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Grazing triggers for southern Australia

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Abstract

The risks and rewards of using cool season burning to manipulate pasture and animal production was investigated using the SGS Pasture model. Annual burning increased pasture growth and nutritive value but decreased pasture mass and intake, relative to current management. As a result animal production was similar or lower than current management depending on the percentage of area burnt and the time of burning. The modelling highlighted increased risk of low pasture mass, used as a surrogate for ground cover, with cool season burning. This risk could be minimised by burning in years when soil water content was high, as this favoured a more rapid increase in pasture mass. Tactical use of cool season burning based on pasture mass and/or soil water content in autumn showed promise as a trigger to decide whether or not to burn. Confidence in model outputs was high for metrics related to pasture production and water balance, and moderate for animal production outputs because of the models limited capacity to simulate different management options within a paddock. The SGS Pasture model is a tool well suited to the analysis of production and natural resource management issues in the grazing industries.

Executive summary

Cool season burning has been suggested as a low cost management option for steep hill country to increase the nutritive value of pasture and improve animal production. The focus of this study was on a 250 ha area of hill country within a case study property in north eastern Victoria. The area is currently used to run 30 Angus breeding cows, calving in mid-August with calves weaned at 5 months of age. This analysis of cool season burning, conducted using the SGS Pasture model, has highlighted the tradeoffs in production and natural resource management risks.

Cool season burning was shown to provide some advantages to the production system, in particular by increasing both pasture nutritive value (digestibility and metabolisable energy (ME) content) and annual pasture growth. The increase in nutritive value was due to higher legume content and an increase in the ratio of green:dead plant material. There were also disadvantages to the production system associated with cool season burning, because low pasture mass following burning limited pasture intake. This was particularly the case with burning carried out later in the season (June-August) compared to burning in Autumn, and when a large percentage (>50%) of the farm area was burnt on an annual basis.

The tradeoffs in cool season burning between the advantages of increased pasture growth and nutritive value, and disadvantages of lower pasture mass, were assessed in terms of animal production (cow liveweight and calf weaning weight). From the simulation analyses conducted in this study, two conclusions were drawn:

1. Under conditions where 50% or more of the area underwent cool season burning late in the season (June-August), lower cow and/or calf weaning weight was simulated.
2. Under conditions where 25% of the area underwent cool season burning early in the season (March-May), cow and/or calf weaning weights were similar to the baseline scenario. When limitations of the model were considered, small increases in animal production may be possible in these scenarios.

The major change in the risk of degradation to the natural resource base with cool season burning was increased frequency of breaching the minimum pasture mass threshold (used as an indicator of ground cover). Under current management the threshold was breached in 21% of years, but burning breached this threshold each time it was carried out. Runoff was also predicted to increase in burnt areas. Burning increased the risk of soil erosion losses.

Knowledge of soil water content (SWC) in autumn can assist in making a decision on whether or not to burn because it alters the risk associated with low pasture mass. For the cool season burning option of 25% of area on 15 March, if SWC was in the highest one-third of historical values on the date of burning then pasture mass increased more quickly than if SWC was in the mid or lowest thirds of historical values. Burning when SWC is high minimised the time that pasture mass was low, as such knowledge of SWC at time of burning can be used to minimise the risk of soil erosion.

A summary of the changes in production and natural resource management metrics when annual cool season burning was implemented in mid-March on 25% of area is provided in Table 1, along with an indication of the confidence in SGS Pasture model outputs.

Tactical use of burning in autumn only in years when pasture mass was >3 t DM/ha showed promise to maintain animal production and minimise risks associated with low ground cover, compared to burning every year. Pasture mass and soil water content in autumn are recommended as triggers for use of cool season burning. The two indicators were correlated in this study with high soil water content observed in 4 of the 7 years that burning based on the pasture mass threshold occurred.

Table 1. Summary of the changes to production and natural resource management risks relative to current management when cool season burning was implemented annually on 25% of the property in mid-March. An indication of the level of confidence in the SGS Pasture model outputs is also provided.

Metric	Change with 15 March cool season burning[1]	Confidence in SGS model prediction[2]
Production		
Annual pasture growth (t DM/ha)	🟩	High
Pasture quality (MJ ME/kg DM)	🟩	High
Pasture feed on offer (t DM/ha)	🟥	High
Pasture DM intake (kg DM/ha)	🟧	Moderate
Pasture ME intake (MJ ME/cow)	🟧	Moderate
Calf weaning weight (kg)	🟧	Moderate
Cow weight (kg)	🟧	Moderate
Natural resource management risks		
No. years minimum pasture mass threshold breached	🟥	High
Runoff (mm)	🟧	High
Drainage below the root zone (mm)	🟧	High
Nutrient loss risk	🟧	Not applicable
Greenhouse gas emissions (t CO_2-e/ha)	🟧	Low
Soil carbon (t C/ha, 0-30 cm depth)	🟧	Low

[1] green/orange/red colours indicate an increase/little change/decrease in production metrics or lower/little change/higher natural resource management risk.

[2] 'High', 'Moderate' or 'Low' confidence in model prediction takes into account the strengths and weaknesses of the model, the capability of the model to simulate the management strategies, and the extent to which the science on an issue has been defined and incorporated into the model.

Confidence in the SGS Pasture model predictions was high for metrics associated with pasture production and water balance. Moderate confidence in animal production metrics was due to the inability of the model to simulate the within paddock management differences associated with cool season burning, which may have had implications for predicted animal production. Low confidence in greenhouse gas emissions and soil carbon was specifically because the impact of burning on these metrics has not been incorporated into the model. Where moderate or low confidence in the model output is indicated the model results must be interpreted within limitations of the SGS Pasture modelling framework. Nevertheless, this case study demonstrated that the SGS Pasture model provides an effective tool for analysis of production and natural resource management issues in the grazing industries.

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1. Background

Purpose

The project will provide a pilot process to assess by modelling tradeoffs and opportunities in production and resource management risks.

Description

By modelling the opportunities for cool season burning on pasture growth, animal production, soil and nutrient changes, a case study for north east Victoria will be developed. This case study will be used to explore opportunities for using the SGS Pasture model to assist with grazing and management decisions (opportunities, tradeoffs, risks for production and natural resource management).

2. Project objectives

By 20 June 2013 to have provided to MLA an assessment of a case study property in north eastern Victoria to address the question: what are the tradeoffs between production and sustainability with cool season burning?

Provide recommendations as to the effectiveness of the SGS Pasture Model to identify and highlight risks and rewards across production and natural resource management factors.

3. Methodology

Background to livestock operation

The case study property runs a herd of 1900 Angus breeding cattle in north east Victoria (36.0°S, 147.55°E). Breeding cows calve in August, with calves weaned at 5 months of age and grown out to a target liveweight of 450-500kg at 14 months of age when they are sold on to feedlots. Breeding cows are primarily run on steep hill country with calves weaned onto improved pastures on river flats. The hill country contains a mix of native perennial grasses, including wallaby grass (*Austrodanthonia* spp.) and microlaena (*Microlaena stipoides*), and oversown subterranean clover (*Trifolium subterraneum*), but is heavily infested with weeds, in particular St Johns wort (*Hypericum perforatum*) and blackberry (*Rubus fruticosus*).

The hill country in its current state has low carrying capacity and the farm manager is interested in options for the future use of this area. Two options for the hill country have been identified:

1. Business as usual. This option involves continuing the system as outlined above.
2. Use cool fire burning as a low cost management tool to manipulate forage quality and species composition, and improve livestock productivity. The cool fire burning management proposal suggested by the landowner applies

burning to a proportion of the area each year (ie. the whole area is not burnt every year), but the most effective time to burn and proportion of the property to burn have not been identified.

These two options formed the scenarios investigated in this modelling project. The focus of this study was on a 250 ha area of hill country within the property that is currently used to run 30 breeding cows, calving in mid-August with calves weaned at 5 months of age.

