GLOBAL FOOD SECURITY GUARANTEED?

Evaluating The Effects Of Grazing Management

Year 11 Scientific Investigation - Survey

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Abstract

Despite volumes of research and advice from mainstream farming communities, conventional farming proponents fail to offer an economic and environmentally sustainable answer to climate change and global food security. A new approach to land management - cell grazing - claims to address both of these issues but proponents of conventional farming practices claim there is little evidence to support this method. This survey aims to compare these two approaches and determine what benefits, if any, accrue to landholders who implement cell grazing.

Initially we performed extensive background research that presented both sides of the issue. This research, however, served only to embroil us deeper in the controversy, and did not provide any concrete answers. We decided to perform an independent investigation into the effects and benefits of these forms of land management.

To do this, we collected and compared data on soil moisture content, pasture production, plant biodiversity and the frequency of beneficial plant species in eight paddocks across our farm. Four of these were conventionally managed and four have been cell grazed since 2006.

The results demonstrated that planned cell grazing has multiple financial and ecological benefits for landholders. These include increased water use efficiency; increased pasture productivity; a greater number of beneficial plant species; and increased plant biodiversity. When applied on a larger scale, the results also showed that cell grazing could provide a potential solution to global food security by improving both beef production and ecological health.

Introduction

We live on a 2300 hectare grazing property called “Danthonia” in the New England Region of New South Wales. After its purchase in 1999, conventional management continued as it had been since the 1950s, when the property was first cleared and farmed. This included use of chemical fertilizers, herbicides and continuous grazing.

During the first years after the purchase, plant and animal production decreased, land health deteriorated, and the bank balance was unsustainable. A cost effective and efficient managing technique was needed to restore ecological health and profits. Could persevering with conventional farming practice provide an answer or would we need a new approach?

In looking for answers, the farm manager stumbled upon Allan Savory’s “Holistic Grazing Management”. This is an agricultural system in which ruminants are used as a tool to encourage plant growth and increase soil nutrients through rotational grazing, also known as “planned” or “cell” grazing. After studying this concept, he invited Judi Earl, a student of Savory, to our farm. She recommended cell grazing as a solution to the issue of land degradation and advised our farm manager on how to implement it here. Since 2006, he has managed one pilot section of our farm using cell grazing and the rest of it using conventional methods.

Ten years on, we set out to collect, analyse and present data comparing the effects of the two forms of management on our farm. Our project stems from the concern to increase the biological productivity of our pastures while maintaining a healthy ecosystem. Successful grass farming is essential to maximising the productivity of not only our farm, but any livestock operation that uses grass as the primary source of nutrition. In fact, grassland is increasingly important to agriculture and our global food diet because the consumption of animal products is increasing, a trend that is predicted to continue. Understanding how a grazing strategy can impact the productivity and health of pasture is essential to maintaining livestock production at a sustainable level.

Maximizing the productivity of the world’s grasslands will be essential to feed a growing world population, with expected meat consumption doubling in the next century. This project began with the consideration of how to increase the productivity of the pastures on our farm, but soon we realized that increased grassland productivity is a global concern.

Aim

To evaluate what benefits, if any, accrue to land holders who implement cell grazing in place of conventional grazing and to determine what effect this would have on global food security.

Background Research

Farmstyle Australia (2016) states that grazing management can be defined as "where and when to move grazing animals", but the reasons and strategies behind grazing systems are complex and require explanation. Grazing management needs to simultaneously consider the needs of the animal, the pasture, the land and the farming business.

According to the Australian Bureau of Statistics (2015) there are two main categories of grazing implemented in Australia. These are conventional grazing and cell grazing also known as rotational grazing.

Conventional grazing, carried out across most of Australia's farmland, is a system in which ruminants such as cattle graze continuously, or for long periods, on one area of land at low stock density. One major benefit of this system is the relatively low input and simplicity of management. For example, fencing costs are usually far lower than an equally sized rotational system because fewer fences are needed. Despite these benefits, conventional grazing can have several drawbacks. Pasture utilization is often uneven as stock may preferentially graze some areas, such as north-facing slopes, over others. Also, more palatable grass species can decrease while less desirable species increase, lowering overall forage nutrition. In addition, stock density per hectare is often much lower than that of rotational grazing as cattle are spread over large areas. Lastly, ground cover is often sparser, leading to loss of water in the soil and less resistance to drought (Reinhart 2004).

The second approach, cell grazing, has seen increasing interest from scientists and graziers alike in the last decade (McCosker 2000).

Cell grazing is a rotational grazing system in which ruminant herds are regularly moved to fresh rested areas of pasture with the intent to maximise the quality and quantity of forage growth. The primary goal of cell grazing is to have a vegetative cover over all grazed areas at all times and to prevent complete removal of vegetation from grazed areas (Undersander; et al, 2013).

Similar to cell grazing, planned grazing is a rotational grazing system where the primary goal is to achieve optimal ecological health and therefore sustainable production. Our farm implements planned cell grazing, however, for the purposes of this report, we will refer to it simply as "cell grazing".

In order to implement cell grazing, the grazing management must be carried out according to the following six guidelines:

1. Allow plants adequate rest
2. Adjust stocking rate to carrying capacity
3. Plan, monitor and manage grazing
4. Manage livestock effectively to achieve the goals of cell grazing
5. Apply maximum stock density for minimum time
6. Manage for biodiversity and ecosystem health (Voisin 1988).

In cell grazing, the herd grazes only one portion of a pasture for a short time while allowing the other areas to recover. Resting grazed land allows the vegetation to renew energy reserves, rebuild shoot systems and deepen root systems with the result being long-term, maximum biomass production. In contrast to other grazing systems, cell grazing follows adaptive management. This means that the recovery period is determined by plant growth rate and is not calendar-based. For example, a pasture may be grazed every 40-80 days during times of high growth but only every 80-180 days in winter (*Farmstyle Australia* 2016).

Allan Savory explains that this adaptive rest period is important when grass physiology is considered. As grass grows, the root system grows with it. During this “adolescent” growth spurt, 30% of the products of photosynthesis are pumped through the roots into the soil. These exudates feed microbes which symbiotically source nutrients for the plants in return. The grass plant grows rapidly with adequate moisture and nutrients. During this period of growth it is converting sunlight to sugar, storing energy reserves in its roots and feeding soil microbes. When the plant reaches maturity it can be safely grazed, whereas grazing during the rapid growth phase weakens plants significantly. Interestingly, when a grass plant is bitten off by a grazing animal, the roots die back to a corresponding degree and add to soil organic carbon. This underscores the importance of planned rest and graze periods that are responsive to climate and growth conditions (1999).

Furthermore, cell grazing allows the animals to exist in an environment more suited to their natural growth and development. As animals move to a new paddock, (mimicking wild herds clumped together to fend off predators) wastes are left behind and allowed to decay without the animals nearby. The animals thus experience less disease without the need for regular and expensive drenching (Jones 1993).

Bart Davidson, a biological agronomist, told us that another benefit of this effect is the physical redistribution of nutrients from areas of high to low concentration. This means a herd can pass through a highly fertile area and shift nutrients to areas of lower fertility by moving to the next paddock before they have dumped manure. This leads to a slow but steady redistribution of nutrients.

Despite these benefits, one limitation of any land management system is that economically powerful advocates can easily quantify and manipulate their data to suit their needs. One common criticism of cell grazing is that while farmers and ranchers around the world believe that it works for them, the majority of scientists have not been able to experimentally confirm that intensive rotational grazing systems show a benefit and claim that managers’ reports of success are merely anecdotal (Itzkan 2016). Because of this controversy we decided to perform a study that investigated whether either of these two forms of land management held an advantage over the other.

