10.1071/AN14613_AC

Supplementary Material: *Animal Production Science*, 2014.

The case for and against perennial forages in the Australian sheep–wheat zone: modelling livestock production, business risk and environmental interactions

Andrew D. Moore

CSIRO Sustainable Agriculture National Research Flagship & Plant Industry, GPO Box 1600, Canberra, ACT 2601, Australia. Email: Andrew.Moore@csiro.au

Derivation of the costs and prices used in the financial calculations

Average real grain, wool and sheep prices for 2008-2012 were calculated from Australian Bureau of Agricultural and Resource Economics and Sciences statistics. Since the Bureau publishes free-on-board grain prices, farm-gate grain prices were calculated by subtracting location-specific transport and handling costs obtained by referring to price lists published by the main grain handling companies; these costs totalled between $55 and $95/tonne.

Costs for growing and harvesting crops (including seed, herbicides and pesticides, machinery costs, non-nitrogen fertilizers, lime and the cost of windrowing canola), livestock husbandry, the costs of marketing products and the costs of establishing pastures were taken from recent gross margin budgets prepared by State agencies. Contractor rates were used for harvesting costs. Maintenance phosphorus requirements for pastures were estimated from the grazing intensity and soil type, using the method of Cayley and Quigley (2005). Grain used to feed livestock (wheat, barley, lupins or a combination thereof) was costed at its farm-gate price. Supplementary Table S4 details the costs and prices used.

Details of the index of wind erosion risk

As described in the body of the paper, an index proposed by Webb (2008) was used to assess the relative long-term wind erosion risk of each modelled farming system:

$$ER_{wind} = \sum_{p} \frac{A_p}{\sum_q A_q} \cdot RE_p \cdot \sum_{t} exp\left(-\frac{\theta_{1p,t}}{0.042}\right) \cdot exp\left(-\frac{C_{p,t}}{0.108}\right) \cdot \int_{v=0}^{\infty} f(v|\bar{v}_t) \cdot \max(0, v - 6.0)^3 \, dv$$

where

p	denotes a paddock
t	denotes a day of the simulation
A_p	is the paddock area (ha)
RE_p	is the relative erodibility for wind of each paddock (3.0 if the clay content of the surface soil < 0.07 g/g and 1.0 otherwise)
$\theta_{1p,t}$	is the modelled volumetric water content in the surface soil layer (m^3/m^3)
$C_{p,t}$	is the modelled projective foliage cover (0-1)
$\bar{v}_t$	is average daily wind speed (m/s)
$f(v\|\bar{v})$	is the probability density function of instantaneous wind speed v over the course of the day.

Synoptic wind speed data were acquired for nearby Bureau of Meteorology stations (Supplementary Table S1) for input to the wind erosion risk calculations. The wind speed data sets generally had much shorter periods of record than the weather data used to drive the simulation models, and so the daily mean wind speeds were extended to the period 1974-2011 by quantile-matching the wind speed data for each station to the gridded daily wind speed estimates of McVicar *et al.* (2008).

Exploratory data analysis of the synoptic wind speed data indicated that the frequency distribution of windspeed through the day, $f(v|\bar{v})$, could be adequately represented by Weibull distributions with a non-zero probability of zero wind speed, and that the parameters of these Weibull distributions were location-specific functions of the daily mean wind speed:

$$f(v|\bar{v}) = \begin{cases} f_0 & v = 0 \\ (1 - f_0) \cdot \frac{\alpha}{\beta^{\alpha}} \cdot v^{\alpha-1} \cdot exp(-(v/\beta)^{\alpha}) & v > 0 \end{cases}$$

where

$f_0 = exp\left(-(\bar{v}/k)\right)$

$$\alpha = \alpha_1 + (\alpha_2 - \alpha_1) \cdot max\left(0, min\left(\frac{\bar{v} - v_1}{v_2 - v_1}, 1\right)\right)$$

$$\beta = \frac{\bar{v}}{\Gamma(1 + 1/\alpha)}$$

The five parameters for the $f(v|\bar{v})$ distributions (i.e. k, v_1, v_2, α_1 and α_2) were fitted to the original intra-day windspeed data for each location by the method of least squares.

Table S1. Bureau of Meteorology identifiers for the weather stations used for daily weather inputs and for the wind speed data used to estimate relative erosion risks, and soil identifiers from the APSoil database of soil characterizations described by Dalgliesh *et al.* (2009)

Transect	Location	Weather station	Wind data station	Soil type	APSoil identifier
NSW Riverina	Merriwagga	075142	075041	Sandy loam over sandy clay loam	697
	Ardlethan	074000	073151	Red Kandosol	543
				Sandy clay over medium clay	698
	Temora	073038	073151	Red Chromosol – non-arable	913[A]
				Light Red Chromosol	913
				Heavy Red Chromosol	179-YP
WA central wheatbelt	Merredin	010092	010035	Deep yellow sand	409
				Yellow and brown sandy earth	482
				Shallow loamy duplex soil	493
				Gravelly duplex soil	475
	Wyalkatchem	010140	010035	Gravelly pale deep sand	479
				Deep sandy duplex	486
				Deep loamy duplex	406
				Acid yellow sand	478
	Wongan Hills	008138	008137	Sandy loam	400
				Acid sandy loam	402
				Duplex sandy gravel	487
Murray Mallee – central Victoria	Waikerie	024018	024048	Light loamy sand	360
				Sandy loam over red sandy clay	MM142
	Hopetoun	077018	077010	Alkaline loamy sand	[B]
				Alkaline clay loam	[B]
	Charlton	080006	080128	Sandy clay loam	740
				Clay loam	747

[A]Rooting depth in this soil type was reduced from the corresponding APSoil description to reflect a non-arable landscape position.
[B]Soil descriptions taken from Hunt et al (2013).