Modelling approach

The business as usual, hereafter referred to as the 'baseline' scenario, and cool fire burning production systems described above were modelled using the SGS Pasture model version 4.8.16 (Johnson *et al.* 2003; 2008). The model was parameterised to reflect conditions of the site. Daily climate data for the location was sourced from the 'Data drill' service of the SILO database (http://www.longpaddock.qld.gov.au/silo/; Jeffery *et al.* 2001). The systems were simulated using climatic data from January 1980-March 2013. The site has a winter dominant rainfall pattern with an average annual rainfall (1980-2012) of 845 mm (Figure 1).

The soil type on hill country was classified as a sandy clay loam with a maximum plant rooting depth of 30 cm. The plant available water holding capacity of the soil was 36 mm. The average slope of the site was 10°. The pasture was simulated as a mix of a perennial C_3 native grass and a short-season subterranean clover cultivar.

The Angus breeding herd was stocked at 30 cows in the area of 250 ha. The breeders had a maximum weight of 550 kg liveweight. Cows calved on 15 August, with each cow producing one calf. Calves were weaned off the area at 150 days after calving. No supplementary feed was fed.

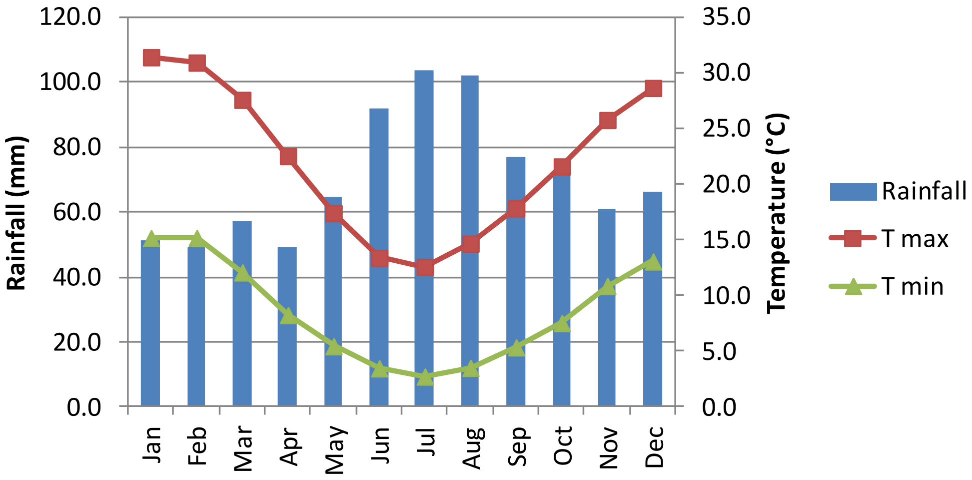


Figure 1. Mean monthly rainfall (mm), maximum (T max) and minimum temperatures (T min, °C) at the case study property in north east Victoria.

Simulation of cool season burning

The SGS Pasture model (version 4.8.16) does not include fire as a management option, so a pasture cutting protocol was used to simulate fire. To simulate burning the pasture was cut and removed, leaving a residual of 0.2 t DM/ha on the burnt area.

The cool fire burning management proposal suggested by the landowner applies burning to a proportion of the area each year (ie. the whole area is not burnt every year). Since the SGS Pasture model applies management options at a whole paddock level, it was necessary to simulate multiple paddocks so that different proportions of the area could be burnt. The area was divided into four paddocks so that cool season burning applied to 25, 50 and 100% of the total area could be simulated. A grazing management system where livestock spent 1 day in each paddock was applied, as the best compromise to best reflect a continuously stocked management option in a multiple paddock system.

Annual cool fire burning management was applied at four times between early autumn and mid-winter at approximately 6 week intervals. The specific dates are available in Table 2. Burning was applied on the specified date each year in the simulation period. Production and natural resource management metrics from cool fire burning scenarios were compared to the ‘baseline’ scenario.

Table 2. Dates of burning and percentage of farm area simulated as cool season burning on the case study property.

Date of cool season burning	Percentage of total area burnt
15 March	25%
1 May	50%
15 June	75%
1 August	100%

The cutting protocol used to simulate burning in this study was applied on each date irrespective of the grasslands ability to carry a fire. However, burning may not be feasible if the moisture content of the pasture is high. In Tasmania, recommendations for successful burning of grassland include that the percentage of dead fuel should be >60% (Marsden-Smedley 2009). Using this as a guide, burning in these simulations would have been successful in 84% years on 15 March, 73% years on 1 May, 27% years on 15 June, and would never be successful on 1 August.

In addition to the annual cool season burning scenarios described above, a ‘tactical’ cool season burn was simulated based on pasture mass in mid March to limit burning to years when pasture mass was high at the end of summer. In this tactical simulation burning occurred on 15 March if pasture mass exceeded 3.0 t DM/ha on this date. The 3 t DM/ha threshold was applied individually to the four paddocks in the simulation.

Soil water content (SWC)

To investigate the effect of SWC on production and natural resource management metrics in these systems, the SWC on 15 March was used to define each of the 33 years in the simulation into one of three SWC categories (11 years per category) with equal probability of occurring:

1. Low SWC: plant available water was 0 mm.
2. Moderate SWC: plant available water was 1-7 mm.
3. High SWC: plant available water was 8-40 mm.

For comparison, the production and natural resource management metrics for the SWC categories were compared with autumn rainfall in High, Mid and Low years. Low autumn rainfall years had <115 mm, Mid had 115-207 mm, and High rainfall was >207 mm.

Data analysis

The key animal production outputs from the baseline and cool fire burning scenarios modelled were cow liveweight, calf weaning weight and pasture intake. These data were reported across the grazing system that is as outputs from grazing across the burnt and non-burnt parts of the property. Greenhouse gas emissions, consisting of methane and nitrous oxide, were also reported at this ‘whole of systems’ level. Greenhouse gas emissions were expressed as tonnes carbon dioxide equivalents per ha (t CO_2-e/ha) by multiplying the amount of methane and nitrous oxide production by their respective 100-year global warming potentials of 21 and 310.

For pasture and water balance model outputs a comparison was reported for the burnt area compared to the baseline simulation. This was provided to show the effect of burning on pasture growth, species composition, pasture mass, feed quality (digestibility and metabolisable energy (ME) content), as well as annual runoff and drainage below the root zone. The number of years in which the minimum pasture mass in the simulation was less than 700 kg DM/ha was also reported. This threshold is used as an indicator of when ground cover is not sufficient to protect against soil and nutrient loss (Alcock 2006).

Data from the farm description and model outputs were used in the ‘Farm Nutrient Loss Index’ (Melland *et al.* 2007) to determine the risk of phosphorus and nitrogen losses from the system. An area from the ‘baseline’ simulation and a burnt area were used, with the only differences being in runoff characteristics (baseline was net deceleration and burnt net acceleration of runoff) and ground cover (70% for baseline and 50% for burnt area).

The simulated animal production results (cow liveweight, calf weaning weight and pasture intake) were presented for all simulations. Further results for scenarios where animal production was negatively affected by cool season burning were not presented. A full description of results for pasture and natural management metrics were presented for the scenario were 25% of the area was burnt on 15 March each year. In each case the results are compared with the 'baseline' scenario where no burning was implemented.

For the tactical burning on 15 March scenario, the results were compared with the baseline and burning 25% area on 15 March scenarios.

4. Results

Effects of annual cool season burning on animal liveweight and pasture intake

The mean cow liveweight in the baseline scenario was 441 kg (Figure 2). When annual cool season burning was implemented on 25% of the area there was little impact on cow liveweight, however burning of 50% or more of the area had a negative effect on cow liveweight. There was little difference in cow liveweight between the burning dates when the same percentage of farm area was burnt.