Hypothesis

From our background research we formed the opinion that various forms of grazing management will not adversely affect pasture productivity or soil health. We do not expect to see any significant benefits accrue to landholders who implement either conventional management or cell grazing on their property.

Risk Assessment

This survey involved a number of potential hazards. These are addressed below, accompanied by their respective safety procedures:

1. Electric Fencing
   8000 volt, low amperage electric fencing is used extensively on our farm to subdivide paddocks within the grazing cell. Contact with these fences poses a high risk of electric shock. To counter this, we will exercise awareness near fences and observe our farm safety rules.

2. Farm Machinery
   There is always a risk of injury when using utility vehicles for transport on our property. Therefore, we will only visit the surveying sites under the supervision of a responsible adult.

3. Environmental Hazards
   In Australia, excessive sun exposure poses a risk of sunburn and dehydration. As much of the data collecting will be conducted outside, we will need to wear sunscreen and protective clothing when collecting samples.

4. Soil Dehydrator
   In the process of determining soil moisture content, we used a commercial combination oven to dry the samples. Incorrect use of the dehydrator could result in serious burns so we will exercise caution and use insulated gloves when handling hot soil samples.

5. Bovine Zoonotic Diseases
   There are several known diseases that can be spread from cattle to humans. To ensure this won't occur during the process of this survey, we will only take soil samples from paddocks with no cattle in them, and wash hands on completion of each site visit.

6. Animal Ethics
   While our survey is based on the effects of grazing cattle, we will not be running any trials on the cattle themselves. Therefore, there are no ethical issues associated with this survey.

Selection of Sites

The selection of sites was based on several parameters that needed to be accounted for in order to obtain unbiased and valid results. An important part of this survey was to provide a fair representation of paddocks across the farm. As with any farm there were a number of variables such as topography and historical records between the compared paddocks. Many of these variables can be controlled by selecting sites that adhere to the following criteria. All the sites had to be close in proximity and similar in:

- aspect and slope
- pasture type (native or improved)
- basic soil type
- fertilizer history
- production history before cell grazing was introduced
- graze pressure throughout the last 6 years

Following these criteria we selected four sites to account for variants across the individual sites. Each of these sites consisted of a cell grazed paddock adjacent to a conventionally grazed paddock. For the purpose of this survey, we labelled the sites as 1-4 with the individual paddocks labelled A (cell grazed), and B (conventionally grazed). This will ensure a broad and fair assessment for the effects of grazing management on our property.

Data Collecting Techniques

1. Soil Moisture Content

The purpose of this procedure is to compare moisture holding capacity of the soil between paddocks in all four sites. Throughout the process of conducting soil moisture analysis we had to ensure that the method was reliable and accurate. To do this, we used the Australian Department of Sustainable Natural Resources sampling standards. The department’s standard method “determination of the moisture content of a soil: oven drying method” fulfilled our requirements for accurately assessing soil moisture content. This method covers the laboratory determination of the moisture content of a soil as a percentage of its oven-dried weight. The method may be applied to fine, medium and course grained soils for particle sizes from 2mm to greater than 10mm. The method is based on removing soil moisture by oven-drying a soil sample until the weight remains constant. The moisture content (%) is calculated from the sample weight before and after drying. Using this result we could then calculate the amount of water in litres per hectare in each paddock.

<u>Sample Collecting</u>:
The way the soil samples are collected can drastically affect the results. For this reason, we used the NSW Government Department of Industry and Investment guidelines for conducting soil sampling in the paddock. Soil moisture content varies with location, so it was important to avoid sampling in areas that were not typical of the rest of the paddock. These include unrepresentative areas close to fences, existing trees, tracks, windrows, stock camps and old tree stumps. Soil moisture also varies with depth, so sampling needed to be done carefully as small errors in soil collecting can result in big errors in the moisture test.

A large number of representative cores plus care with depth control were necessary for obtaining a representative composite sample for measuring the soil moisture at each site. We repeated the sample collecting at one, three and seven weeks after 30mm of rainfall in order to track the ability of the paddock to store and use water efficiently.

Special Apparatus
For medium-grained soils (maximum particle size 10mm)

- Soil sampling devise
- Plastic sampling bags
- A thermostatically controlled oven of the forced-air type, capable of maintaining a temperature between 105 ^{o}C and 110 ^{o}C
- A balance readable and accurate to 0.01g
- Suitable, airtight, corrosion–resistant container of about 400g capacity
- A scoop

Procedure
For medium-grained soils:

a. Using soil core sampler take 15 representative cores from each paddock and place in a labelled, air-tight sampling bag
b. Clean and dry the container, place it on the scale and tare. Place a sample of about 300g of soil in the container, and weigh to 0.01g (W_1)
c. Remove the lid, place the container in the oven, and dry the soil between 105 ^{o}C and 110^{o}C to a constant weight
d. After drying, remove the container from the oven, replace the lid and allow to cool
e. Weigh the container with contents to 0.01g (W_2)
f. Calculate the moisture content of the soil as a percentage of the dry soil weight
    i. Subtract W_2 from W_1 to determine weight of water in the soil sample (W_3)
    ii. Divide W_3 by W_1 and multiply by 100
    iii. This result is the percent moisture content of the soil

2. Plant Biodiversity

The purpose of determining the number of plant species in a paddock is to compare plant biodiversity within sites. Increased biodiversity is a recognized measure of soil health and a vibrant ecosystem because plant biodiversity boosts productivity. Biologically diverse pastures recover faster from drought and other unpredictable events and provide protection of water resources (Global Issues 2016). For this reason we used the diversity of plant life to compare the health of paddocks in each site.

Special apparatus:

- Field Guide to Paddock Grasses
- Log book

Procedure:

a. In each site systematically cover the majority of the paddock using the field guide to identify all plant species present and record results in log book.

Classifying species:

We classified the species into four categories: C3 perennial grasses, C4 perennial grasses, legumes, and “other species”. C3’s and C4’s are perennial grasses that are distinguished by the different pathways that plants use to capture CO_2 during photosynthesis. These differences are important because the two pathways are associated with different growth requirements. C3 plants are adapted to cool season establishment while C4 grasses tolerate warm or hot seasonal conditions. Legumes are plants that are able to take nitrogen from the air and convert it into compounds that enrich soil and therefore are beneficial to any cattle farmer. Finally “other species” includes herbs, forbs and annual grasses commonly found in the paddock.

3. Frequency of Desirable Plant Species

One standard measure of the effects of grazing management is determining the frequency of desirable plant species in a given paddock. Desirable species include plants with one or more of the following characteristics: high feed quality, high productivity, drought resistance, and a long growing season. However, “desirability” is necessarily subjective and depends ultimately on the farmer’s opinion and the paddock’s condition. In conjunction with our farm manager, we selected eight plant species and measured their frequency in each paddock. To do this, we followed the “Northern Rivers Soil Health Card” recommendations for sampling plant frequency data.

Special apparatus:

- 500mm x 500mm quadrat
- Grass Identification Guide
- Log Book

Procedure:

a. Select a 200m transact that is representative of the paddock
b. Place quadrat on the ground and identify all desirable species inside the marked area
c. Move 10m along transact
d. Repeat steps (b) and (c)20 times in each paddock
e. Record results in table

4. Pasture Production

The purpose of collecting pasture production data is to compare the amount of grass grazed between paddocks in the four sites. In this survey, ‘pasture production’ means a measurement of the amount of grass grazed, not total biomass produced in the paddock. This demonstrates the amount of foraging material consumed by cattle in a paddock, clearly showing the strength of that paddock. Using the NSW Agriculture Department’s “Animal Rating Tables” our farm manager has calculated the pasture production of all eight paddocks since 2010. This method of forage utilization measurement assumes pastures are all grazed with plant and ecosystem health as primary concerns.

