Comparison of haymaking strategies for cow-calf systems in the Salado Region of Argentina using a simulation model. 2. Incorporation of flexibility into the decision rules

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Abstract

In pastoral farming systems, pasture production normally exceeds demand in the spring–summer period. Consequently, conserving forage at this time for use during the following winter is a widespread practice. The objective of this study was to assess the possible advantages of incorporating flexibility into a calendar-based haymaking policy. A range of flexible haymaking strategies were simulated and compared against a calendar-based strategy by using a simulation model to estimate long-term performance of cow-calf farm systems under each strategy. The results suggest that controlling haymaking in a flexible fashion, basing the decisions of closing, releasing and cutting paddocks on a simple pasture budget, could give the system productive advantages over using a calendar-based approach. In terms of liveweight production per hectare, compared at the same area harvested, the flexible approach had higher average annual calf liveweight production (an increase of up to 0.15) and lower system variability (a reduction of 0.10 in the coefficient of variation (CV)) depending on the stocking rate. The results indicated that allocating more than 0.50–0.60 of the farm area to conservation would only be advantageous at very high stocking rates. In contrast to the calendar-based strategy, making more hay than required for the immediate next winter, where possible, can reduce system variability.

Keywords: cow-calf systems, computer model, long-term simulation, haymaking policy, flexibility

Introduction

Pasture production is highly seasonal, with 0.50–0.70 of the total production occurring in spring and summer in many parts of the world (Anslow and Green, 1967; McCall and Smith, 1998). As a result, pasture production normally exceeds demand during this period. Consequently, conserving forage for use during the following winter is a common practice worldwide. As well as improving herbage utilization, conservation can be used for risk management, buffering the system against climatic variations (Lowman and Illius, 1985; McMillan, 1989).

Pasture conservation is a complicated and expensive exercise, and requires a considerable amount of planning. However, as pointed out by Hodgson (1990), preliminary judgements about the proportion of the total area taken out for conservation have to be made and, because this area must be isolated for some time, the control can only be approximate. When deciding to close paddocks for conservation, the future climatic conditions are unknown. In addition to uncertainty arising from the weather, the dynamic nature of the system makes it difficult to assess the consequences of management decisions.

Haymaking planning can be based on what happens in an average year (Anderson and White, 1991), and the haymaking policy, described in the previous paper of the series, is based on this idea (Romera et al., 2005). This approach is designed to be easy to implement, communicate and control, which are especially important considerations in the case of large and/or intensive farms. The problem with this is that year-to-year variations in climate, which are crucial in strategic and tactical decision-making (Van Keulen and Penning de Vries, 1993), are not considered. Flexibility has been recognized as a key element in planning forage conservation. Hodgson (1990) argued that it is important to retain flexibility in the timing and extent of the conservation programme. He explained, for example, that there is no reason to assume that swards initially
set up for conservation should not be used instead for grazing if conditions require it.

The objective of this paper was to analyse the performance of a range of haymaking policies for cow-calf systems, specifically to assess the possible advantages of incorporating flexibility into a calendar-based haymaking policy described in Romera et al. (2005). Long-term simulations using real weather data were used to explore a range of possibilities.

Materials and methods

The cow-calf farm computer model described by Romera et al. (2004) was used to compare a range of haymaking strategies. A key component of flexible haymaking strategies is the ability to assign individual paddocks to grazing or to conservation as the year unfolds. In the simulated farm, the cattle were grouped into three herds, each herd grazing rotationally its own group of paddocks (‘block’). Blocks 1 and 2 are grazing blocks, for heifers (herd 1) and cows respectively (herd 2). Block 3 (for herd 3), in this particular simulated farm, is a single wintering paddock. This paddock returns to the grazing circuit once all the cows have calved and joined herd 2, and is then treated as any other paddock. Block 3 does not participate in the exchange of paddocks during winter. Different numbers of paddocks can initially be allocated to these blocks but decision rules may dynamically move paddocks between blocks (and hence herds). This feature of the model permits a more realistic representation of what a farmer might do. In a real situation farmers would not assign a fixed area to each herd but instead paddocks would be grazed alternatively by each group of cattle. To accomplish this, apart from the blocks used by the cattle, the model creates two auxiliary blocks. The intOffer block contains paddocks that can be can deposited or borrowed by the herds according to demand, using the analogy of a savings bank. The closed block contains paddocks that are temporarily excluded from the grazing sequence, for example paddocks assigned to forage conservation. More details about the implementation of this part of the model are presented in Romera et al. (2004).

