Spatial grazing in mixed farming systems: the potential for virtual fencing

Rick S. Llewellyn[1], Marta Monjardino[1], Michael Moodie[2], Mark Trotter[3] and Zac Economou[2]

[1] CSIRO, Locked Bag 2, Glen Osmond, SA 5064, Email rick.llewellyn@csiro.au
[2] Mallee Sustainable Farming/Moodie Agronomy PO Box 10189 Mildura, VIC 3502
[3] Central Queensland University, Rockhampton, QLD 4701

Abstract
Mixed farming systems remain common but trends in management for cropping efficiency include increasingly large paddock sizes. This makes achieving high grazing efficiency and maintaining optimal levels of crop residue on areas vulnerable to soil erosion a major management challenge. Particularly in environments with substantial within-paddock soil variation there is potential for temporary sub-paddock fencing to greatly improve both cropping and livestock productivity. In this paper we report on the potential for virtual fencing technology that would allow spatial within-paddock grazing. We begin with a survey of Australian grain growers that indicates the extent of growers perceiving potential benefits from virtual fencing across major mixed farming regions. Using GPS monitoring of sheep grazing behaviour in a paddock at Nandaly, Victoria, the poor grazing inefficiency and potential erosion risk on large paddocks was demonstrated. For example, when grazing a vetch paddock, sheep were found to spend approximately 75% of time on 50% of the paddock and 25% of the available grazing area was unutilised. Whole-farm bio-economic modelling analysis was then used to evaluate the potential profitability of sub-paddock grazing technology in a low-rainfall region where farmers report high levels of soil variability and the potential for soil-specific management. Results show that introducing spatial grazing in a typical Mallee crop-livestock system has the potential to increase the profitability of livestock in the system, and increase farm profit by 15% (excluding the cost of the technology), largely by avoiding the need to remove livestock from an entire paddock when just one soil or zone incurs excessive groundcover loss and subsequent erosion risk.

Keywords
Virtual fencing, precision agriculture, cropping, pasture, soil-specific management, EverCrop.

Introduction
Most grain growers in southern Australia also manage livestock in a mixed farming system. The crop-livestock mix is important for farm business diversification, but achieving optimal integration of cropping and grazing remains a major management challenge. As an example, increasing paddock sizes (or in some cases removing fences) to increase cropping efficiency usually reduces the ability to graze efficiently and manage any areas vulnerable to soil erosion. There is potential for sub-paddock fencing to improve both cropping and livestock productivity by facilitating more soil-specific or management zone-based grazing of pastures and crop residue within cropping paddocks.

Being able to avoid excessive grazing pressure on the most vulnerable parts of the paddock could also make grazing more profitable and less risky when meeting the increasing demand for early-season crop grazing to provide winter feed for livestock. Electric fencing for sub-paddock grazing is rarely used because of the labour and other costs associated with managing temporary fences where farms are often over 3000 ha and paddocks greater than 150 ha in size. The potential for virtual fencing using GPS-enabled devices which are attached to animals and provide a signal to animals to deter them from grazing in particular areas of a paddock (e.g. Lee et al. 2009) is an attractive option to many farmers. The commercial release of such a device designed for cattle is proposed in the near future. However, only relatively recently has attention been given to the potential for virtual fencing in the context of an Australian mixed farm involving sheep.

This paper begins with evidence of the level of perceived benefits from spatial grazing among Australian grain growers. It then examines an example of spatial behaviour of sheep grazing. Finally it analyses the potential whole farm impacts if a technology such as virtual fencing enabled sub-paddock grazing. The analysis is largely focused on the benefits of improved utilisation of available feed on a crop-livestock farm. Other potential benefits of spatial grazing include the ability to target grazing on areas of paddocks with high weed levels, reduce grazing pressure on vulnerable areas of establishing pastures, reduce risk of crop yield loss caused by overgrazing vulnerable areas of grazed grain crop, and protect areas for revegetation. These additional benefits were not included in this analysis and may further add to the potential value of spatial grazing technology. The study gives an indication of the potential gains from sub-paddock fencing technology and thereby an indication of how cost-effective any new sub-paddock fencing technology needs to be for it to become economically viable for use by crop-livestock farmers.

Potential demand by grain growers

The primary cropping decision maker from 573 broadacre grain farms (with >500 ha of grain crop) across 12 southern and western grain growing regions in Australia were interviewed by telephone in August-October 2012. Farmers in each region were randomly selected from a comprehensive data base of grain growers until the target number of respondents for each region was reached (see methodology described in Llewellyn and Ouzman 2014). Respondents were asked; if technology became available that could control where livestock grazed using electronic collars or ear tags, often called virtual fencing, how beneficial do you think it would be to your farm? Overall, of crop-livestock farmers 31% said very beneficial and 17% moderately beneficial (Table 1). NSW Riverine Plains and the Upper Eyre Peninsula were the two districts with farmers most likely to expect the technology to be very beneficial and SA Mallee has the most farmers who see some level of benefit. SA Mallee, Upper Eyre Peninsula and Victorian Mallee were the three regions with the highest proportion of farmers recognising that most of their cropping paddocks contain a wide range of different soil types (Llewellyn and Ouzman 2014). The spatial grazing analyses that follow focus on a mallee farming landscape.