Because Australia's rainfall is highly unpredictable, agricultural scientists have linked pasture production to rainfall by calculating how many DSE's per hectare (kilograms of fodder) are produced and consumed per 100ml of rainfall on a rolling year basis. For this reason we present our farm manager's calculations in a format that accounts for annual rainfall and in doing so eliminates a major variable.

Procedure:

a. Calculate the average weight and daily gain of the ruminant herd every 2-3 months
b. Record the number of days the paddock was grazed per graze event
c. Use the animal rating table to find dry stock equivalent (DSE) – the amount of grass consumed by each animal per day
d. Multiply DSE per animal by number of animals to find the total amount of dry matter consumed in that paddock for one day
e. Multiply this by the number of days paddock was grazed.
f. Divide this by the size of paddock in hectares
g. The result shows the amount of grass consumed per hectare in a given paddock in a measurement called DDH (DSE Days per Hectare)

Reporting the Results:

Once we obtained these records from our farm manager, we reconfigured them into a more relevant format. We converted DSE's to revenue in dollars/hectare as well as kilograms of beef/hectare. Assuming 10 DSE is equal to .75 kg of beef gained per head (our three-year property average), and beef is sold at $3.20/kg live weight:

a. Divide annual DSE/hectare total by 10 – the average amount of grass a ruminant must consume to gain .75kg
b. Multiply this result by .75 to get the kilograms of beef gained per hectare
c. Multiply this result by 3.20 to calculate revenue generated per hectare in the respective paddock.

Results

Site 1.

Table 1.

	Site 1 A	Site 1 B
Rainfall (mm)	750	750
Temperature (C)		
Winter average	10.3	10.3
Summer average	22.7	22.7
Soil type	Basalt Clay	Basalt Clay
Pasture type	Native perennial pasture	Native perennial pasture
Paddock size (ha)	3.5	37.4
Aspect and Grade	East facing gentle slope	Flat plateau
Groundcover (%)[1]	98	95
Paddock Rating (1-10)[1]	6	4
Soil Carbon (%)	3.85	2.25
Fertiliser history	2007: 100 kg gypsum, 3 kg Zn, 1 Kg Boron 2009: Super 40S 100 kg	2007: 100 kg gypsum, 3 kg Zn, 1 Kg Boron 2009: Super 40S 100 kg
Livestock type	Cows/calves, steers, heifers	Cows/calves, steers, heifers

Table 1. presents information on climate, soils, pasture description, and livestock in Site 1.

(1) ground cover % and paddock rating based on estimates of agricultural scientist Judi Earl

Figure 1

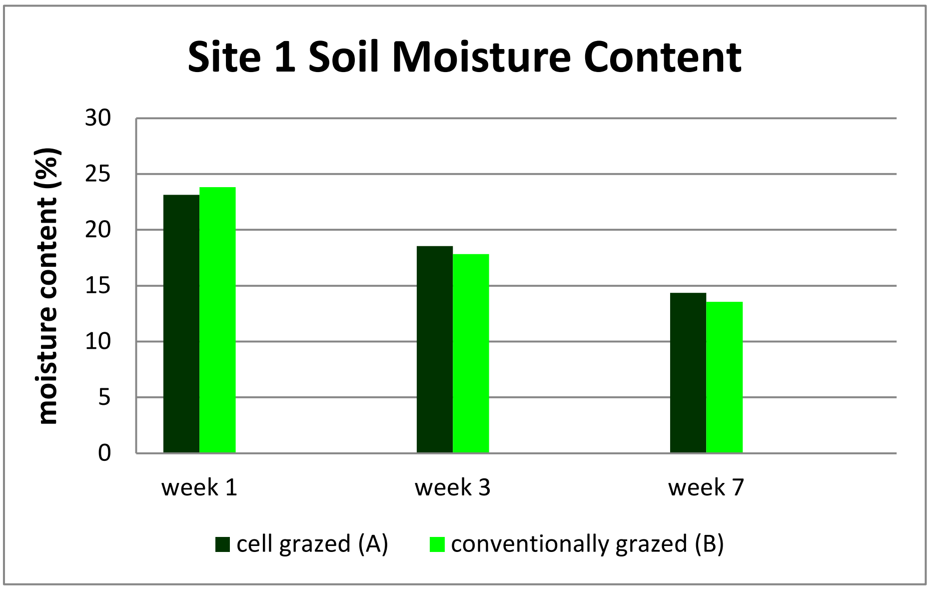

Figure 1 displays moisture content percentage of soils in site 1 taken at 1, 3, and 7 weeks after 29mm of rainfall. This data compares moisture holding capacity of a soil over time.

Table 2.

	C3 Grasses	C4 Grasses	Legumes	Other species
Site 1A	Danthonia Chilean needle grass Poa tussock Stipa	Red grass Paspalum Wild sorghum Parramatta Wire grass Barb wire Kangaroo Queensland blue Wild oats grass	Lucerne	Wild carrot Wild rice
Site 1B	Danthonia	Red grass Wire grass	Lucerne White clover	Not present at time of study

Table 2. categorizes all the plant species identified in site 1. Common names were used for recognition purposes.

Table 3.

Site 1	Danthonia	Stipa	Poa tussock	Red grass	Paspalum	Wild Sorghum
A(%)	85	40	15	30	55	40
B(%)	35	0	0	100	50	0

Table 3. shows the percent frequency of desirable plant species in site 1. This data is based on 20 quadrat measurements taken along a 200m representative transact.

Figure 2.

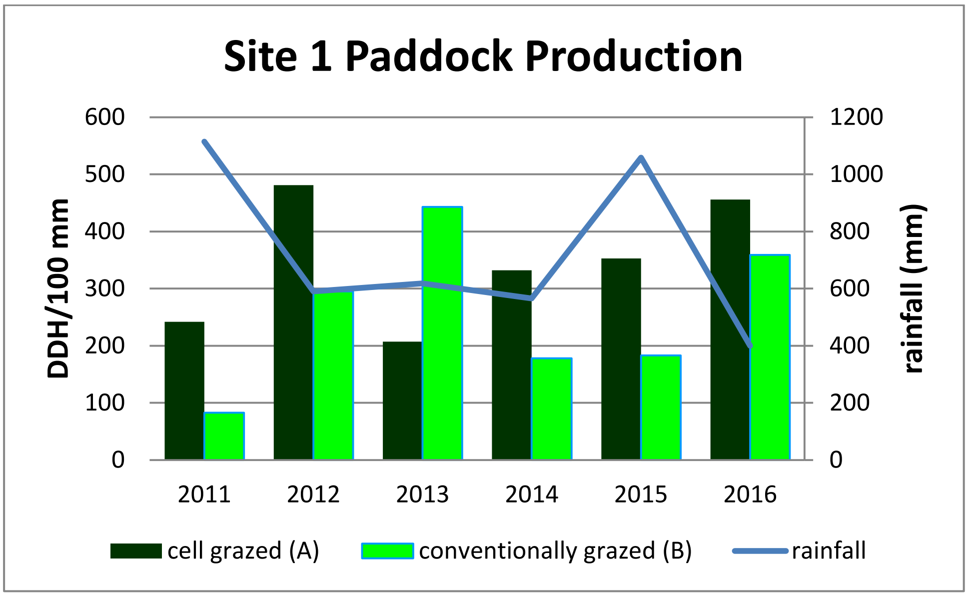

Figure2. compares the annual total of grass consumed by cattle between the paddocks in site 1, measured in dry stock equivalent days per hectare per 100ml of rainfall (DDH/100mm). Adjacent to this is a line graphing the annual rainfall of the site.