Table S2. Average N fertilizer rates applied to wheat, reference stocking rates, reference date of joining (start of the mating period), productivity of annual pastures and the resulting utilization rate in the reference (annual pasture only) simulation at each location, and the long-term average farm gross margin calculated for the reference simulation

Transect	Location	Average fertilizer N applied to wheat crops (kg N/ha)	Stocking rate (ewes/winter pasture ha)	Start of joining	Average annual pasture growth (t/ha)	Legume proportion of pasture growth	Pasture utilization rate (kg/kg)	Gross margin ($/farm ha)
NSW Riverina	Merriwagga	40	1.7	1 Feb	3.4	0.40	0.28	180
	Ardlethan	74	4.0	1 Dec	5.4	0.47	0.46	400
	Temora	72	6.2	1 Dec	5.5	0.45	0.59	470
WA central wheatbelt	Merredin	40	1.1	1 Jan	2.7	0.30	0.28	160
	Wyalkatchem	50	1.9	1 Jan	2.0	0.34	0.39	210
	Wongan Hills	60	4.4	1 Jan	3.5	0.26	0.43	330
Murray Mallee – central Victoria	Waikerie	20	1.7	1 Dec	2.6	0.21	0.30	50
	Hopetoun	36	5.8	1 Feb	4.9	0.88	0.55	330
	Charlton	40	5.6	1 Feb	5.5	0.73	0.48	380

Table S3. Modelled land use changes associated with the introduction of perennials into annual-only crop–livestock systems

The land use sequences for the "separated" and "phase farming" systems show the phases in a fixed cycle of land uses on the paddocks of each soil type. The phases in different paddocks are offset so that each phase of the sequence is present in one paddock in each year. The value preceding each land use sequence is the proportion of the farm area devoted to that sequence when 100% of annual pasture land is converted to perennial forages. Allocation order is the order in which perennial forages are allocated to different soil types as the proportion of perennial forage is increased

Transect	Location	Soil type	Separated farming system		Phase farming system	
			Land use sequence[A]	Allocation order	Land use sequence	Allocation order
NSW Riverina	Merriwagga	Sandy loam over sandy clay loam	0.333 P 0.667 ∅CWWBW	1	1.000 PPP∅CWWBW	1
	Ardlethan	Red Kandosol	0.187 P 0.313 WCWBW	2	0.500 PPPWCWBW	1
		Sandy clay over medium clay	0.187 P 0.313 WCWBW	1	0.500 PPPWCWBW	2
	Temora	Red Chromosol – non-arable	0.100 P	1	0.100 P	3
		Light Red Chromosol	0.075 P 0.125 WCWBW	2	0.200 PPPWCWBW	2
		Heavy Red Chromosol	0.311 P 0.389 WCWBW	3	0.700 PPPPWCWBW	1
WA central wheatbelt	Merredin	Deep yellow sand	0.125 P 0.125 LWW	2	0.250 PPPLWW	1
		Yellow and brown sandy earth	0.150 WWCB 0.100 WCWL	4	0.150 WWCB 0.100 WCWL	
		Shallow loamy duplex soil	0.100 P 0.200 W	1	0.300 PPPWWW	2
		Gravelly duplex soil	0.200 WCWL	3	0.200 WCWL	
	Wyalkatchem	Gravelly pale deep sand	0.120 P 0.080 CW	1	0.200 PPPCW	1
		Deep sandy duplex	0.300 WLWCB	4	0.300 WLWCB	
		Deep loamy duplex	0.300 WFWCB	3	0.300 WFWCB	
		Acid yellow sand	0.040 P 0.016 BWLW	2	0.200 PPWLW	2

Transect	Location	Soil type	Separated farming system		Phase farming system	
			Land use sequence[A]	Allocation order	Land use sequence	Allocation order
	Wongan Hills	Sandy loam	0.400 WCWB	3	0.400 WCWB	
		Acid sandy loam	0.075 P 0.225 LWW	2	0.300 PPP3(WLW)	2
		Duplex sandy gravel	0.180 P 0.120 W	1	0.300 PPPWW	1
Murray Mallee – central Victoria	Waikerie	Light loamy sand	0.136 P 0.364 2(WWB)WW	2	0.500 PPP2(WWB)WW	1
		Sandy loam over red sandy clay	0.136 P 0.364 2(WWB)WW	1	0.500 PPP2(WWB)WW	2
	Hopetoun	Alkaline loamy sand	0.300 KWBCWB	2	0.300 KWBCWB	
		Alkaline clay loam	0.233 P 0.467 WB	1	0.700 PPP3(WB)	1
	Charlton	Sandy clay loam: VCWB	0.300 VCWB	3	0.300 VCWB	
		Sandy clay loam: AAWBW	0.202 P 0.298 BWW	1	0.500 PPWBW	2
		Clay loam	0.075 P 0.125 WBLCW	2	0.200 PPPWBLCW	1

[A]Phases in each land use sequence are denoted by A=annual pasture; P=perennial pasture; V=vetch pasture; W=wheat; B=barley; C=canola; L=lupin; F=field pea; K=chickpea; ∅=fallow. Sub-sequences in brackets are repeated the nominated number of times.