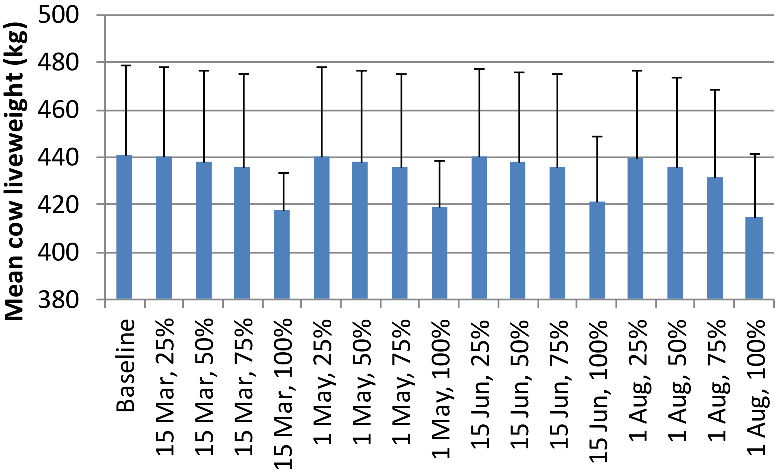


Figure 2. Mean annual cow liveweight (kg) for the baseline and annual cool season burning scenarios. Burning scenarios are denoted by the date and percentage of area burnt. Error bars indicate one standard deviation across years.

The mean calf weight at weaning in the baseline scenario was 175 kg (Figure 3). None of the annual cool season burning scenarios increased calf weaning weight. Burning of 25% of the area had a small negative impact on weaning weight. Burning of larger proportions of the area resulted in weaning weights lower than in the baseline, with the largest impacts associated with higher proportions of area burnt, and with the later burning dates.

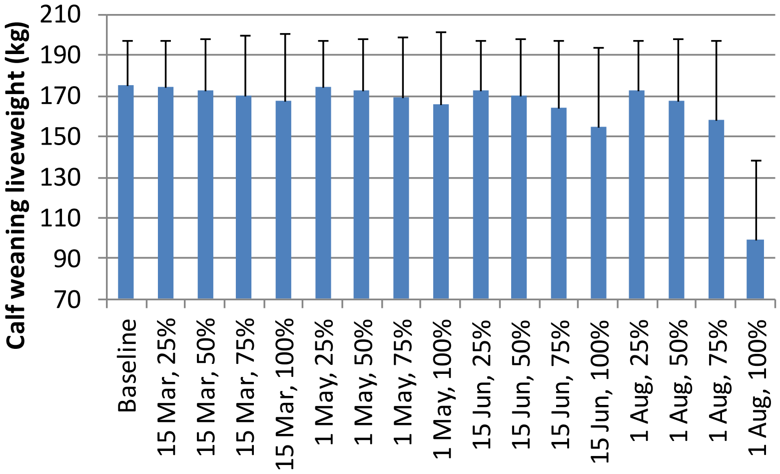


Figure 3. Mean annual calf weaning weight (kg) for the baseline and annual cool season burning scenarios. Burning scenarios are denoted by the date and percentage of area burnt. Error bars indicate one standard deviation across years.

Pasture intake (t DM/ha) was highest in the baseline scenario with 0.51 t DM/ha consumed (Figure 4). In the cool season burning scenario where 25% of the area was burnt, pasture intake was 2-4% lower than in the baseline. Decreases in intake were larger when a higher proportion of the area was burnt, with larger reduction in intake occurring at the later times of burning.

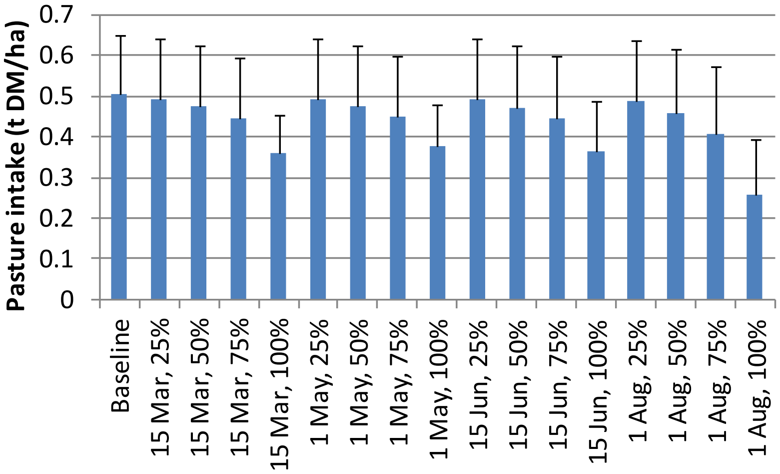


Figure 4. Mean annual pasture intake (t DM/ha) for the baseline and annual cool season burning scenarios. Burning scenarios are denoted by the date and percentage of area burnt. Error bars indicate one standard deviation across years.

Effects of annual cool season burning on pasture growth, pasture mass, species composition, feed quality and intake

Annual cool season burning on the 15 March resulted in higher annual pasture growth, with mean annual pasture production of 2.8 and 3.6 t DM/ha in the baseline and cool season burning scenarios respectively (Figure 4). Inter-annual variation in pasture growth was similar in the two scenarios.

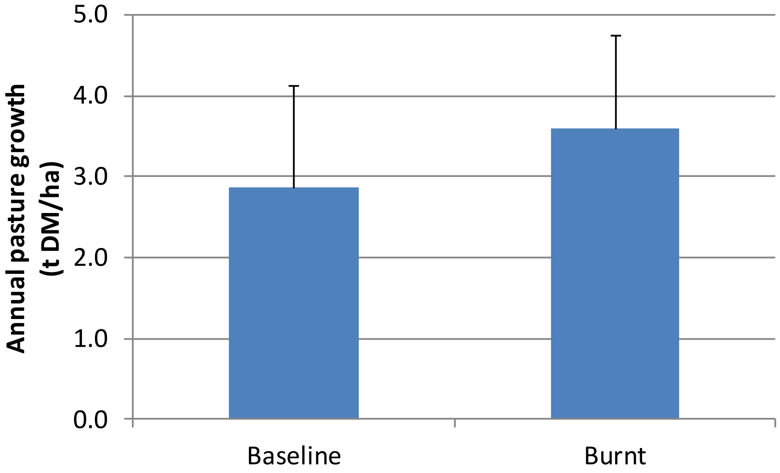


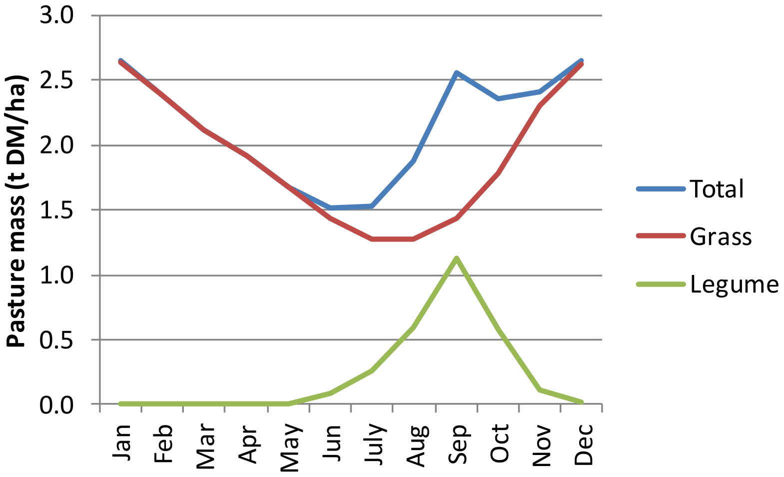
Figure 5. Mean annual pasture growth (t DM/ha) for an area in the baseline farm and an area burnt on 15 March each year. Error bars indicate one standard deviation across years.