Site 2.

Table 4.

	Site 2 A	Site 2 B
Rainfall (mm)	750	750
Temperature (C)		
Winter average	10.3	10.3
Summer average	22.7	22.7
Soil type	Basalt Clay	Basalt Clay
Pasture type	Native perennial pasture	Native perennial pasture
Paddock size (ha)	2	22
Aspect and Grade	North facing medium slope	North-east facing rolling slopes
Groundcover (%)	100	95
Paddock Rating (1-10)	4.5	2.5
Soil Carbon (%)	4.21	4.02
Fertiliser history	No applications of fertiliser	2007: 100 kg gypsum, 3 kg Zn, 1 Kg Boron 2009: Super 40S 50 kg 2013: Gypsum 125 kg
Livestock type	Cows/calves, steers, heifers	Cows/calves, steers, heifers

Table 4. exhibits a description of the paddocks in site 2. This information includes soil type, climate, livestock types and topography.

Figure 3.

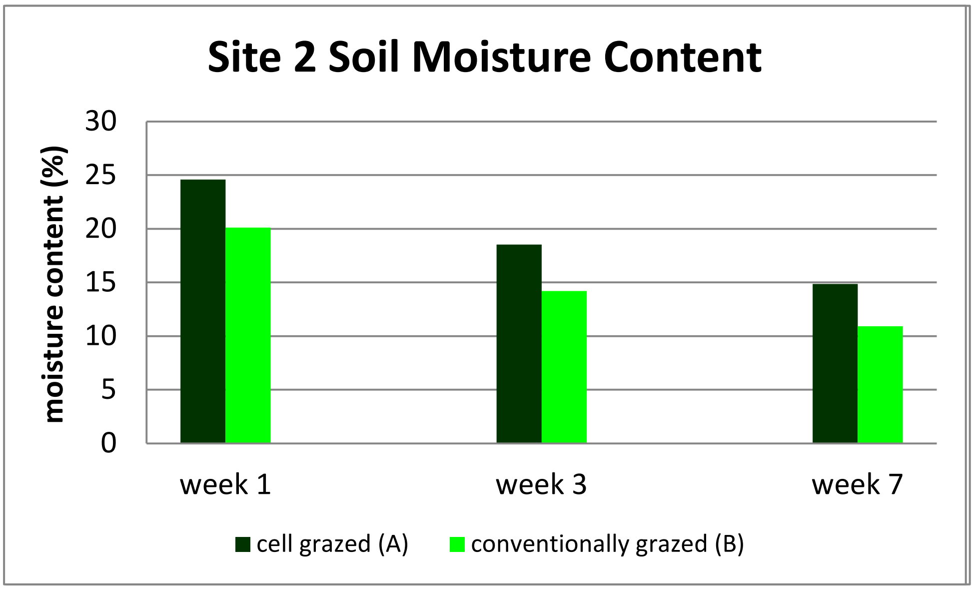

Figure 3. compares the moisture content of soils in site 2. Measurements were taken at 1, 3, and 7 weeks after 29mm of rainfall and are shown as a percentage of soil dry weight.

Table 5.

	C3 Grasses	C4 Grasses	Legumes	Other species
Site 2A	Danthonia Stipa Poa tussock Chilean needle grass Plains grass	Red grass Paspalum Wild sorghum Parramatta Wire grass Barb wire Kangaroo Panicum	Not present at time of study	Not present at time of study
Site 2B	Danthonia Stipa Poa tussock Chilean needle grass Slender bamboo	Red grass Wild sorghum Wire grass Barb wire Panicum	Not present at time of study	Not present at time of study

Table 5. categorizes the plant species identified in Site 2. Common names were used for recognisability and ease of reference.

Table 6.

Site 2	Danthonia	Stipa	Poa tussock	Chilean needle grass	Red grass	Paspalum	Wild Sorghum
A(%)	65	10	10	75	10	15	5
B(%)	50	5	45	30	0	0	5

Table 6. displays the frequency of desirable plant species in site 2. This data is based on 20 quadrat measurements taken over a 200m representative transact.

Figure 4.

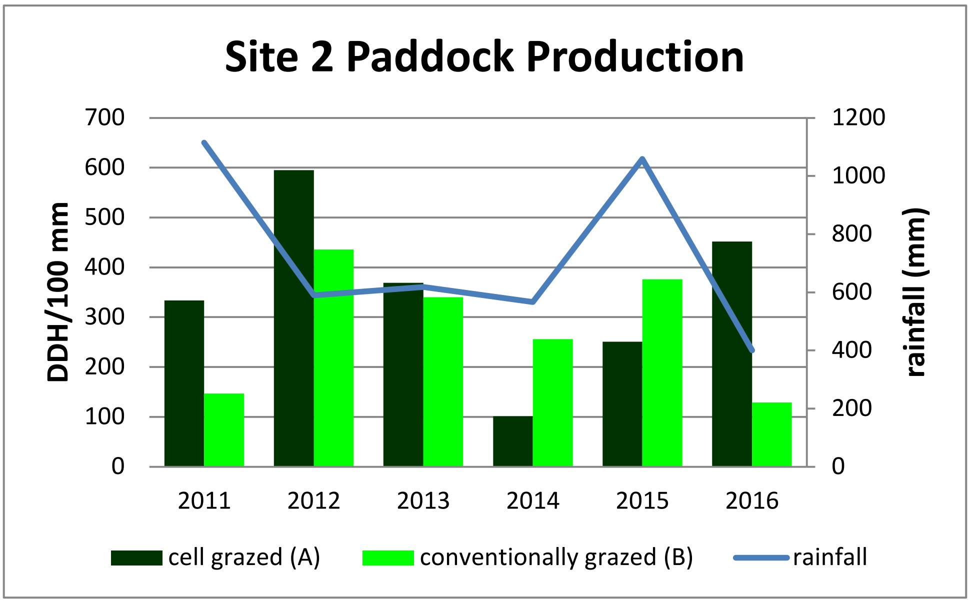

Figure 4. collates the annual total of grass consumed by cattle between paddocks in site 2. This comparison is measured in dry stock equivalent days per hectare per 100mm of rainfall. Also shown is a line graphing the annual rainfall at the site since 2011.

Site 3.

Table 7.

	Site 3 A	**Site 3 B**
Rainfall (mm)	750	750
Temperature (C)		
Winter average	10.3	10.3
Summer average	22.7	22.7
Soil type	Basalt Clay	Basalt Clay
Pasture type	Old cultivations sown to improved pasture	Old cultivations sown to improved pasture
Paddock size (ha)	2.5	20
Aspect and Grade	Flat	Flat plateau
Groundcover (%)	75	30
Paddock Rating (1-10)	4	2
Soil Carbon (%)	1.67	2.11
Fertiliser history	2007: 100 kg gypsum, 3 kg Zn, 1 kg Boron, MAP 50 kg 2010: Solidstart compost 500 kg 2012: Gypsum 100 kg 2013: MAP 50 kg , Natramin 50 kg 2015: Solidstart compost 250 kg, gypsum 250 kg, Zinc 3 kg, Boron 1 kg	2007: 100 kg gypsum, 3 kg Zn, 1 Kg Boron, MAP 50 kg 2012: Gypsum 100 kg 2013: MAP 50 kg, Natramin 50 kg
Livestock type	Cows/calves, steers, heifers	Cows/calves, steers, heifers

Table 7. presents information on climate, soil, pasture description and livestock types in Site 3.