The flexible haymaking policy applied was as follows. The closed paddocks can be grazed if required without making hay in cases where there is not enough herbage for the animals. This principle is analogous to the ‘buffer grazing system’ described by Lowman and Illius (1985) and Hodgson (1990). The decision rules for this flexible haymaking strategy are:

1. Only the paddocks in the intOffer block can be closed, provided that it is in the spring or summer. Blocks 1 and 2 deposit their first ranked paddock in terms of herbage mass to the intOffer block only when:
   a) the paddock herbage mass is >3 t DM ha\(^{-1}\), and
   b) the paddock is not currently being grazed, and
   c) there are more than \(n\) paddocks with more than 1.5 t of green DM ha\(^{-1}\) ahead of the herd in the projected grazing cycle (\(n = 5\) and 10, for blocks 1 and 2 respectively).

2. Blocks 1 and 2 can borrow paddocks from the intOffer block (one at a time) if the number of paddocks with more than 1.5 t DM ha\(^{-1}\) falls below 4 (block 1) or 8 (block 2).

3. Closed paddocks can be released for grazing:
   a) after being cut (note that a paddock that is released can be closed/cut again in the same season), or
   b) at the end of summer, or
   c) when a maximum area (AREA) has been already harvested, or
   d) when the number of paddocks with more than 1.5 t DM ha\(^{-1}\) in the blocks is <3 or 8 in blocks 1 or 2, respectively, and there are <4 paddocks on offer.

4. Closed paddocks are harvested when a minimum target herbage mass (MASS) is reached.

Three management variables, comparable to those studied in Romera et al. (2005), were explored: the target cow number [total number of cows in 100 ha after the autumn sales (SR)]; the maximum area allocated for haymaking (ha, AREA) including, where appropriate, the summation of area from paddocks cut more than once; and the minimum herbage mass at which hay is harvested (t DM ha\(^{-1}\), MASS). If the target herbage mass for cutting is not reached by a limit date (1 April), the closed paddocks are released for grazing.

Simulations were simulated factorially on a 100-ha cow-calf farm using the levels of SR, AREA and MASS specified in Table 1. Note that the area used for haymaking could be over 100 ha as paddocks can be harvested more than once. The ‘unlimited’ value for area does not impose an explicit ceiling on the area harvested (i.e. AREA = \(\infty\)), but the other conditions for closing and cutting paddocks must still be met.

| Table 1 Management strategies compared in the study. |
|-----------------|-----------------|
| Variable | Levels |
| Target cow number | 170*/200/230/260/ |
| SR (cows + heifers) | 290/320/350 |
| Area closed for | 20/30*/40/50/60/ |
| haymaking: AREA (ha) | 70/100/unlimited† |
| Target herbage mass for | 3/4/5/6* |
| cutting: MASS (t DM ha\(^{-1}\)) | |

*Policy approximately applied in Reserva 6 (see Romera et al., 2005).
†No explicit limit imposed in the area allocated for haymaking.
Two hundred and twenty-four strategies \((7 \times 8 \times 4\) levels of SR, AREA and MASS respectively) were tested. Each strategy was used for twenty independent simulations over 50-year periods of random weather, sampled from the actual weather records from Balcarce from 1970 to 2000 (Romera et al., 2005). Each time, the system was re-initialized from a 10-year simulation with average weather data. The results were analysed as randomized complete blocks (replicate as block) for AREA, MASS, SR and their interactions, in an analysis of variance. The GLM procedure of SAS was used (SAS, 1999).

**Results**

As AREA is a maximum limit, the actual area harvested varied from year to year. Similarly, SR is a target number of cows and MASS is a minimum limit, so actual stock numbers, herbage mass at cutting and consequently the amount and quality of hay produced are outputs of the system, and exhibit wide variation between years. As would be expected, the area actually cut was more variable at high AREA and MASS. The herbage mass at cutting was more variable at low MASS. The quantity of hay produced is shown in Table 2 and Figure 1. The digestibility of DM ranged from 0.48 to 0.56 with only the lower minimum cutting herbage masses and greater areas having values >0.52. Variability was similar across all combinations of AREA and MASS.