Monthly mean pasture mass in the baseline scenario peaked at approximately 2.5 t DM/ha in the months from September to February, and reached a minimum of 1.5 t DM/ha in June and July (Figure 6). Pasture species composition was dominated by the perennial grass throughout the year, with the minimum grass composition (56% of DM basis) occurring in September when legume content reached its maximum (44% DM).

When annual cool season burning was applied on 15 March, pasture mass was lower throughout the year compared to the baseline scenario. The minimum pasture mass was reached after burning leading to, on average, low pasture mass (<1 t DM/ha) through June and July. In this system pasture feed on offer reached its maximum value of 2.1-2.3 t DM/ha in the summer months. The species composition was dominated by grass, but legume content was 60-70% DM in August and September, higher than in the baseline scenario. Averaged over the year, the proportion of feed on offer that was dead plant material was higher in the baseline compared to the cool season burning scenario (52 and 45% respectively).

Pasture feed quality, simulated as digestibility (Figure 7) and ME content (Figure 7), was higher following the cool season burning on 15 March compared to the baseline, particularly during the months April to September. During these months the mean ME content of the burnt pasture was 1.0-1.6 MJ/kg DM higher than the baseline scenario. For the remainder of the year the ME content was also higher in the burnt area but the difference was smaller in the range 0.1-0.5 MJ/kg DM.

(a) Baseline



(b) Burnt

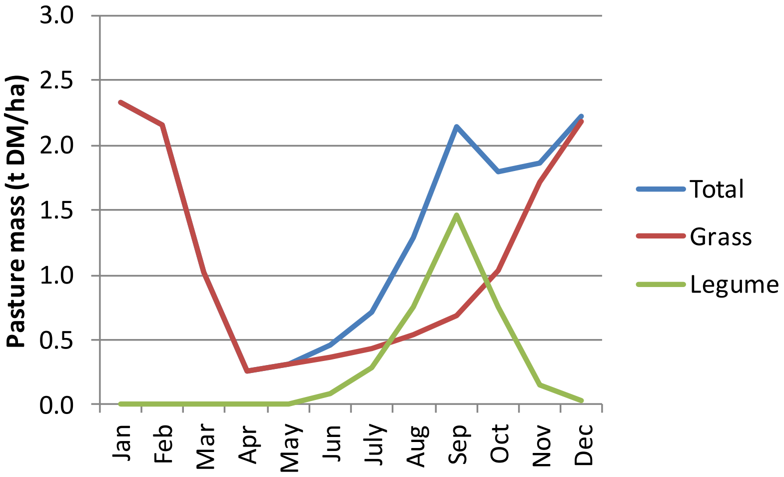


Figure 6. Mean monthly pasture mass (t DM/ha) for an area in the (a) baseline farm and (b) an area burnt on 15 March each year. Total pasture mass and the mass of grass and legume are shown.

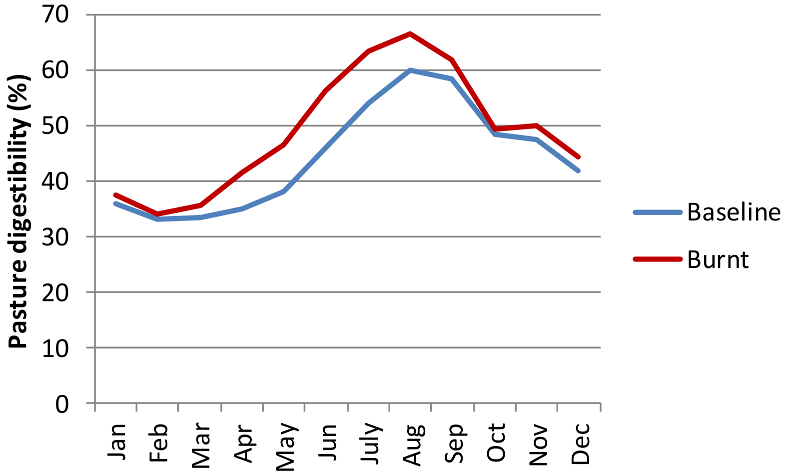


Figure 7. Mean annual pasture digestibility (%) for an area in the baseline farm and an area burnt on 15 March each year.

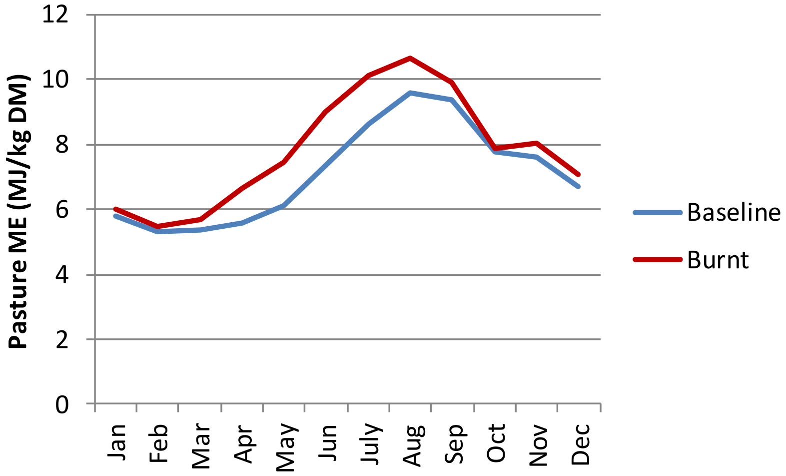


Figure 8. Mean annual pasture metabolisable energy content (MJ/kg DM) for an area in the baseline farm and an area burnt on 15 March each year.

Effects of annual cool season burning on natural resource management risks

In the baseline scenario, the percentage of years that the simulated minimum pasture mass during the year was less than 700 kg DM/ha was 21% (7 out of 33 years). In the scenarios where annual cool season burning was implemented, the burnt areas breached this pasture mass threshold in all of the years, while in the unburnt areas in these simulations the percentage of years that this threshold was breached was similar to the baseline scenario.

The effects of the annual cool season burning treatment on the runoff and drainage below the root zone aspects of the water balance are shown in Figure 9. On the burnt areas, on average, annual runoff from increased by 8 mm (+6%) and drainage below the root zone decreased by 36 mm (-16%) compared to the baseline scenario.

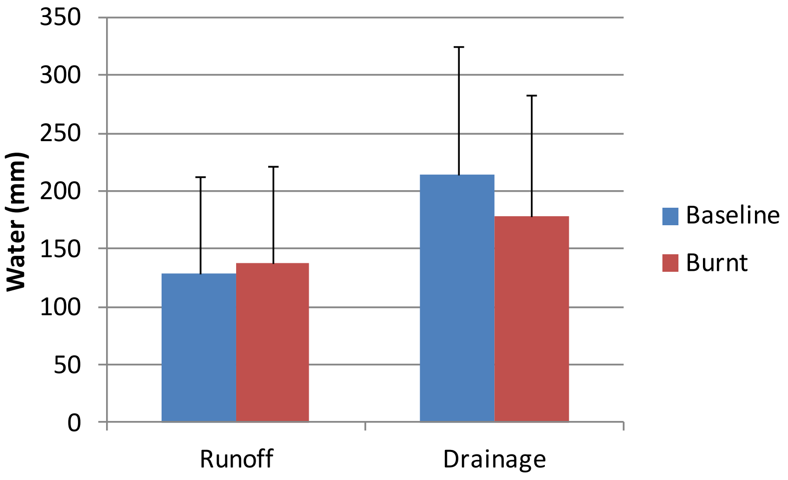


Figure 9. Mean annual runoff and drainage below the root zone (mm) for an area in the baseline farm and an area burnt on 15 March each year. Error bars indicate one standard deviation across years.