Figure 5.

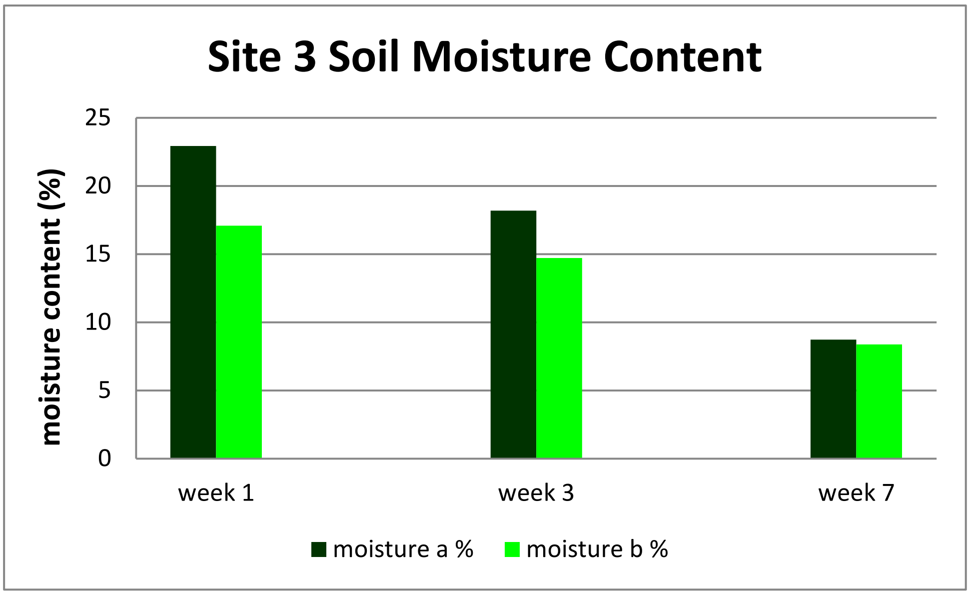

Figure 5. displays moisture content percentage of soils in Site 1. taken at 1, 3, and 7 weeks after 29mm of rainfall. This compares moisture holding capacity of the soil over time.

Table 8.

	C3 Grasses	C4 Grasses	Legumes	Other species
Site 3A	Danthonia Chilean needle grass Fescue	Red grass Paspalum Wire grass Queensland blue Spring grass	Lucerne Woolly pod vetch	Chicory
Site 3B	Danthonia Stipa Plains grass Fescue	Red grass Paspalum Wire grass	Lucerne	Chicory

Table 8. categorizes all the plant species identified in Site 3. Common names were used for recognition purposes.

Table 9.

Site 3	Danthonia	Fescue	Red grass	Paspalum	Chicory	Lucerne
A(%)	100	10	30	50	80	5
B(%)	50	10	10	10	25	45

Table 9. shows the percent frequency of desirable plant species in Site 3. This data is based on 20 quadrant measurements taken along a 200m representative transact.

Figure 6.

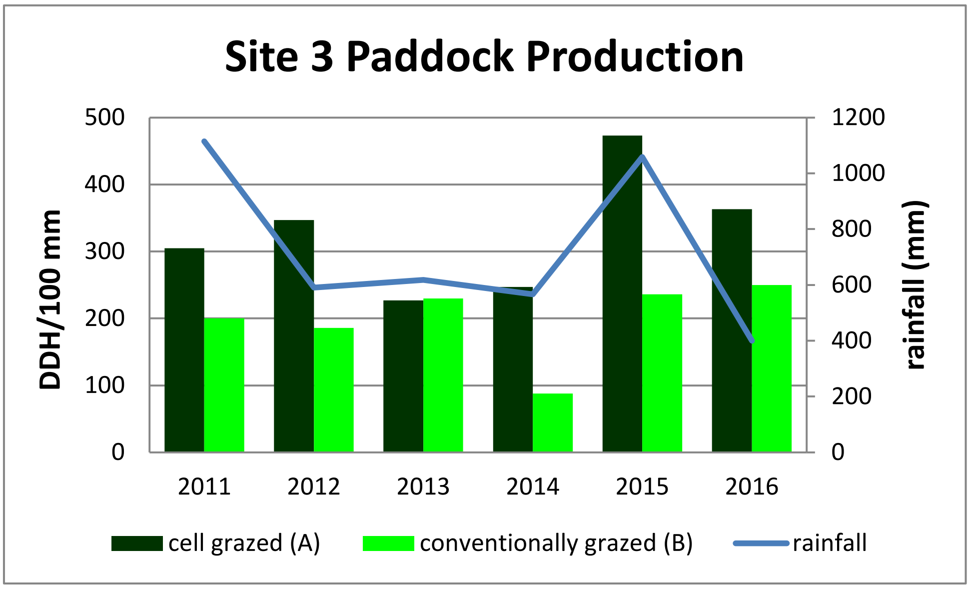

Figure 6. compares the annual total of grass consumed by cattle in the paddocks in Site 3, measured in DDH/100mm. Adjacent to this is a line showing the annual rainfall of the site.

Site 4.

Table 10.

	Site 4 A	**Site 4 B**
Rainfall (mm)	750	750
Temperature (C)		
Winter average	10.3	10.3
Summer average	22.7	22.7
Soil type	Basalt Clay	Basalt Clay
Pasture type	Native perennial pasture	Native perennial pasture
Paddock size (ha)	2.5	9.6
Aspect and Grade	South east facing steep slope	East facing moderate slope
Groundcover (%)	98	98
Paddock Rating (1-10)	3	3
Soil Carbon (%)	4.03	4.37
Fertiliser history	No applications of fertiliser	2007: 100 kg gypsum, 3 kg Zn, 1 Kg Boron 2009: Super 40S 50 kg
Livestock type	Cows/calves, steers, heifers	Cows/calves, steers, heifers

Table 10. exhibits a description of the paddocks in Site 4. This includes information on soil type, climate, livestock types, and topography.

Figure 7.

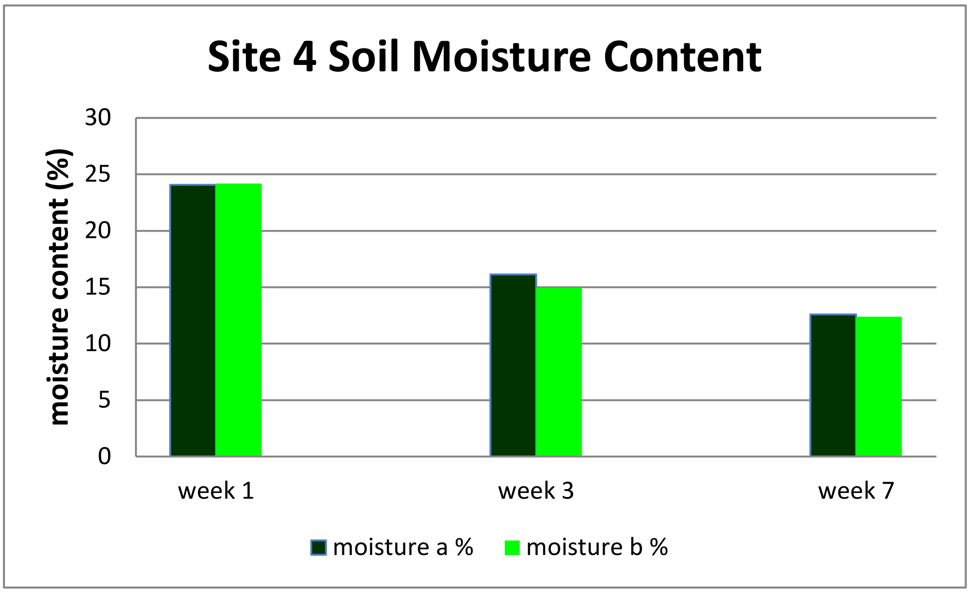

Figure 7. compares the moisture content of the soils in Site 4. Measurements shown are the moisture percentage of soil dry weight.