The amount of hay produced was influenced by the target cow numbers on the farm (Figure 1, upper panel). For example, high cow numbers reduced the chances of closing paddocks to make hay. The cow numbers also had a direct effect on the amount of hay consumed each year. Figure 1 (lower panel) shows how target cow numbers (along with the haymaking policy) determine the proportion of the hay made that is consumed on average in a year (i.e. average annual hay production divided by average hay consumption). Any excess hay at the end of winter, minus the corresponding storage losses, was carried forward into the next year.

The three main effects and the simple interactions were all significant in the ANOVA for the total live weight (LW) sold (kg LW ha\(^{-1}\) year\(^{-1}\)) and live weight of calves sold (kg LW ha\(^{-1}\) year\(^{-1}\)). The variable SR was the most important source of variation for both variables, explaining 0.87 and 0.73 of the variation in total LW sold and calf LW sold respectively. The AREA was more important than MASS. Figure 2 shows the combined effect of AREA and MASS on calf LW sold for the different target cow numbers. The amount of calf LW sold was maximized when no explicit limit was imposed on the area harvested, at intermediate cow numbers, and when hay was made at a low herbage mass. The different haymaking policies had similar response curves to target cow numbers, although the more favourable policies showed higher maxima. Replicate represents the difference between the twenty different 50-year weather sequences and was also an important independent variable explaining 0.07 and 0.13 of the variation in total and calf LW sold respectively.

As the area actually harvested can be smaller than the maximum specified by the variable AREA, in Figure 3 calf LW sold is plotted against the average area actually harvested per year for each policy and cow number. Figure 3 shows that, at the same area harvested, the flexible strategy produced up to 0.15 more calf LW sold per year than the best calendar-based strategy. Figure 3 also suggests that the benefits of the flexible approach were less evident at the highest cow numbers. Note also in Figure 3 that the average production of the calendar-based strategy decreased when more than 0.40–0.50 of the area of the farm was harvested. This decline did not occur with the flexible strategy but, even with this flexible approach, cutting more that 0.50–0.60 of the area would not produce much benefit in production terms except at very high cow numbers.

The effect of the strategies on the variability of the system outputs was also explored. In the ANOVA for the CV of calf LW sold, SR, AREA and their first order interactions were all significant. The variable SR was the most important, accounting for more that 0.80 of the variation in CV for calf LW sold. Figure 4 indicates that, as expected, the variability of the system increased with cow numbers. The differences between the cutting mass policies were small and lacked any consistent pattern across the range of cow numbers. Figure 4 also shows no reduction in variability from harvesting more

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**Table 2** Means (and standard deviation of the mean within a replicate in parenthesis) of the total amount of hay produced per year on the farm (t DM year\(^{-1}\)) for each minimum cutting herbage mass and for each area.

<table>
<thead>
<tr>
<th>AREA (ha)</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>54 (15)</td>
<td>56 (16)</td>
<td>66 (22)</td>
<td>72 (32)</td>
</tr>
<tr>
<td>30</td>
<td>85 (27)</td>
<td>86 (27)</td>
<td>100 (35)</td>
<td>108 (48)</td>
</tr>
<tr>
<td>40</td>
<td>119 (43)</td>
<td>117 (44)</td>
<td>134 (52)</td>
<td>142 (67)</td>
</tr>
<tr>
<td>50</td>
<td>147 (67)</td>
<td>145 (71)</td>
<td>158 (82)</td>
<td>159 (99)</td>
</tr>
<tr>
<td>60</td>
<td>168 (76)</td>
<td>169 (82)</td>
<td>179 (95)</td>
<td>178 (115)</td>
</tr>
<tr>
<td>70</td>
<td>186 (80)</td>
<td>193 (91)</td>
<td>194 (107)</td>
<td>187 (125)</td>
</tr>
<tr>
<td>100</td>
<td>225 (99)</td>
<td>228 (119)</td>
<td>220 (136)</td>
<td>200 (148)</td>
</tr>
<tr>
<td>Unlimited*</td>
<td>284 (147)</td>
<td>255 (152)</td>
<td>224 (151)</td>
<td>198 (149)</td>
</tr>
</tbody>
</table>