The risk rating from the Farm Nutrient Loss Index in the baseline simulation was Low for runoff of phosphorus and nitrogen, and Medium and High for deep drainage losses of phosphorus and nitrogen respectively. In the burnt area the risk ratings were the same for all categories expect for nitrogen losses in runoff which increased from Low in the baseline scenario to Medium in the burnt areas.

Soil carbon was predicted to be higher under the baseline scenario than in the cool season burning scenario. At the end of the simulation period, total soil carbon (0-30 cm soil depth) was predicted to be 52 t/ha in the baseline and 47 t/ha in the burnt scenario, but this does not include the contribution of burning to the soil carbon pool.

There was little difference in mean annual greenhouse gas emissions (t CO_2-e/ha) between the baseline and cool season burning scenarios (Figure 10). The emissions were dominated by methane which made up approximately 85% of total emissions. The emissions intensity of beef production (expressed as t CO_2-e/t calf liveweight weaned) decreased slightly from 10.6 to 10.4 for the baseline and cool season burning scenarios, but this does not include emissions generated in the process of burning.

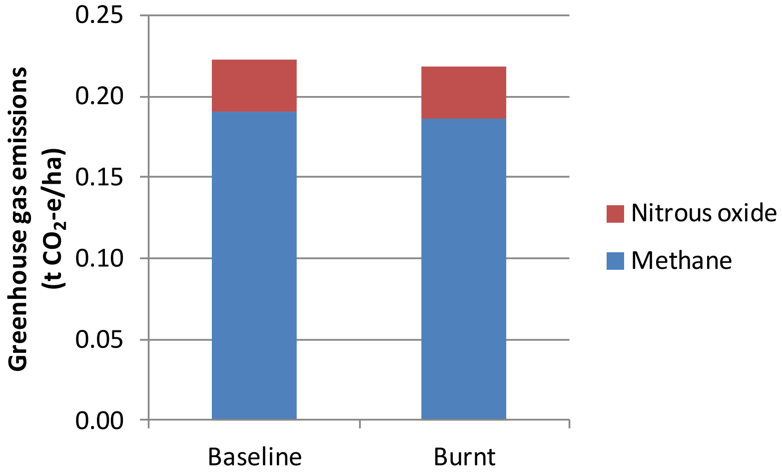


Figure 10. Mean annual greenhouse gas emissions (nitrous oxide and methane, t CO_2-e/ha) from the baseline and annual cool season burning of 25% area on 15 March scenarios.

Influence of autumn soil water content on production and natural resource management risk

Cow liveweight was highest in the years when the SWC in Autumn was High category and lowest when SWC was in the Low category (Figure 11). Calf weaning weight was also highest when SWC was in the High category, but there was little difference between the calf weaning weight in the Mid and Low SWC categories (Figure 12). For both cow liveweight and calf weaning weight in the three SWC categories there was little difference between the baseline and annual cool season burning scenarios.

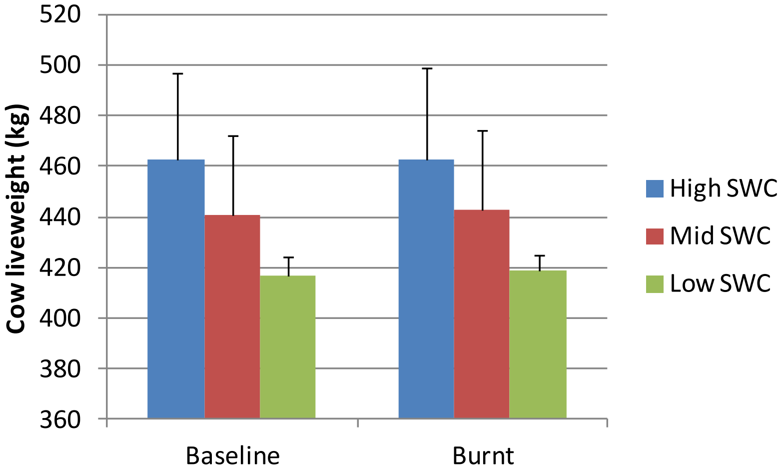


Figure 11. Mean annual cow liveweight (kg) when soil water content was in the High, Mid and Low categories in the baseline and annual cool season burning of 25% area on 15 March scenarios. Error bars indicate one standard deviation across years.

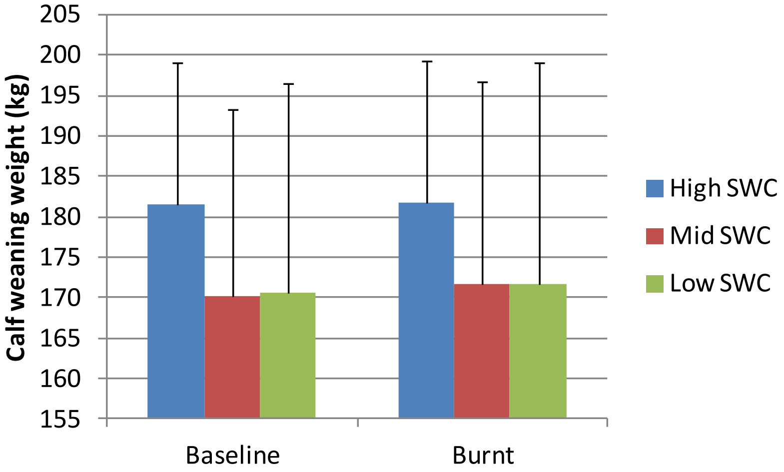


Figure 12. Mean annual calf weaning weight (kg) when soil water content was in the High, Mid and Low categories in the baseline and annual cool season burning of 25% area on 15 March scenarios. Error bars indicate one standard deviation across years.

After burning on 15 March, the increase in pasture mass was more rapid in years with High SWC than in years with Mid or Low SWC (Figure 13). In Table 3 the percentage of years when pasture mass was below the threshold of 700 kg DM/ha during the winter and early spring is expressed for years with SWC in three categories. On 1 July pasture mass exceeded the threshold in more than half the years when SWC was in the High category but never exceeded the threshold when SWC was Low. This shows that pasture mass increased above the threshold more rapidly in the High SWC years. Pasture mass exceeded the threshold in all years on 1 September.

The same analyses using three categories of total autumn rainfall (High, Mid and Low) instead of SWC on 15 March show similar effect of pasture mass (Figure 14) and the percentage of years when the 700 kg DM/ha threshold was exceeded through winter and early spring (Table 4).

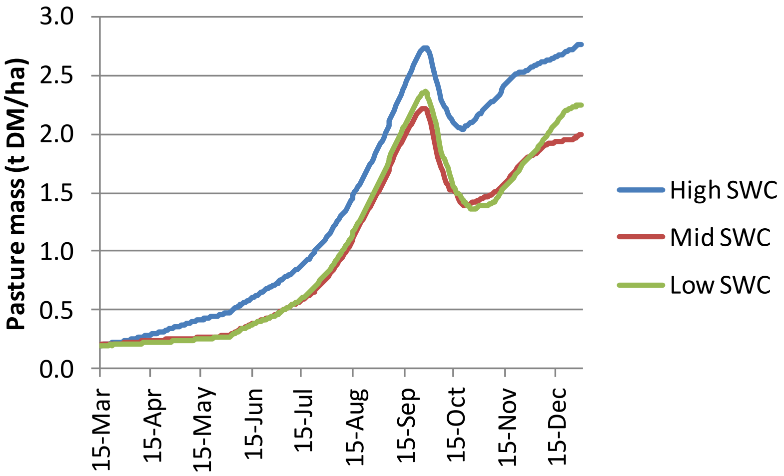


Figure 13. Mean daily pasture biomass (t DM/ha) following annual cool season burning on 15 March when SWC was in the High, Mid and Low categories.

Table 3. Percentage of years when pasture mass exceeded 700 kg DM/ha on the first days of June, July, August and September following annual cool season burning on 15 March when the SWC was in the High, Mid and Low categories.