Table 11.

	C3 Grasses	C4 Grasses	Legumes	Other species
Site 4A	Danthonia Stipa Poa tussock	Red grass Paspalum Wild sorghum Parramatta Wire grass Barb wire Kangaroo Coolatai Panicum	Not present at time of study	Lomandra
Site 4B	Danthonia Stipa Poa tussock	Red grass Paspalum Wire grass Kangaroo Coolatai	Not present at time of study	Not present at time of study

Table 11. categorizes all the plant species identified in Site 4.

Table 12.

Site 4	Danthonia	Stipa	Poa tussock	Red grass	Paspalum	Wild Sorghum
A(%)	30	30	65	5	15	55
B(%)	35	35	15	10	20	0

Table 12 displays the percent frequency of desirable plant species in Site 4. “Desirability” was based on feed quality, drought resistance and a long growing season.

Figure 8.

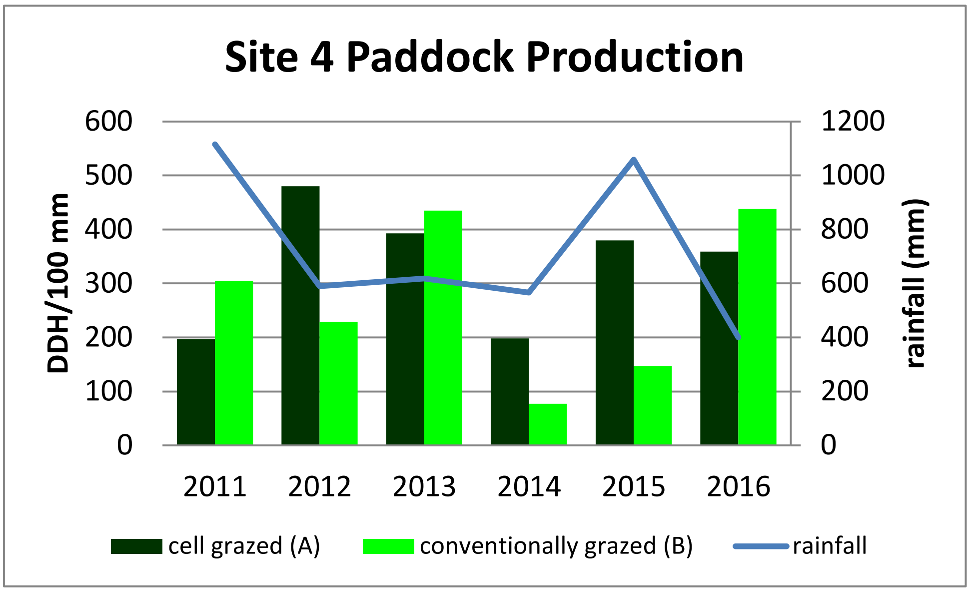

Figure 8. shows the annual total amount of grass consumed by cattle in both paddocks in Site 4 measured in DDH/100mm. Also shown is a line graphing the annual rainfall of the site.

Figure 9.

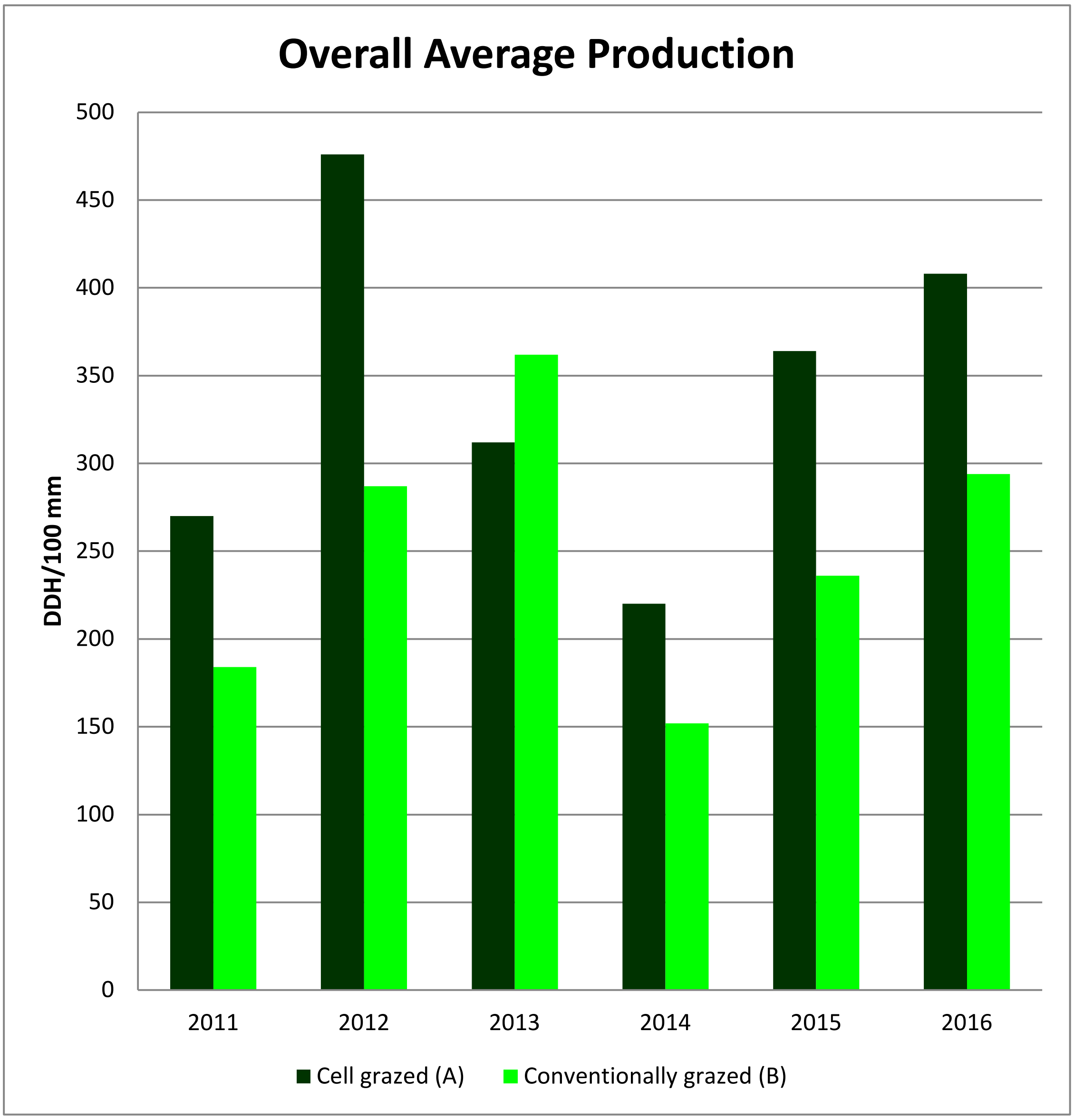

Figure 9. displays the annual total amount of grass produced as an average of all "A" paddocks compared to all "B" paddocks. This graph compiles the data from all four sites over six years and is therefore the most accurate measure of the effects of grazing management on pasture production.