Table 1. Perceived level of benefit of virtual fencing by grain growers (n=573). Results are for all grain growers interviewed in 2012, including those without sheep, except where indicated.

Beneficial	All grain growers	Grains-livestock farmers	WA Northern	WA Midlands	WA Central	WA Southern	NSW Central West	NSW Riverine Plains
Very	23%	31%	24%	28%	15%	27%	23%	34%
Moderately	16%	17%	6%	11%	25%	24%	17%	10%
Slightly	17%	19%	6%	13%	10%	9%	21%	16%
Not	45%	34%	65%	48%	50%	40%	40%	40%
Beneficial	**VIC Loddon**	**VIC Wimmera**	**VIC Mallee**	**SA Mallee**	**SA Upper EP**	**SA Central**	**SA Lower EP**	
Very	14%	16%	23%	24%	33%	17%	14%	
Moderately	14%	18%	13%	12%	16%	15%	28%	
Slightly	30%	18%	17%	28%	10%	12%	14%	
Not	42%	49%	46%	36%	41%	56%	44%	

Spatial grazing behaviour

In 2015 a 107 ha paddock near Nandaly, Victoria, with a range of soils commonly associated with Mallee paddocks (deep sands to clay loams) was used to study the spatial grazing behavior of a flock of 200 two-year-old merino ewes. Twenty five of the animals were fitted with UNE Tracker II GPS collars (Trotter *et al.* 2010). Following a summer grazing of cereal crop residue (see Moodie et al. 2016), the paddock was sown to a vetch pasture in autumn 2015 and the flock entered the paddock on 28 July. The sheep grazed the paddock until 17 September and vetch biomass monitored at 25 locations. At the conclusion of each 10 day grazing period, the collars were removed and the data downloaded from the GPS devices. Data were then analysed for the purpose of quantifying spatial variability in residency (Trotter et al. 2010) (Figure 1). The sheep concentrated grazing on the western end of the paddock during the first 10 days after which paddock utilisation by the livestock slowly increased over time (Figure 1). Sheep concentrated 50% of grazing on 25% of the paddock. A further 25% of the paddock was left unutilised despite the high availability of quality feed on this area. Two hundred ewes with lambs at foot grazed the paddock, or 5.6 Dry Sheep Equivalent (DSE) per hectare. As grazing occurred on only 75% of the area (i.e. 7.3 DSE/ha on the grazed area) it is possible that an additional 65 ewes with lambs could have been fed if the paddock was better utilised.

Whole-farm economics

The MIDAS model is a bio-economic optimisation model that represents a typical crop–livestock farming system in the Australian wheatbelt regions. Here we use Mallee MIDAS (Monjardino et al. 2012) to represent a 3000 ha farm in Mallee which includes equal areas of six main soils. Each has different levels of crop and pasture productivity and assumed minimum groundcover requirements that are used as a trigger to cease grazing (Table 2). Multiple soil types are assumed to occur in paddocks as is the case in the common dune-swale land system. In the absence of spatial grazing, when any one soil in the paddock reaches the residual biomass threshold it is assumed that grazing ceases in that paddock.

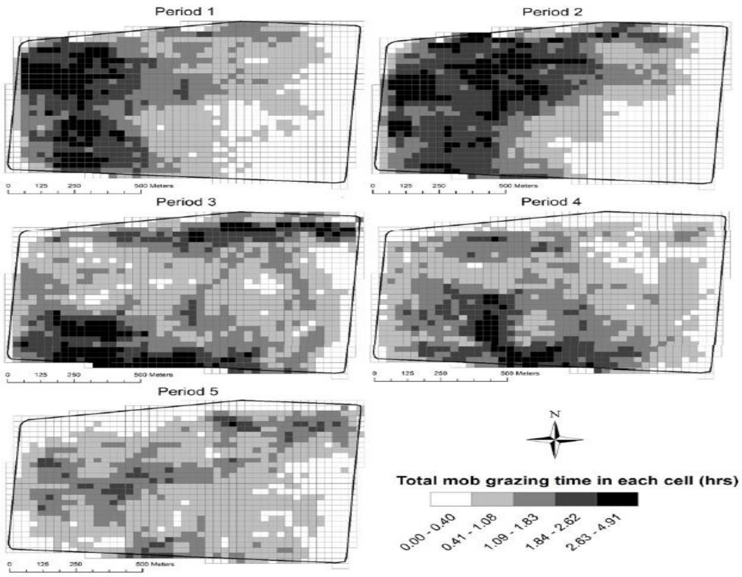

Figure 1. Livestock residency index (hours spent grazing) in 30m 30m cells for 10 day periods in winter.