*No explicit limit imposed in the area allocated for haymaking.
than 0.50 of the area, except at high cow numbers. Compared at the same area harvested, the flexible strategy tended to be more stable than the calendar-based strategy ($\text{MASS} = 4 \text{ t DM ha}^{-1}$ shown as an example in Figure 4), with reductions in CV of up to 0.10.

Figure 5 compares the most productive calendar-based (i.e. harvest 40 ha of hay and cutting at a minimum herbage mass of 3 t DM ha$^{-1}$) and flexible haymaking strategies (i.e. unlimited area for hay and cutting at a minimum herbage mass of 3 t DM$^{-1}$) against the Reserva 6 approach (i.e. harvest 30 ha of hay and cutting at a minimum herbage mass of 6 t DM ha$^{-1}$) (Romera et al., 2005). The three strategies showed maximum calf LW production at similar cow numbers but at the peak of the curves, increases of 0.26 and 0.36 in calf LW production with respect to the Reserva 6 strategy were predicted for the calendar-based and flexible approaches respectively. The CV of calf LW production increased with the increase in cow numbers in all cases, although the rate of increase was notably smaller in the flexible strategy. It must be noted that in order to achieve this increase in productivity and reduction in variability, the flexible strategy produced large quantities of hay. For example, for a target cow number of 290 cows, this strategy produced 0.28 more hay than the amount required for an average winter.

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Figure 3 Influence of the area used for haymaking and target cutting herbage mass at haymaking (●, 3 t DM ha\(^{-1}\); ○, 4 t DM ha\(^{-1}\); ▽, 5 t DM ha\(^{-1}\); ▽, 6 t DM ha\(^{-1}\); and ———, calendar-based policy) on calf live weight (LW) sold for each target cow number (a, 170; b, 200; c, 230; d, 260; e, 290; f, 320; and g, 350). The cutting herbage mass with the highest calf LW sold per year of a calendar-based approach (4 t DM ha\(^{-1}\); see Romera et al., 2005) is included for comparative purposes.

Figure 4 Influence of the area used for haymaking and target cutting herbage mass at haymaking (●, 3 t DM ha\(^{-1}\); ○, 4 t DM ha\(^{-1}\); ▽, 5 t DM ha\(^{-1}\); ▽, 6 t DM ha\(^{-1}\); and ———, calendar-based policy) on average coefficient of variation (CV) within replicate (average of the CVs obtained from each of the twenty simulation runs, see text for details) for calf live weight (LW) sold for each target cow number (a, 170; b, 200; c, 230; d, 260; e, 290; f, 320; and g, 350). The cutting herbage mass with the highest calf LW sold per year of a calendar-based approach (4 t DM ha\(^{-1}\); see Romera et al., 2005) is included for comparative purposes.
day (\(7.5\) kg day\(^{-1}\)) and the number of days (\(150\) days). Note that, allowing for the associated storage losses (proportionately \(0.01\) month\(^{-1}\) in the model), a portion of hay harvested for one winter can be used in the next winter. Figure 6 shows that system stability increased when more hay than the requirement for the following winter was harvested. This was not possible at high stocking rates, even when no maximum limit was imposed on the area to be used for haymaking.

**Discussion**

In general, for a similar area harvested, the flexible policy was more productive and more stable than the best calendar-based option. The effect of incorporating flexibility into haymaking policies has not always been considered. For example, Cacho et al. (1995, 1999) simulated different levels of conservation (proportion of the farm closed for conservation) based on an event-calendar approach, where paddocks were closed at a fixed date and for a fixed period of time (4–5 weeks). Nevertheless, on farm, this flexibility may be unachievable (or expensive), especially when haymaking is done by contractors, or when constrained by the availability of machinery, labour or the organizational skills of the farmer. In many cases, a well-designed calendar-based plan can be easier to follow, and could be a better choice than a flexible plan that is not fully implemented. The degree of flexibility that is actually achievable could be further limited at high stocking rates.