Figure 10.

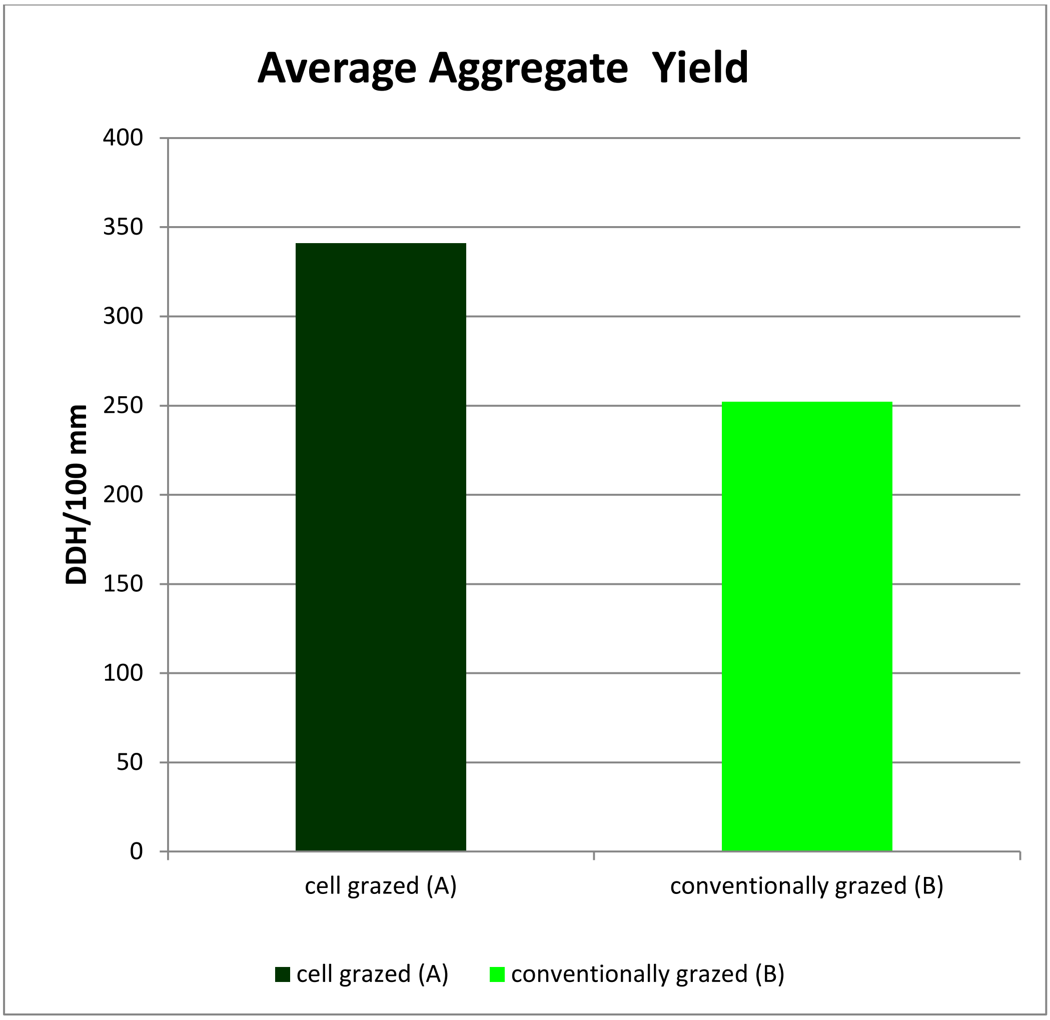

Figure 10. compares the sum of all DSE Days for each management technique over the last 6 years. This shows all yield from all years for both grazing techniques.

Figure 11.

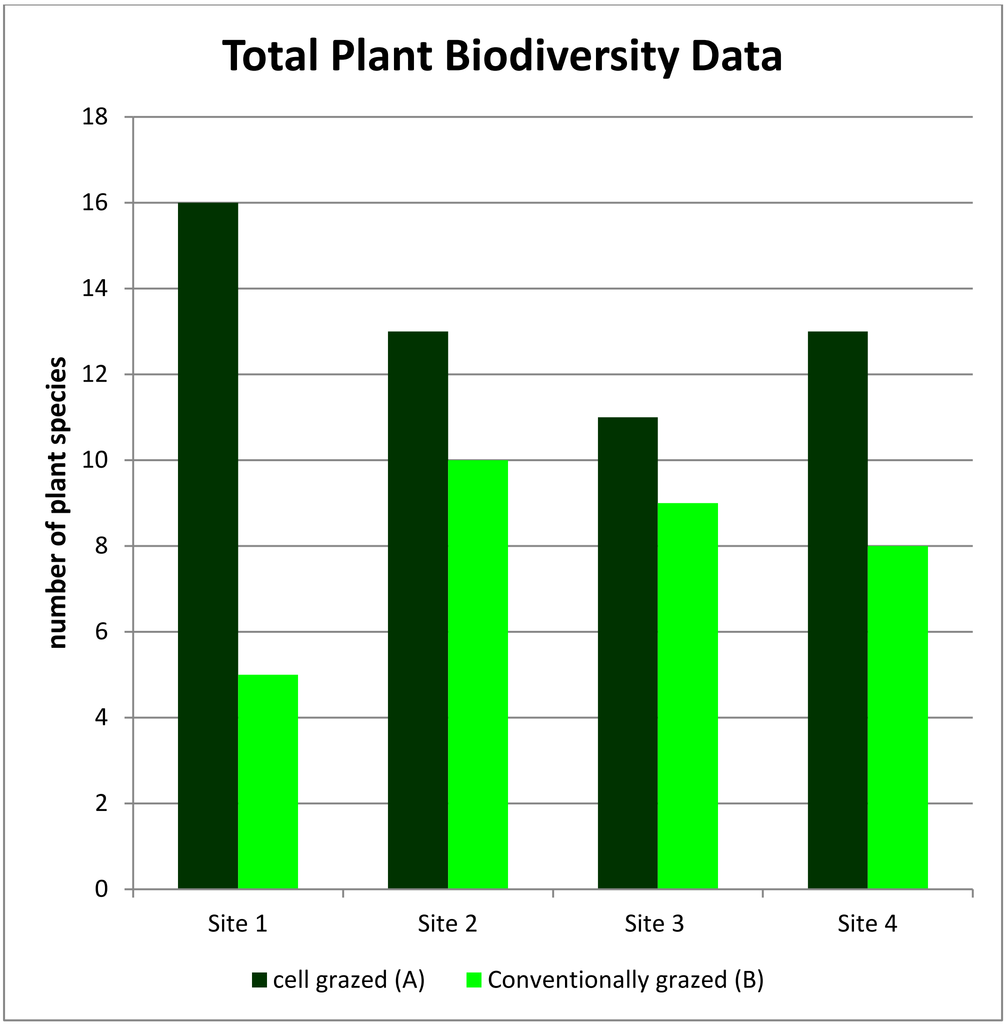

Figure 11. shows the total number of plant species found in each paddock during the course of the data collecting

Data Analysis and Discussion

In this section of our paper, we will locate and classify representative areas of each data type. In addition, we will synthesise this information, explain anomalies, and finally address creative ideas for further survey investigations.

