05$) between CG and SDG were observed for dietary crude protein or in vitro digestible organic matter. SDG did not improve animal performance, diet quality, or forage availability over CG when evaluated over 4 years.

Ortega *et al*. (1997) studied cattle diet quality using oesophageal-fistulated steers within replicated grazing treatments of continuous and short-duration grazing at heavy and moderate stocking rates. The study was conducted at the Welder Wildlife Refuge, Sinton, Texas from October 1987 to July 1989. Digestibility and crude protein of cattle diets were similar between grazing systems and stocking rates.

McCollum and Gillen (1998) compared the nutrient intake of steers grazing tall-grass prairie in Oklahoma under continuous or short-duration grazing (SDG). Stocking rates were the same on both methods. The SDG treatment had 8 paddocks and paddocks were grazed for 3-7 days and rested for 21-49 days. Forage intake and dietary nitrogen concentration were lower on the SDG treatment than the continuous grazing treatment.

Walker *et al*. (1989) compared the diet quality of continuously and rotationally grazed steers in Texas where there was a higher stocking rate for the rotationally grazed steers. The RG steers grazed for 1-5 days with rest periods of 35-65 days in either 14 or 42 paddock systems. There were only minor differences in crude protein, digestibility and botanical composition of the diets. **McKown *et al*. (1991)** measured nutrient intake on the same paddocks and found nutrient intake of steers was higher on the continuous than the rotational plots.

Popp *et al*. (1997) studied steers grazing lucerne-grass pastures over 3 years in Manitoba, Canada under continuous and rotational grazing at two stocking rates with two replicates. The 10 rotational paddocks were grazed for 2-7 days and rested for 18-63 days. There were no differences in herbage mass, dietary crude protein, or diet digestibility (except on one occasion).

Hirschfeld *et al*. (1996) compared season-long and short duration grazing (SDG) in North Dakota. The SDG system had 8 paddocks which were grazed for 3-7+ days and rested for 21-50+ days. Stocking rates were approximately 40% higher on the SDG paddocks. Measurements were made on 8 occasions over two years. Overall intake and diet quality were higher for the SDG animals – intake was higher for 3 of the 8 periods, dietary nitrogen higher for 5 (and lower for one), and digestibility was higher for 6 of the periods.

Teague *et al*. (2011) compared neighbouring properties in north Texas that used continuous grazing or adaptive management with rotational grazing. Measurements of a number of soil and vegetation parameters were made after the grazing practices had been in place for at least 9 years. The rotationally grazed properties had 10-41 paddocks and paddocks were grazed for 1-3 days and rested for 30-90 days. A high stocking rate (27 AU/100 ha) was used on the rotationally grazed paddocks (RG), and either high (27 AU/100 ha) or light stocking rates (14 AU/100 ha) were used on the continuously grazed paddocks (HC and LC). Overall, the botanical composition of the RG paddocks was similar to the LC paddocks and better than the HC paddocks (more tall-grass). There was more bare ground in the HC than the LC and RG paddocks. Soil aggregate stability was lower in HC than LC and RG. Soil penetration resistance was higher in HC than LC and RG. Bulk density and infiltration rate did not differ with grazing management but sediment loss was higher for HC than LC and RG. Soil organic matter and cation exchange capacity were both higher in RG than HC and LC, but soil nitrogen levels were the same. The fungal/bacteria ratio was higher for RG than HC and LC.

Hart *et al*. (1993) compared cattle gains, activity, distance travelled, and forage utilization on a time-controlled rotation system with eight 24-ha pastures, on two 24-ha pastures grazed continuously (season-long), and on a 207-ha pasture grazed continuously, all stocked at the same rate. The experimenters tried to maintain the same stocking rates in all pastures, but this was not always possible with the available livestock and pasture sizes. Utilization on the 207-ha pasture, but not on the 24-ha pastures, declined with distance from water. At distances greater than 3 km from water in the 207-ha pasture, utilization was significantly less than on adjacent 24-ha pastures, at distances of 1.0 to 1.6 km from water. Cows on the 207-ha pasture travelled further (6.1 km/day) than cows on the 24-ha rotation pastures (4.2 km/day), which travelled further than cows on the 24-ha continuously grazed pastures(3.2 km/day). Grazing system, range site, slope, and weather had minimal effects on cow activity patterns. Over 5 years, gains of cows and calves were less on the 207-ha pasture (0.24 and 0.77 kg/day, respectively) than on the 24-ha rotation pastures or 24-ha continuously grazed pastures (0.42 and 0.89 kg/day, respectively), with no differences between the latter.

Abdel-Magid *et al*. (1987) measured bulk density and water infiltration on continuous and short duration (8 paddocks) grazing systems at moderate and heavy stocking rates. Measurements were made in the spring before grazing and at the end of the grazing season in 1983 and 1984. Bulk density was not affected by grazing systems or stocking rate. Infiltration was significantly greater under short duration grazing than continuous grazing in 1984 but not in 1983.

Jacoba *et al*. (2000) compared continuous and rotational grazing on Italian ryegrass-based pastures on farms in Argentina. The rotational systems consisted of 10-12 paddocks grazed for 3-15 days and rested for 25-90 days. The average stocking rates were 0.6 and 1.0 AU/ha for the continuous and rotational systems. There was no difference in total herbage but there were more of the desirable C_3 grasses in the rotational paddocks.