Table S4. Costs and prices used in the financial calculations

Grain prices ($/t)		Wheat	Barley	Canola	Chickpea	Field pea	Lupins
Free-on-board		290	255	570	450	325	290
Farm-gate price (after transport and handling costs are deducted)	Merriwagga	195	160	480			200
	Ardlethan	200	170	485			205
	Temora	210	175	495			215
	Merredin	230	195	505			230
	Wyalkatchem	235	195	505		265	235
	Wongan Hills	235	195	505			235
	Waikerie	201	180				215
	Hopetoun	205	170	490	385		210
	Charlton	215	185	505			225
Deduction for producer levies and insurance		3.2%	3.8%	5.1%	6.2%	2.8%	3.7%
Grain growing costs ($/ha)[A]		Wheat	Barley	Canola	Chickpea	Field pea	Lupins
	Merriwagga	166	144	176			
	Ardlethan	224	219	202			
	Temora	224	219	202			
	Merredin	115	122	108			183
	Wyalkatchem	171	187	164		237	183
	Wongan Hills	171	187	164			183
	Waikerie	115	122				
	Hopetoun	115	122	147	242		
	Charlton	171	187	164			

Grain harvesting costs ($/ha)		Wheat	Barley	Canola	Chickpea	Field pea	Lupins
	Merriwagga	48	37	100			
	Ardlethan	35	35	70			
	Temora	35	35	70			
	Merredin	35	35	70			35
	Wyalkatchem	35	35	70		35	35
	Wongan Hills	35	35	70			35
	Waikerie	35	35				
	Hopetoun	35	35	70	35		
	Charlton	35	35	70			

Livestock prices (all locations)		Adult Ewes	Replace-ments	Merino Weaners	Crossbred Weaners
Fleece price	$/kg clean	11.32	12.80	12.80	10.36
Average:fleece price ratio[B]		0.92	0.92	0.92	0.92
Deduction for producer levies			2%		
Wool brokerage	$/kg clean		0.31		
Wool bales & transport	$/kg clean		0.16		
Livestock saleyard price	$/kg LW	1.28	n/a	2.26	2.26
Livestock sale commission			5%		

Livestock husbandry costs (all locations)		Adult Ewes	Replace-ments	Merino Weaners	Crossbred Weaners
Shearing costs	$/head	6.95	6.95	6.95	6.95
Crutching costs	$/head	1.16	1.16	1.16	1.16
Husbandry costs	$/head/year	5.90	2.40	7.10	5.00

Pasture establishment costs ($/ha; all locations)	Annual	Phalaris	Lucerne	Green panic
	58	97	66	99

Fertilizer costs (all locations)		
Fertilizer nitrogen	$/kg N	1.50
Fertilizer phosphorus	$/kg P	3.50

Maintenance P requirements of pastures (kg P/dry sheep equivalent.year)		Soil type 1	Soil type 2	Soil type 3	Soil type 4
	Merriwagga	0.53			
	Ardlethan	0.77	0.77		
	Temora	1.05	0.93	0.93	
	Merredin	0.90	0.90	0.53	0.90
	Wyalkatchem	0.90	0.90	0.53	0.90
	Wongan Hills	0.93	0.93	0.93	
	Waikerie	0.61	0.61		
	Hopetoun	0.53	0.53		
	Charlton	0.75	0.75		

[A]Excluding costs of windowing and harvest and of N fertilizer, which was applied at different rates on different soil types and hence is costed separately.
[B]Allowance for the lower price received for belly wool and crutchings.

References

Cayley J, Quigley P (2005) 'Phosphorus for sheep and beef pastures.' (Department of Primary Industries, Victoria: Melbourne)

Hunt JR, Browne C, McBeath TM, Verburg K, Craig S, Whitbread AM (2013) Summer fallow weed control and residue management impacts on winter crop yield through soil water and N accumulation in a winter-dominant, low rainfall region of southern Australia. *Crop & Pasture Science* **64**, 922-934

McVicar TR, Van Niel TG, Li LT, Roderick ML, Rayner DP, Ricciardulli L, Donohue RJ (2008) Wind speed climatology and trends for Australia, 1975-2006: Capturing the stilling phenomenon and comparison with near-surface reanalysis output. *Geophysical Research Letters* **35**, L20403

Webb NP (2008) Modelling land susceptibility to wind erosion in western Queensland, Australia. University of Queensland.