Figures 1, 3, 5 and 7 compare the moisture holding capacity of each paddock. The results from all sites show that all cell grazed (“A”) paddocks can hold between 0.18% and 3.93% more water than conventionally grazed (“B”) paddocks seven weeks after rainfall. While this may seem insignificant, we computed that each percent of moisture in a one hectare area to a depth of 100mm is equal to 14,400 litres of water. For a grazier this means that his or her cell grazed paddocks will produce grass for a longer period of time in drought. This buffer could provide enough grass to sustain a cattle operation through an extended period without rain.

Contrary to our expectations *figures 1 and 7* show that initially the conventionally grazed paddocks contained more water after rain. We hypothesized that this is due to low soil porosity of these paddocks as well as less vegetative cover. However, seven weeks after rainfall, the cell grazed paddocks in these sites retained up to 21,000 litres more per hectare than the conventionally grazed paddocks.

Another significant finding of this paper was the data relating to plant biodiversity. The results showed that each “A” paddock had between two and eleven more plant species than its corresponding “B” paddock. Because our background research showed us that plant biodiversity boosts ecosystem productivity, graziers who implement cell grazing should experience this benefit from bio-diverse paddocks. Interestingly *table 2* shows that the cell grazed paddock in site 1 contained 16 species whereas the conventionally grazed paddock had merely 5 species. To the farmer this means that he will obtain sustainable growth year-round, due to the presence of both C3 and C4 species.

The third part of our data collecting addressed the frequency of desirable plant species in the four sites. Across the board, we found that “A” paddocks contained over 60% more desirable plant species than “B” paddocks. This was an interesting result, as it corresponded to the water-holding capacity and productivity of the same paddocks. With increased frequency of desirable plant species a grazier can expect higher productivity from his or her pasture.

The final aspect of the results covered the grass productivity of each site. This is a measure of the annual total amount of grass consumed by cattle in the respective paddock. Over the six years that the farm manager recorded this data, 70% of the results showed that cell grazed paddocks produced more grass in this time. Most importantly, the production levels in each cell grazed paddock actually increased over the six year period. Based on the results, it appears that conventional grazing is possibly detrimental to ecological health and ultimately production.

Figure 6 shows that the production in cell grazed paddocks in 2016 was significantly greater than that of the conventionally grazed paddocks. This is supported by *figures 2 and 4*. However, *figure 8* contrasts this by displaying a higher DDH per 100mm in paddock “B”. One reason for this is that the water content of both paddocks in site 4 (see *fig. 7*) was only 0.18% different seven weeks after rainfall. This slight difference most likely accounts for the anomaly in the data as there was little total rainfall in 2016 as of the time of this survey.

Figures 3 and 4 highlight a significant observation. In 2016 soil moisture content of paddock “A” in site 2 was 3.93% greater than that of paddock “B” (see *fig. 3)*, which is equal to nearly 57,000 additional litres per hectare. This data is mirrored by the pasture production records for this year (see *fig. 4)* which show that paddock “A” produced 1330 DSE’s per hectare more than paddock “B” – a huge productivity gain.

Figures 2, 6 and 8 demonstrate that after a number of years, the cell grazed paddocks have been better able to convert soil moisture to production than the conventionally grazed paddocks. For example, during the wetter period of 2015 the cell grazed paddocks produced over 30% more grass than the conventionally grazed paddocks as they recovered faster from drought.

Figure 9 shows that in five out of six years, the cell grazed paddocks produced more grass than the conventionally grazed paddocks. On average this means 651 additional DDH per year were produced in the cell grazed paddocks. As each DDH is equal to $0.24, we computed that a farmer who implements planned cell grazing could increase their annual revenue by $156.24 per hectare. Moreover, the cell grazed paddocks produced an average 26.1% more grass across all four sites over a six year period (see *fig.10*)

Clearly cell grazing has several advantages over conventional grazing, but what would these benefits look like on a larger scale? Based on the findings of this trial we applied the results to a national and global perspective. For critical purposes we used a 50% conservative estimate of the data from our farm. What we found was astonishing. For example, if the Australian cattle grazing industry was to implement cell grazing nation-wide it could generate over $4.6 billion in additional annual revenue. Furthermore this action could potentially retain over 1134 gigalitres of water in the soil. That is equivalent to two times the volume of Sydney Harbour. The current global beef production reached 76.5 million tonnes in 2015. If cell grazing was implemented world-wide across the land already grazed by cattle, an additional 40.3 million tonnes of beef could be produced. This exceeds the projected beef consumption for 2050 by over 7 million tonnes.

Indisputably, cell grazing has many significant benefits for landholders, but how do these occur? Based on our observations during the course of this survey, we realized the answers are complex and varied. However, we will discuss the primary drivers of these benefits below.

As all farmers know, water is an invaluable asset to a successful farm. The results showed that cell grazing increased moisture content and water-holding capacity of the soil. One primary reason for this is that ground cover in the cell grazed paddocks was significantly better than the conventionally grazed paddocks. Because cell grazing is an intensive management technique, the cattle move from the paddock after one to three days leaving trampled organic material and manure behind. This ground cover both minimizes evaporation and adds to soil organic matter. Contrasting this is conventional grazing in which cattle graze one area until there is no foraging material left. This approach severely limits vegetative cover, leading to loss of soil moisture and nutrients.

Another important cause of the benefits of cell grazing is the planned rest period. Both the cell and conventionally grazed paddocks were stressed during times of drought but the cell grazed paddocks always got rest from grazing after that stress. The benefit of this is evident in the post dry-time recovery outcomes with cell grazed paddocks recovering much faster from drought.

This adaptive rest period also allows for new species to establish themselves in the 40-200 days between grazes. Resting grazed land allows the desirable species to recover after the cattle have targeted them during the intensive graze. As the paddock accommodates more species and the beneficial species become dominant, pasture production increases dramatically, as we have seen in this study. For these reasons cell grazing provides a distinct advantage for landholders who implement this technique on their farm.

While we took extensive efforts to collect valid data, as with any in-situ survey, there were some variables we could not control.

1. Sample collecting for soil moisture data may have been slightly inconsistent, as it was difficult to maintain a consistent depth across the 360 samples taken.
2. Plant species data collecting was conducted in Autumn, which unintentionally excluded some annual grass species from identification.
3. Also due to the season, identification of other grass species was difficult and could have resulted in some error.
4. Finally, no two paddocks are ever identical. Therefore, controls used in the survey were not as consistent as controls used in a laboratory.

Although this survey covered four sites spanning our property, it was confined to one geographic region. A more comprehensive study could determine the success of cell grazing on other climactic areas. Additionally a close look at the financial benefits would be of value to the Australian beef industry as start-up costs and infrastructure involved in cell grazing may offset the initial profits. Recent studies have documented that cell grazing can increase soil carbon and by doing so, mitigate the effects of climate change (McCosker 2011). A further study that tested whether these results are mirrored on our property could prove that cell grazing can increase farmers' profits while providing an ecologically sustainable solution to climate change and global warming.

Conclusion

The results contradicted our hypothesis, which stated that cell grazing would not provide any distinct advantages over conventional grazing. More to the point, this survey has shown that, on average, cell grazing can:

- Improve ability of soils to retain water by 1.32%
- Increase plant biodiversity by 60.38%
- Increase the number of beneficial plant species by 62.9%
- Boost pasture productivity by 26.1%

This investigation has provided additional data that supports a potential solution to global food security and climate change.

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