PRISM: a MIDAS-like farm model for the southeastern Australian cropping zone

Brett Robinson, Giles Butler and Brian Kearns

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Or -

Separating the crême de la crême: Identifying and understanding the best and worst in farm management using a new generation model of mixed farms at Wagga Wagga.

Brett Robinson[1], Giles Butler[1] and Brian Kearns[2]

[1]NSW Agriculture,
Agricultural Research Institute,
Private Mail Bag,
Wagga Wagga, NSW 2650

[2]Agriculture Victoria
Victorian Institute of Dryland Agriculture
Private Bag 260
Horsham, Victoria 3400

Corresponding author,
Brett Robinson
NSW Agriculture,
Agricultural Research Institute,
Private Mail Bag,
Wagga Wagga, NSW 2650
Ph 069381866
Facs. 069 381809
E-mail robinsb@agric nsw.gov.au

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Brett Robinson[1], Giles Butler[1] and Brian Kearns[2]

[1]NSW Agriculture,
Agricultural Research Institute,
Private Mail Bag,
Wagga Wagga, NSW 2650

[2]Agriculture Victoria
Victorian Institute of Dryland Agriculture
Private Bag 260
Horsham, Victoria 3400

ABSTRACT

Farming is complex. In the southeast of Australia's cropping zone, small mixed farms produce a range of grains, wool and meat. It is argued that specialised technical information does not assist farm management. Whole-farm mathematical programming models have the potential to identify and analyse better farming systems.

PRISM (Profitable Resource Integration - Southern MIDAS) has been developed to assess and maximise the profitability of small dryland mixed farms in southeastern Australia. It represents the following activities and their interactions; crop and pasture rotations, livestock enterprises, fodder conservation, grain selling and feeding, and the costs of finance. Operation of a typical 1000 ha mixed farm on Red Earth soil near Wagga Wagga was investigated.

The results show that cropping systems that maximise wheat yields and sales through growing pastures and canola, and sometimes lupins, are more profitable than traditional pasture-wheat rotations by $20, 000 to $80,000 per annum. Although following canola with wheat (CaW) is prevalent in the most profitable rotations, wheat following lupins following wheat (WLW) is also a highly profitable cropping phase. This crop sequence (WLW) may be valuable where soil pH or wild radish infestations prevent the economical production of canola.

Potential improvements to PRISM are discussed. These include the addition of risk and sustainability indices, beef cattle enterprises and rotations with continuous cropping and perennial pastures. The livestock enterprises submodel could be modified to allow the flock structure to be optimised. Potential applications of PRISM are also discussed.

Introduction

Mixed farm management

The evidence shows that farming is a complex business. Management of a farm business in southeastern Australia involves complex strategic decisionmaking concerning the biological and economic structures of the farm. Plant varieties, animal breeds, machinery, and a myriad of management systems such as weed control and animal parasite control must be suited to the climate, soils and financial conditions. Daily management consists of expert tactical decisionmaking to reduce the impacts of adverse variation in seasonal conditions, costs and prices, while capitalising on favourable conditions and opportunities. From a theoretical viewpoint, it is likely that best farm management integrates tactical management into a sound strategic biological and financial plan.

Farmers of the wheat-sheep belt operate many enterprises. These farms produce cereals, pulses and oilseeds, each of which is likely to be graded and marketed according to quality or acceptability parameters. Wheat, barley, triticale, oats, peas and lupins and canola are the chief crops. The crop area is likely to be half of the total area of 500 to 1,500 ha for a family farm. Animal production systems usually involve lamb and wool production from Merino cross or purebred Merino animals. However, there are many variations in the animal production systems, and even the simplest of them involves trading or producing several classes of animals and the marketing of wool, meat, replacement stock and skins. It is also common to breed beef herd replacement stock or fatten beef cattle on mixed farms. Financial management involves the income and expenditure of several hundred thousand dollars.