	Percentage of year when pasture biomass >700 kg DM/ha		
Date	High SWC	Mid SWC	Low SWC
1-Jun	18	0	0
1-Jul	54	9	0
1-Aug	100	64	100
1-Sep	100	100	100

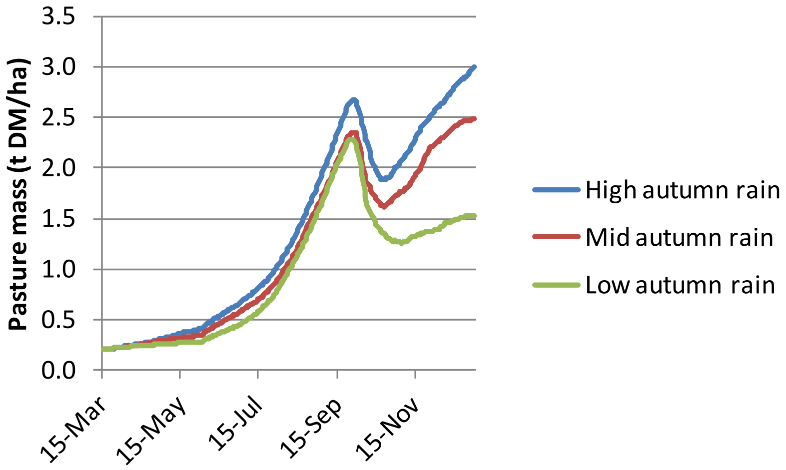


Figure 14. Mean daily pasture biomass (t DM/ha) following annual cool season burning on 15 March when autumn rainfall was in the High, Mid and Low categories.

Table 4. Percentage of years when pasture mass exceeded 700 kg DM/ha on the first days of June, July, August and September following annual cool season burning on 15 March when autumn rainfall was in the High, Mid and Low categories.

	Percentage of year when pasture biomass >700 kg DM/ha		
Date	High autumn rainfall	Mid autumn rainfall	Low autumn rainfall
1-Jun	9	9	0
1-Jul	36	27	0
1-Aug	100	82	82
1-Sep	100	100	100

Tactical cool season burning

Tactical burning was implemented on 15 March if pasture biomass in the paddock was >3 t DM/ha. This occurred in seven of the 33 years simulated (21% of years). In all cases when tactical burning was simulated in the model three of the four paddocks were burnt and one paddock did not meet the threshold for burning, so 75% of the area was burnt.

There was little difference between the tactical burning, annual burning of 25% area on 15 March and baseline scenarios in mean cow liveweight (Figure 15) and calf weaning weight (Figure 16). However in the 7 years when tactical burning was implemented, all three scenarios had higher average cow liveweight and calf weaning weight compared to the average of all years, with cow liveweight slightly higher again when tactical burning occurred in combination with High SWC.

The effects of tactical burning on pasture growth, mass, species composition and nutritive value within the year that burning occurred were similar to those reported in Figures 5-8. The effects did not persist for more than one year, for example while pasture mass was low and legume content high in the growing season following burning, they returned to levels similar to the 'baseline' scenario in the following year.

The only substantial difference between the natural resource management metrics for the tactical burning scenario and those reported earlier was in the percentage of years that the minimum pasture mass threshold was breached. In the tactical burning scenario the threshold was breached in 45% years (15 of 33 years simulated), compared to 100% of years in the annual burning scenario and 21% of years in the baseline scenario.

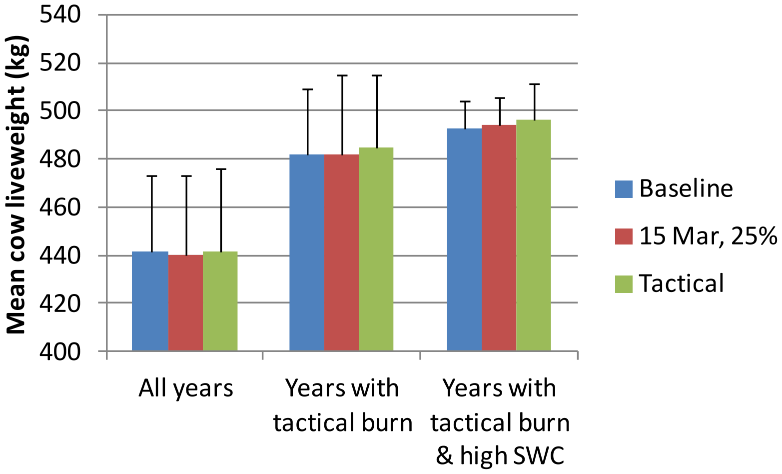


Figure 15. Mean annual cow liveweight (kg) for the baseline, annual cool season burning of 25% area on 15 March and tactical burning on 15 March scenarios. Results are shown for all years in the simulation (33 years), the years when tactical burning was carried out (7 years), and years when tactical burning occurred with High SWC (4 years). Error bars indicate one standard deviation across years.

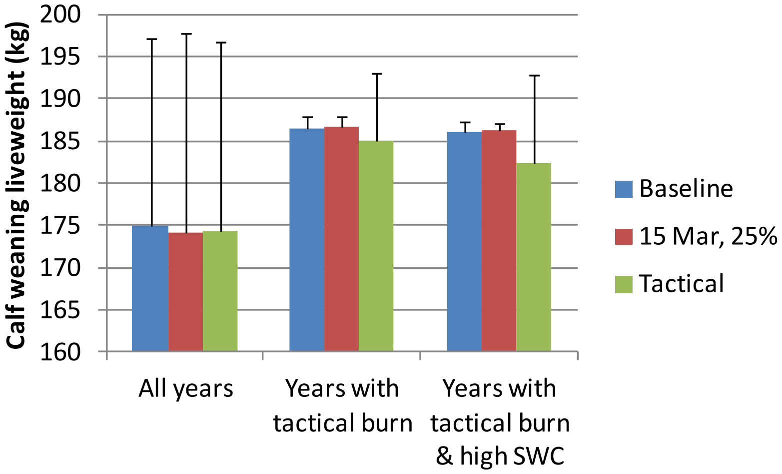


Figure 16. Mean annual calf weaning liveweight (kg) for the baseline, annual cool season burning of 25% area on 15 March and tactical burning on 15 March scenarios. Results are shown for all years in the simulation (33 years), the years when tactical burning was carried out (7 years), and years when tactical burning occurred with High SWC (4 years). Error bars indicate one standard deviation across years.

5. Discussion

This analysis of cool season burning as a management option for hill country in north eastern Victoria, conducted using the SGS Pasture model, has highlighted tradeoffs in production and natural resource management risks.

Pasture and animal production

Cool season burning was shown to provide some advantages to the production system, in particular by increasing both pasture nutritive value (digestibility and ME content, Figures 7 and 8) and annual pasture growth (Figure 5). The increase in nutritive value was due to higher legume content (Figure 6) and an increase in the ratio of green:dead plant material. Burning in autumn or early winter removed the bulk of dead plant material carried over the summer, and this allowed greater growth of sub clover through the winter and early spring. Higher legume content caused more atmospheric nitrogen fixation which was the main reason that the simulated pasture growth was higher in the burnt areas.

There were also disadvantages to the production system associated with annual cool season burning, because low pasture mass following burning limited pasture intake by livestock (Figure 4). This was particularly the case with burning carried out later in the season (June-August) compared to burning in Autumn, and when a large percentage (>50%) of the farm area was burnt on an annual basis. Compared to burning in Autumn, late season burning occurred at a time when pasture mass was lower, nutritive value higher, and when animal energy demands were increasing in late gestation. Therefore increase in pasture nutritive value was less and the limitation in pasture intake was more pronounced with late season burning, leading to lower animal production.