With the flexible haymaking policy, the cutting herbage mass was not exactly determined by the variable MASS, because of the greater number of elements involved in the decision-making process, compared with a simple calendar-based approach (Romera et al., 2005). This reduced the range of the DM digestibility of hay across treatments but increased the variability of hay quality and quantity within treatments. While hay quality appears to be less important for dry cow feeding, it could become a problem if the hay was going to be used by other stock classes. Making one decision often precludes taking others and many actions are irreversible (Sterman, 2000). For example, delaying making hay may mean that it will not be possible to produce high-quality hay later on. Making low-quality hay means that it can only be used for maintenance nutrition, limiting other possible uses. Thus, being flexible at one point in time (making hay) might signify restricting flexibility in future (feeding hay back).

System productivity and stability increased with more area dedicated to haymaking, although, in general, the benefits from cutting more than \(0.50–0.60\) of the total area of the farm were relatively minor. In contrast to the calendar-based strategy, the productivity of the system would not collapse even if very high proportions of the farm were harvested. Because of the flexible approach, cutting \(0.50–0.60\) on average means that in some years a larger (or a smaller) area is cut. For example, to cut \(0.50\) on average with cow numbers greater than \(230\), it was necessary to set up the maximum limit to \(0.70\) of the area or more.

The system cannot consume unlimited quantities of hay, especially low-quality hay, but, in many cases, certain redundancy of resources (hay in this case) can give stability to systems (Skittner, 2001). Using a flexible haymaking policy that considers not only time...
Haymaking strategies for cow-calf systems

of the year, but also cattle requirements and current pasture conditions, would allow managers to exploit redundancy to improve system stability. The results indicated that harvesting more hay than the amount estimated for one season considerably reduced system variability. In the simulations, hay surpluses (minus storage losses) were carried into the next year, compensating for those years when, due to environmental conditions, it is not possible to produce the target amount of hay, for example, in very dry years. A proportion of these surpluses could be sold. This possibility could only be realized at the medium cow numbers (260–290 cows). It was not possible to accumulate much hay surplus when the cow numbers were high, and there were little benefit in doing so when cow numbers were low (see Figure 6). With the calendar-based policy, on the other hand, making more hay than required for the following winter was counterproductive, increasing the variability without any benefit in the average calf liveweight production.

In decision-making situations perfect rationality is not to be expected (Simon, 1997). The problems of complexity, time pressure, uncertainty and cognitive limitation limit the capacity for making optimal decisions, forcing reliance on habits and heuristic rules of thumb (Hodgson, 1997; Sterman, 2000). In this study, counting the number of paddocks ahead in the rotational grazing cycle proved to be a useful simple criterion for controlling grazing and hay management. Identifying this type of simple rule is one of the benefits of using decision rules to simulate management.

Conclusions

Controlling haymaking in a flexible fashion, basing decisions of closing, releasing and cutting paddocks on a simple pasture budget (number of paddocks ahead in the projected grazing cycle), should give productive advantages relative to a calendar-based approach. Compared at the same area harvested, the benefits would include increases in average productivity along with reductions in the variability of the system. However, whether or not the advantages observed here are sufficiently attractive against the simplicity of a calendar-based approach may depend on each particular farm situation.

The results indicate that there are important potential gains in terms of liveweight production per hectare and its stability from allocating up to 0.50 of the farm area to conservation in a flexible strategy, but that the benefits are relatively minor beyond this point. Also, making more hay than required for the immediate next winter, where possible, can buffer the system and reduce production variability. However, this buffering function of haymaking would not be possible if the stocking rate is too high, and would provide little advantage if the stocking rate is too low.

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References


Decision-making Processes in Administrative Organizations.
New York, NY, USA: Free Press.


Sterman J.D. (2000) Business Dynamics. System Thinking and
Modeling for a Complex World. New York, NY, USA:
McGraw-Hill Education.

under uncertainty: terminology and techniques. In:
Buxton D.R., Shibles R., Forsberg R.A., Blad B.L., Asay
Crop Science 1, pp. 139–144. Madison, WI, USA: Crop
Society of America.