The Three Management Zones scenario assumes that there is a level of soil-specific management for cropping based on Sands (soils 2 and 4), Mid-slope loam soils (soils 1 and 3) and Swale (soils 5 and 6). Without spatial grazing within paddocks, sheep are allowed to graze until they reach the residual biomass threshold of the most erodible soil on the farm (i.e. 1.5 t/ha in the soil 4 deep sand). In the Three Zone scenario that includes Spatial Grazing, sheep are removed when residual pasture biomass reaches the highest threshold of the vulnerable zone e.g. sheep are removed from both of the sandy soils at the 1.5 t/ha threshold level for deep sands but they can graze on the Mid-slope until residual biomass reaches 0.8t/ha (see Table 2).

Table 2. Characteristics of the Mallee soils considered in this analysis, including land class, associated wheat and pasture average yields, erosion risk/rating, minimum residual biomass, and proportional areas of the modelled default 3,000 ha farm.

Soil types	Ave. wheat yield (t/ha)	Relative pasture growth (%)	Risk of wind erosion	Soil-specific min. residual biomass threshold (t/ha)	Residual biomass when grazed with no spatial grazing in multi-soil paddocks (3/6 zones)
1- Sandy loam	2.0	90	Low to moderate	0.8	1.5/1.2
2- Sand	1.8	67	High	1.2	1.5/1.2
3- Intermediate soils	1.6	67	Low to moderate	0.8	1.5/1.5
4- Deep sand	0.8	17	Very high	1.5	1.5/1.5
5- Loam over clay (with subsoil constraints)	0.6	40	Very low	0.5	1.5/1.5
6- Loam over clay (with no subsoil constraints)	1.4	100	Very low	0.5	1.5/1.2

In the Six Management Zones scenario (without spatial grazing) it is assumed that each of the 6 soil zones can be managed for cropping specifically, but sheep are assumed to graze only until they reach the residual biomass threshold of 1.2 t/ha on paddocks with soils 1, 2 and 6, and 1.5 t/ha on paddocks with soils 3, 4, and 5. When Spatial Grazing is introduced to the Six Cropping Management Zone scenario it allows sheep to be removed separately from each soil when residual pasture biomass reaches the threshold of that particular soil (Table 2).

The optimisation based on maximising whole-farm profit shows that introducing spatial grazing of pastures can increase profit by 11% in the Three Zone scenario and 15% in the more profitable Six Zone scenario (Table 3). Importantly, introducing spatial grazing increases the relative profitability of livestock in the system. Under the Three Zone scenario, sheep are not part of the most profitable land uses unless spatial grazing is introduced. Under a Six Zone Scenario the sheep stocking rate that maximises profit increases from 0.33 to 0.87 DES/ha with spatial grazing. The results only represent pasture grazing benefits but do not include any cost for implementing spatial grazing (e.g. with virtual fencing).

Table 3. A comparison of spatial management scenarios with and without spatial grazing based on a 3000 ha grain growing farm represented in Mallee MIDAS.

Key farm indicators	3 Crop Zones- no spatial grazing	6 Crop Zones- no spatial grazing	3 Zones for Crop-with spatial grazing	6 Zones for Crop- with spatial grazing
Management zones	3 x 1000 ha	6 x 500 ha	3 x 1000 ha	6 x 500 ha
Cropped land (% of farm)	100%	90%	75%	81%
Wheat (ha)	1667	1631	1379	1524
Barley (ha)	1333	1036	879	964
Other (ha)	0	309	0	71
Livestock count (DSE[1])	0	981	3102	2620
Stocking rate (DSE/ha of farm)	0	0.33	1.03	0.87
Whole-farm profit ($)	**210,382**	**229,323**	**234,312**	**263,553**
Whole-farm profit ($/ha/year)	70	76	78	88
Grain sale ($/ha/year)	210	185	170	184
Sheep sale ($/ha/year)	0	14	43	37
Wool sale ($/ha/year)	0	7	23	20

Conclusion

There is a substantial number of grain growing farmers who expect that spatial grazing using virtual fencing, if available, would be very beneficial to their farming system. As demonstrated by a field study of spatial grazing behaviour, feed utilisation by sheep when grazing large paddocks can be very poor and concentration of grazing pressure can lead to erosion risks. Whole-farm bio-economic analysis of soil-specific pasture grazing shows that this practice has the potential to increase farm profit and substantially increase the role of livestock on mixed farms. The results offer encouragement for the ongoing pursuit of cost-effective virtual fencing technology.

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