An unusual characteristic of mixed farms in southeastern Australia is that a large number of potential enterprises are directly competing for resources such as land, labour, machinery and cash. The high degree of complementarity between some enterprises, such as legume pastures and cereal crops, further complicates the enterprise selection process.

Farm management economics

Malcolm (1990) reviewed the Australian farm management economic literature, and concluded that in the 1980s there was a strong decline in output. The problems of "partial-farm management" orientation and a lack of balance between disciplines had taken their toll. Back in the 1960s it was often suggested that new technology would have an impact on farm management through tools such as simulation, linear programming and farm management games (Longworth 1969). Although these management tools may have had limited impact, it is nevertheless likely that there are many instances of poor management, and any system that can improve farmers' management skills can improve the profitability and viability of many farms. By the late 1970s Nuthall (1979) was able to document several thousand cases of the use of decision aids, including several farm-level management models.

In spite of the evidence that management could be analysed and potentially improved, research and development in this area has been a low priority for Australian government agencies. Farmers and their private consultants were seen as the farm management experts, and the government agencies have supplied the detailed technical information.

Without proper analysis, it is possible to underestimate the value of improved farm management. One could argue that few farmers have any business management training, yet most farms are profitable (ABARE, 1993). However, farm income and farmers' terms of trade have fallen in recent years, in spite of increases in farm output. This is indicated by a real net value of farm production in the 1980s of only 64 % of its value in the 1950s (Chisolm 1992). The cost-price squeeze and other pressures have necessitated a more critical examination of farming methods than ever before. Although the traditional diversity of enterprises, a conservative approach to expenditure, and the management skills learned informally by most farmers may have been sufficient to successfully operate their farm businesses in the past, this situation may have changed. Few mixed farms in New South Wales are as profitable in the 1990s as they were in the 1950s and 1960s (Davis *et al.* 1979, Chisholm 1992).

In the secondary and tertiary industrial sectors there was a rapid development in economic management tools during World War II (Lapin 1988). Mathematical programming (MP) was used to solve problems involving the coordination or combination of many activities or ingredients, and was most useful where there are many constraints on the legitimate combinations of ingredients or activities. Such problems exist in the agricultural sector for feed ration formulation (e.g. Kellaway 1990), dairy farm management (George Olney *et al.* (agsystems)) and land use planning (Greiner 1993). In farm management research MP models have been used to identify optimum combinations of farm enterprises or farm management units. By the late 1970s MP models were in wide use, albeit with a mixture of successes and "disasters" (Nuthall 1979). Although severely criticised for some failings over a protracted period (see Drynan 1987, and Malcolm 1990), MP models have been popular. Hardware and software advances in the 1980s have enhanced this reputation by making mathematical programming simple and efficient for non-mathematicians.

MIDAS and MUDAS

MIDAS (Model of A Dryland Agricultural System, Morrison *et al.* 1986) is a whole-farm MP model developed in West Australia that represents mixed farms. It can quantify the effects of changes in conditions and management, and identify the optimum management strategy for a given set of conditions. Successful applications include assessments of animal husbandry practices (Morrison and Young 1991), crop and pasture management (Pannell and Falconer 1988, Falconer *et al.* 1988). A more complex form of the model, MUDAS (Model of an Uncertain Dryland Agricultural System, Kingwell *et al.* 1991), represents variation in crop and pasture yields over a series of years. Some old arguments, such as those put by Menz and Longworth (1976), that long-term planning on Australian farms is useless due to ever-changing conditions have been defeated by the successful application of MUDAS and similar models.

PRISM

As farms in the southeastern Australian wheatbelt differ considerably from the West Australian farms for which MIDAS was developed, the PRISM model required new submodels to be developed. Some differences between the farming systems of the eastern wheatbelt of West Australia and the southeastern wheatbelt of New South Wales are shown in Table 1. The climate at Merredin has a winter-dominant pattern, while Wagga Wagga has a seasonally uniform distribution that is made winter effective by high summertime evaporation rates. