Optimising Broadacre Crop Rotations using Dynamic Programming

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Abstract:
A Dynamic programming Model is used to select the most profitable crop rotation from seven crop alternatives including pasture. Crop yields within a rotation are estimated by specifying growing season rainfall, water use efficiency and weed and disease penalties caused by the three previous years crop history. A provision exists to include the effect on yield of other natural resource limitations.
Regional variations can be accounted for by varying rainfall, management practices, yield penalties and input costs. A nitrogen-phosphorous calculator ensures sufficient fertiliser is applied for the crop to achieve its expected yield.
This approach can be used to measure the productivity implications of advances in technology as well as the impact of rainfall, yield and price variations on optimal rotations.

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INTRODUCTION:

Our objective is to measure the impact of new crop technology in the cereal zone of South Australia as an aid to allocating research dollars. A Dynamic Programming model is used to estimate the impact the new technology on the cropping system. The productivity change is measured by comparing the optimal crop rotation before and after the new technology.

BACKGROUND:

We started out with a copy of PRISM - a farm model developed for the Victorian Mallee. We acknowledge the assistance of the staff at DENR for their assistance in the initial stages of the project. The PRISM model (a derivative of MIDAS) was an Excel based linear programming model that considered six crop alternatives and a two-year crop history – a total of 216 potential rotations. The two-year history was used to determine the likelihood of any yield penalties (from weed, disease, soil moisture and nutrition effects) that would reduce the yield potential of the current crop.
Yield potential for each crop was determined using the French – Schultz Potential Yield Model.

Potential Yield (t/ha) = (April-Oct rainfall (mm) – Evaporation) X Water Use Efficiency (kg/mm/ha).

Typically the potential yield of cereals with 300mm of April/Oct rainfall in South Australia is:

$$(300 - 110).(20)/1000 = 3.8\text{t/ha}$$

The Expected Yield is the Potential Yield less any yield penalties that may arise because of the previous crop history.

MODIFICATIONS TO THE MODEL:

- **More crop combinations**

We began to adapt the model to the mid north of South Australia where the annual rainfall is 4-500mm. Because of the higher rainfall and increased crop possibilities we wanted to consider more crop combinations. We consulted the local agronomists to seek their input in specifying the weed and disease penalties. In their opinion it was necessary to consider a three-year crop history to properly specify the disease penalties associated with growing some crops (grain legumes and canola) too close together in a rotation.
The combination of extra crops and the three year history exceeded the capacity of the Excel based LP (eight crops and a three-year history resulted in 4096 possible rotations) so we were forced to adopt the Dynamic Programming approach. We downloaded a copy of the GPDP Model courtesy of J Kennedy and the Latrobe web site and started again.

- **Nitrogen/Phosphorus calculator**

The original model included fertiliser as a fixed input. Changing the growing season rainfall by 100mm increases the potential yield of wheat by 2 tonnes/ha with a significant increase in fertiliser required. Unless the fertiliser applied was manually increased in the crop input table this increase yield would result in an artificially high crop gross margin. The N/P calculator automatically adjusts the amount of nitrogen and phosphorous applied to meet the nutrient demands of the crop at the expected yield. This saves having to adjust the fertiliser input every time growing season rainfall, water use or management efficiency is altered. Organic carbon, soil phosphorous, target grain protein levels and legume content of pastures were included in the model to assist in calculation of nitrogen and phosphorous requirements. These additions have expanded the potential uses of the model to look at the effect of different levels of organic matter and soil phosphorus on the profitability of crop rotations.

- **Livestock**

Livestock are not included in the model as an activity. Rather pasture is a crop option (either sown or volunteer). The expected yield of pasture is converted to dry sheep equivalents (dse's) by making an assumption about the rate of pasture utilisation and the kilograms of dry matter required to sustain a dse.

- **Management Efficiency**

The agronomists indicated that the Potential Yield Model produced yields well above actual yields. To reduce Expected Yields to district average yields we introduced a management efficiency factor. The revised formula for expected yield became:

Expected Yield = (Potential Yield – Yield Penalties) x Management Efficiency

Where: Potential Yield = Water Use x Potential Water Use Efficiency

And: Water Use = Growing Season Rainfall + Soil Water Used – Evaporation loss

Early runs of the model produced rotations with higher proportions of canola and durum wheat than is actually grown by farmers. There are several possible explanations for this. It could be that farmers discount the expected yields of these crops to account for perceived risk or that they have different price expectations to those used in the model. We have had to manipulate both management efficiency and prices for the model to produce crop rotations with a crop mix similar to actual crop areas sown.

THE NEW MODEL

All of the model data is stored in an Excel file. Crop yields are calculated from growing season rainfall, crop water use efficiency, weed and disease penalties (determined by the previous three years crop history) and management efficiency as shown in Table 1
A gross margin is calculated for each possible crop and three-year history combination using the specified crop inputs and prices and the fertiliser required as determined by the Nitrogen – Phosphorous calculator. Samples of the crop gross margins are shown in Table 2. Note that the seven gross margins for wheat are all different and vary from $204 to $325 per ha depending on the crop history. A copy of the Crop Input table is shown in the appendices.

Table 1: Estimating the Expected Yield of Crops from Water Use and Potential Water Use Efficiency

Crop	Growing Season Rainfall (mm)	Soil Water Used (mm)	Evaporative Losses (mm)	Water Use (mm)	Potential WaterUse Efficiency (kg/ha/mm)	Pasture utilization rate %	Kg Dry Matter per DSE	M'gment Efficiency
Wheat	250	0	110	140	20			0.85
Durum	250	0	110	140	20			0.70
Barley	250	0	110	140	20			0.85
Canola	250	0	110	140	12			0.70
Oaten hay	250	0	110	140	35			0.90
Legume 1	250	0	130	120	15			0.8
Legume 2	250	0	70	180	45	40%	330	0.75

3 year paddock history			Proposed crop this year	Potential Yield t/H	Weed Effect + or - %	Disease Effect + or - %	Expected Yield t/ha
Ca	Ba	Wh	Wh	2.8	-5%	-18%	1.83
Ca	Ba	Du	Wh	2.8	-5%	-22%	1.74
Ca	Ba	Ba	Wh	2.8	-5%	-10%	2.02
Ca	Ba	Ca	Wh	2.8	0%	-2%	2.33
Ca	Ba	Ho	Wh	2.8	0%	-5%	2.26
Ca	Ba	L1	Wh	2.8	0%	-2%	2.33
Ca	Ba	L2	Wh	2.8	-3%	-8%	2.12

Table 2: Sample Crop Gross margins ($/Ha)

Paddock History			Current Crop (Yt)						
Y_{t-3}	Y_{t-2}	Y_{t-1}	Wh	Du	Ba	Ca	Ho	L1	L2
Ca	**Ba**	**Wh**	$217	$192	$240	$221	$204	$186	$84
Ca	**Ba**	**Du**	$204	$102	$240	$221	$204	$186	$84
Ca	**Ba**	**Ba**	$242	$209	$146	$221	$204	$186	$84
Ca	**Ba**	**Ca**	$308	$307	$278	$93	$238	$186	$84
Ca	**Ba**	**Ho**	$289	$280	$264	$230	$214	$186	$84
Ca	**Ba**	**L1**	$325	$312	$278	$246	$257	$28	$127
Ca	**Ba**	**L2**	$280	$281	$266	$244	$242	$186	$105

The Dynamic Programming Model uses the data generated in the Excel file. For each three-year history combination the model selects the crop with the highest Gross Margin. The crop history is updated by the addition of the selected crop and the process is repeated until a rotation is established. The Optimal rotation is selected on the basis of the discounted value of the cash flow generated over a period of 50 years.

APPLICATIONS:

1. **Climate Change**
   It is expected that global warming over the next 50 or so years will reduce winter rainfall in the cereal zones of southern Australia by about 15%. At the same time an increase in carbon dioxide levels is likely to improve the water use efficiency of crops. The effect of reduced

growing season rainfall combined with a 5 and 10% increase in water use efficiency was examined assuming present growing season rainfall of 250 and 200mm per annum.

The estimate impact of global warming on the optimal rotation and Av Annual Gross Margin

Treatment	Rotation	Av Annual G.M.
Status Quo, **250mm** Apr-Oct rainfall	W B C W L1 W C	$258/ha
-15% Apr-Oct rainfall +5% water use efficiency	W B C W W C	$185/ha
-15% Apr-Oct rainfall +10% water use efficiency	W B C W W C	$197/ha
Status Quo, **200mm** Apr-Oct rainfall	W C W	$128/ha
-15% Apr-Oct rainfall +5% water use efficiency	Continuous volunteer pasture	$77/ha
-15% Apr-Oct rainfall +10% water use efficiency	Continuous volunteer pasture	$81/ha

Given existing technology the impact of global warming is predicted to reduce the profitability of cropping and in low rainfall regions make cropping unprofitable.

2. Rotating tillage depth to remove hardpans.

Cultivation over a long period of time at the same depth and soil compaction caused by heavy machinery has caused hard pans to develop in some cropping soils. The hard pan restricts water absorption and root growth thereby limiting the water available to the crop. Trials have indicated that reduced tillage and variation of tillage depth to break up the hard pan can improve crop yields by up to 10%.

Treatment	Optimal rotation	AV Annual G.M.
250mm Apr-Oct rainfall Conventional Cultivation	W B C W L1 W C	$258/ha
Reduced Tillage Varying tillage depth 10% Increase in Yield	W C W B L1	$290/ha

3. Improved Crop Variety

Assume a new legume variety has an increased water use efficiency of 10%

Treatment	Optimal rotation	AV Annual G.M.
Stuatus Quo 250mm Apr-Oct rainfall	W B C W L1 W C	$258/ha
New legume variety 10% improvement in water use efficiency	W L1 W C	$264.75/ha

SUMMARY:

The model is very versatile and can be used to look at a variety of different circumstances. The input tables are easily manipulated to examine different machinery systems or chemical inputs. The effect of growing season rainfall, management or water use efficiency on the optimal rotation can be examined by changing a single cell in the worksheet. In the case of pastures you are able to vary the rate of pasture utilization, the legume content of the pasture and the kg of dry matter required per dry sheep equivalent and assess the impact on the optimal rotation.