The tradeoffs in cool season burning between the advantages of increased pasture growth and nutritive value, and disadvantages of lower feed on offer, can be assessed in terms of animal production (cow liveweight and calf weaning weight). From the simulation analyses conducted in this study, two conclusions can be drawn:

1. Under conditions where 50% or more of the area underwent cool season burning late in the season (June-August), lower cow and/or calf weaning weight was simulated. In these conditions the disadvantages from lower pasture feed on offer outweighed the pasture growth and nutritive value benefits of burning.
2. Under conditions where 25% of the area underwent cool season burning early in the season (March-May), cow and/or calf weaning weights were similar to the baseline scenario. In these conditions the benefits of higher pasture growth and nutritive value were counteracted by lower pasture feed on offer.

   These conclusions must be tempered because of some limitations of the modelling process in representing the ‘real’ management that would occur on farm. This relates to the ability of the model to represent the real grazing system imposed on farm, which has implications for the amount and nutritive value of pasture consumed and therefore animal production. These reasons for, and implications of, these modelling limitations are discussed below, and an estimate of animal production when these limitations are taken into account is provided. In general, it is likely that the grazing system imposed in the modelling study slightly underestimated animal production.

The cool season burning management suggested by the case study farmer involved burning a proportion of the area that the grazing animals had access to, so that the animal would have access to the burnt and unburnt areas every day. In the SGS Pasture model management of grazing or cutting (along with fertiliser, irrigation etc.) is applied at the paddock level, so management changes that occur within a paddock a poorly represented. In this study to represent the treatments where 25% of the area was burnt, the cutting option was applied to one out of a four paddocks, and grazing was simulated by the animals spending 1 day in each paddock to best represent the continuous grazing policy practised on farm. The result of this modelling approach was that livestock spent 25% time grazing the burnt area and 75% grazing the rest of the paddock. This may not accurately reflect the grazing behaviour of animals in this situation, as the cows may spend more time (or less) time grazing the burnt area. If, within a day, cows spent some time on the grazing the higher quality burnt area and some time on the un-burnt area they may have been able to overcome the pasture intake limitation caused by low pasture mass on the burnt areas. This grazing behaviour may have overcome the negative effects of cool season burning on animal production. The SGS Pasture model does not allow the livestock to compensate for being under-fed on one day by consuming more on the following day. Further model development to improve the representation of management within a paddock and/or measurement of grazing behaviour and animal production in the field is required to address this issue more comprehensively.

While the limitations of the SGS Pasture model in modelling animal production in this case study are noted, it is possible to estimate the effect on animal production if animals were allowed access to the burnt and un-burnt sections of the paddock simultaneously. Using the scenario where 25% of area was burnt on 15 March annually as an example, annual average pasture intake was 95 kg DM/cow less (-2.5%) in this scenario compared to the baseline with most of the restriction in intake occurring during the months April-September when pasture mass was low following burning. If animals were allowed access to the burnt and un-burnt areas simultaneously, during these months the average pasture digestibility of the diet can be assumed to be 2 units higher in the burnt scenario compared to baseline (based on 25% pasture consumed from burnt area and 75% from un-burnt area, Figure 8). On this basis, intake per cow could be expected to increase by ≈0.5 kg DM/day during these months assuming intake was no longer limited by low pasture mass. This increased intake of ≈90 kg DM/cow would compensate for the simulated reduction in intake following burning. This pasture consumed has a slightly higher digestibility compared to the baseline scenario so a small increase in liveweight for this cool season burning scenario compared to the baseline could be assumed. In the cool season burning scenarios where burning occurred later and/or where a larger percentage of the area was burnt and lower cow/calf (Figure 2/3) and pasture intake was simulated (Figure 4), it is unlikely that higher animal production compared to the base line would be predicted even when this effect was taken into account.

The increased intake considered would have no appreciable effect on the natural resource management metrics simulated, as it is equivalent to additional intake of only 12 kg DM/ha.

Animal production was strongly influence by the growing season, with higher animal production simulated in years with high SWC in March (Figures 15 and 16), reflecting higher pasture DM intake (data not shown). In years with high SWC in March, the reduction in pasture DM intake from the baseline to the annual cool season burning of 25% area on 15 March scenario was 1.2%, but the difference was larger in the mid and low SWC years (2.8 and 3.5% respectively). This suggests that a strategy of burning when SWC is high in autumn is more favourable for animal production, because the higher pasture mass in these years limits the intake reduction that can occur.

A second limitation of the modelling was the inability of the SGS Pasture model to represent plant species composition change. A central proposition in the thinking behind use of cool season burning was that burning would disadvantage weed species (in particular St Johns wort and blackberry) resulting in a higher presence and biomass of more favourable grass and legume species for grazing. This was not able to the tested in the SGS Pasture Model because the ecological processes governing species persistence and weed population change are not built into the model. This has long been recognised as a limitation to the SGS Pasture model (eg. Johnson *et al.* 2003; Cullen *et al.* 2008), so the likelihood of cool season burning leading to species composition change must be assessed independently of the modelled results. If the proposition that cool season burning leads to favourable changes in species composition was found to be true, then burning could have longer lasting (more than 1 year) positive effects of pasture nutritive value meaning that it would not have to be burnt each year. If burning was not required each year to increase pasture nutritive value the low pasture mass limitation on intake that was modelled might not be as large leading, potentially, to increased animal production. There is limited literature available on the control of St Johns wort using burning, however Naughton and Bourke (2007) state that “burning checks the growth of St John wort and destroys seeds on the plant, but has a more detrimental effect on the associated pasture”. While this finding casts doubt on the effectiveness of burning to substantially increase desirable pasture species and reduce the presence of St Johns wort, the full range of cool season burning options have not be investigated in this respect.

Natural resource management risks

The major change in the risk of degradation to the natural resource base with annual cool season burning was increased frequency of breaching the minimum pasture mass threshold (used as an indicator of ground cover). In the baseline scenario the threshold was breached in 21% of years, but burning breaches this threshold each time it is carried out. In the cool season burning management option simulated in this study burning was applied to an area of the farm every year, so the minimum pasture mass threshold was breached every year. In areas that were burnt runoff was also predicted to increase slightly. Thus, burning increases the risk of soil erosion losses.

There are management options that can be implemented to reduce the risk of low pasture mass following burning. These include burning a small percentage of the area, so that only a fraction of the total area is exposed to low pasture mass, and burning less frequently than once per year. With respect to burning less frequently than every year, knowledge of SWC in autumn can assist in making a decision on whether or not to burn because it alters the risk associated with low pasture mass. For the cool season burning option of 25% of area on 15 May, if SWC was in the highest one-third of historical values then pasture mass increased more quickly than if SWC was in the mid or lowest thirds of historical values. Burning when SWC was high minimised the time that pasture mass was low with mass exceeding the minimum threshold in 50% of years by 1 July, which was not achieved in any years when SWC was in the mid or low categories at the time of burning. As such, knowledge of SWC at time of burning can be use to minimise the risk of soil erosion. It should be noted however that irrespective of SWC at the time of burning the minimum threshold was exceeded in all years by 1 September.

Interestingly when changes in pasture mass were incorporated into the ‘Farm Nutrient Loss Index’ the risk ratings for phosphorus and nitrogen losses did not alter much. In this index characteristics of the site (in particular slope, stocking rate and fertiliser inputs) largely determined the risk of losses, rather than the impacts of cool season burning management. The SGS Pasture model is a more useful tool to examine the risks associated with the change in management because it dynamically predicts pasture mass on a daily basis and takes climate variability into account.

There was little difference between the baseline and cool season burning simulations in the other natural resource management issues investigated. Soil carbon was predicted to be higher in the baseline scenario than in areas that were burnt each year because less leaf litter is returned to the soil, but the difference was relatively small (<10%) and unlikely to be able to be detected using current measurement techniques (Robertson and Nash 2013). This analysis also does not include the contribution of charcoal to soil carbon produced during burning, as there is little empirical evidence to determine the amount of the charcoal produced. Similarly total greenhouse gas emissions per ha were similar between the baseline and cool season burning treatments, but this does not include the contribution from nitrous oxide produced during burning as there is no empirical evidence to use in modelling this.