The biggest limitation to substituting other crops into the model is the specification of the disease and weed penalties for the 2401 rotation combinations and the possible recalibration of the N-P calculator for the new crop.

At this stage the model does not take any account of the risk associated with yield and price fluctuations in crop production nor does it tell us anything about the robustness of the result. The model may select a seven or nine year rotation that is only a few dollars a hectare better than a three year rotation.

REFERENCES

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APPENDICES

Inputs, Prices & Costs **low rainfall regions**

		Wh Wheat	Du Durum	Ba Barley	Ca Canola	Ho Oaten hay	L1 Legume 1 (field peas)	L2 grass past
QUANTITY:	**per ha**							
Farm Inputs *								
Seed	kg	80	100	75	5	100	100	0
Fertiliser1	kg							
Fertiliser2	kg							
Fertiliser3	kg							
Fertiliser4	kg							
Herbicide1	L	0.8	0.6	1	1.5	1	1	1
Herbicide2	L	10	0.5	0.8	0.6	0.085	0.4	0
Herbicide3	L	0.6	5.0	0.3	0.25	1.5	0.25	
Herbicide4	L	0.075	1.0	0.2	0.6	0.08		
Insecticide1	L	0.35			0.2		1	0
Insecticide2	L	0.35					0.05	0
Insecticide3								
Insecticide4								
Fungicide1	kg							
Fungicide2	kg							
Land Preparation1	hrs	0.20	0.20	0.20	0.20	0.20	0.20	
Land Preparation2	hrs				0.1	0.1	0.1	
Sowing	hrs	0.25	0.25	0.25	0.25	0.25	0.25	
Harvesting	hrs	0.2	0.2	0.2	0.20		0.25	
Fert.Application	hrs							
Herb.Application1	hrs	0.06	0.06	0.06	0.09	0.06	0.09	0.06
Herb.Application2	hrs	0.06	0.06	0.06	0.06	0.06	0.06	
Herb.Application3	hrs		0.06			0.06		
Herb.Application4								
Insect.Application	hrs				0.12		0.06	
Insect.Application2								
Fung.Application	hrs							

		Wh Wheat	Du Durum	Ba Barley	Ca Canola	Ho Oaten hay	L1 Legume 1 (field peas)	L2 grass past
PRICES:								
Outputs								
Silo Return		205	255	186	350	132	250	20
Premium/Bonus								
Other Costs						24.00		
freight		15	15	15	15	22.00	15	
Marketing Costs								
Farmgate Price	$/t	190	240	171	335	86	235	20
Farm Inputs								
Seed	$/kg	0.20	0.30	0.20	3.50	0.12	0.24	
Fertiliser1	$/kg	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Fertiliser2	$/kg	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Fertiliser3	$/kg			0.00			0.45	0.45
Fertiliser4	$/kg							
Herbicide1	$/L	9.00	7.00	9.00	6.50	7.00	9.00	7.00
Herbicide2	$/L	0.42	9.25	7.00	7.00	40.00	4.00	
Herbicide3	$/L	7.00	0.30	9.25	59.80	6.45	59.80	
Herbicide4	$/L	40.00	22.00	15.50		58.00		
Insecticide1	$/L	6.45			28.50		6.00	
Insecticide2	$/L	15.50					28.50	
Insecticide3	$/L							
Insecticide4	$/L							
Fungicide1	$/kg							
Fungicide2	$/kg							
Land Preparation1	$/hr	50.00	50.00	50.00	50.00	50.00	50.00	
Land Preparation2	$/hr				30.00	30.00	30.00	
Sowing	$/hr	60.00	60.00	60.00	60.00	60.00	60.00	
Harvesting	$/hr	80.00	80.00	80.00	80.00		100.00	
Fert.Application	$/hr							
Herb.Application1	$/hr	30.00	30.00	30.00	40.00	30.00	40.00	40.00
Herb.Application2	$/hr	30.00	30.00	30.00	30.00	30.00	30.00	
Herb.Application3	$/hr		30.00					
Herb.Application4	$/hr							
Insect.Application1	$/hr				30.00		30.00	
Insect.Application2	$/hr							
Fung.Application	$/hr							
OTHER COSTS:								
Insurance	$/ha	4.50	5.00	4.00	5.00	2.00	6.00	
Aerial Spraying	$/ha				8.00		8.00	
Any Other	$/ha				20.00	60.00		
Total		4.50	5.00	4.00	33.00	62.00	14.00	0.00