Tactical cool season burning

Tactical use of cool season burning when pasture mass exceeded 3 t DM/ha showed potential to capture some of the benefits from improving pasture nutritive but reduce the risk associated with low ground cover. The tactical burning scenario restricted its use to years when pasture mass and cow and calf weaning weights were higher than the average of all years (Figures 15 and 16), so this strategy will avoid adverse effects associated with burning when pasture mass is already low. The risk of having low ground cover is also reduced compared to annual use of burning. As such, pasture mass in autumn can be used as a trigger to decide whether or not to burn.

Tactical burning used by a producer could be further refined than the system implemented in the model. In this study all of the area was allowed to the burnt if the criteria were met, whereas a producer could limit the total area to the burnt to achieve a balance between improving pasture quality and limiting intake and ground cover. There was a reasonably strong correlation between the years when tactical burning occurred and having High SWC (4 of 7 years). The High SWC years have quicker regrowth following burning, limiting the chance that soil degradation may occur, so burning in years with high pasture mass and SWC is likely to provide the best balance between production and natural resource management outcomes. However this combination of conditions occurred infrequently (4 out of 33 years), limiting the use of the strategy to control weeds if that were one of the primary objectives of using cool season burning.

Effectiveness of the SGS Pasture Model in identifying and highlighting risks and rewards across production and natural resource management factors

To provide an effective evaluation of the production and natural resource management risks and rewards from a grazing system, a model must be able to:

1. Adequately simulate the grazing system, including the climate, soil, pasture types and grazing management applied; and
2. Provide credible simulation results for all the variables of interest (or surrogates), including pasture and animal production characteristics, water balance, soil carbon and greenhouse gas emissions.

In terms of the SGS Pasture models capability to simulate the system, it is well suited to the climate zone, pasture and soil types on the case study property. It also has the appropriate animal systems. The grazing systems simulated in SGS Pasture model allow for multiple-paddock grazing, but in the case of cool season burning a simplification of the management was applied in this study because management cannot be applied to a sub-section of a paddock in the SGS Pasture model. Further comments on the implications of this were provided above.

The SGS Pasture model is capable of simulating almost all of the production and natural resource management metrics required. Where they are not directly available surrogates can be used, in this study a pasture mass threshold was used as an indicator of low ground cover. For further analysis on specific issues there are opportunities to link the output from biophysical models to other tools, in this study ground cover outcomes from the SGS Pasture model were used in the ‘Farm Nutrient Loss Index’ to assess the implications for phosphorus and nitrogen losses.

The user must also have confidence in the model outputs. An assessment of the confidence in model predictions should take into account the documented strengths and weaknesses of the model in simulation of the various components of the production system, the capability of the model to simulate the necessary management strategies implemented on-farm, and the extent to which the underlying science on an issue has been defined and incorporated into the model. High confidence is provided in simulation of pasture mass and feed quality as well as aspects of the water balance, based on extensive previous validation of the model (Cullen *et al.* 2008; Lodge and Johnson 2008). Moderate confidence in animal production characteristics is due to the inability of the model to exactly replicate farm management (ie. the bunt and non-burnt areas were modelled as separate paddock, so livestock did not have access to both on the same day). There are however methods to estimate the effect that this had on animal production, as discussed above. In addition there are some deficiencies in the animal production module of the SGS Pasture model, for example the effect of lower cow weight on reproductive success and mortality is not implemented in the SGS Pasture model. Low confidence in greenhouse gas emissions and soil carbon was specifically related to the lack of knowledge about effects of fire on these aspects of the system. Despite this low confidence, the simulations did indicate that methane and nitrous oxide emissions would be similar between the systems, and that soil carbon may be slightly lower with regular burning, but the impact of burning on greenhouse gas emissions and charcoal input to soil carbon could not be quantified.

Where moderate or low confidence in the model output is indicated that is not to suggest that the model results are not useful but rather that they must be interpreted within limitations of the SGS Pasture modelling framework. It is very likely that any new management option will require an update to model functionality and/or the underlying science to fully address the issue. For example in this case with cool season burning, improvements to representation of pasture management within a paddock would enhance the modelling outcomes for the reasons highlighted above, and updates to the underlying science on the contribution of burning to soil carbon and greenhouse gas emissions are required. Nevertheless, this case study demonstrates that the framework of the SGS Pasture model provides an effective structure for an analysis of production and natural resource management issues in the grazing industries.

6. Conclusion

This analysis of cool season burning highlights the valuable role that biophysical modelling can play in assessing the risks and rewards of changing management systems. In this case the SGS Pasture model was used to assess the production and natural resource management outcomes from a range of cool season burning management interventions. Where a high percentage of the area was burnt and/or when burning was carried out in June-early August, the modelling indicated poorer animal production as measured by cow liveweight and calf weaning weight. Where burning was carried out in mid-March and 25% of the area was burnt animal production was similar to the baseline scenario, as higher pasture growth and nutritive value in the burnt areas compensated for lower pasture mass. The main increased risk to the natural resource base of grazing systems utilising cool season burning was that of low pasture mass and ground cover following burning. A summary of the results is provided in Table 5, along with an indication of the confidence that can be placed in the model predictions.

Table 5. Summary of the changes to production and natural resource management risks relative to current management when cool season burning was implemented annually on 25% of the property in mid-March. An indication of the level of confidence in the SGS Pasture model outputs is also provided.

Metric	Change with 15 March cool season burning[1]	Confidence in SGS model prediction[2]
Production		
Annual pasture growth (t DM/ha)	🟩	High
Pasture quality (MJ ME/kg DM)	🟩	High
Pasture feed on offer (t DM/ha)	🟥	High
Pasture DM intake (kg DM/ha)	🟧	Moderate
Pasture ME intake (MJ ME/cow)	🟧	Moderate
Calf weaning weight (kg)	🟧	Moderate
Cow weight (kg)	🟧	Moderate
Natural resource management risks		
No. years minimum pasture mass threshold breached	🟥	High
Runoff (mm)	🟧	High
Drainage below the root zone (mm)	🟧	High
Nutrient loss risk	🟧	Not applicable
Greenhouse gas emissions (t CO_2-e/ha)	🟧	Low
Soil carbon (t C/ha, 0-30 cm depth)	🟧	Low

[1] green/orange/red colours indicate increased/little change/decreased in production metrics or lower/little change/higher natural resource management risk.

[2] 'High', 'Moderate' or 'Low' confidence in model prediction takes into account the documented strengths and weaknesses of the model in simulation of the various components of the production system, the capability of the model to simulate the necessary management strategies implemented on-farm, and the extent to which the underlying science on an issue has been defined and incorporated into the model.

An additional strength of the SGS Pasture model is that it can be used to examine the effects of climate variability on management. In this context an examination of how use of SWC can be used to guide management to reduce the risk of low ground cover following burning was considered. The analysis also indicated that pasture intake was reduced by a smaller proportion in years with high SWC because pasture mass was higher in these years, suggesting that burning in autumn when SWC is high may achieve small animal production benefits and minimise the risk of low ground cover. A tactical approach to burning based on having high pasture mass in autumn has similar potential to capture benefits and minimise risks associated with cool season burning. Pasture mass and SWC can be used as triggers to decide whether or not to burn.

Together these results indicate that the SGS Pasture model is highly effective tool in the analysis of new management options for grazing systems. There are however some limitations of the modelling, in this case modelling of within paddock variation of pastures and in describing the changes in weed and pasture species plant populations, so results need to be interpreted within these limitations. These knowledge gaps may also provide the basis for further research.

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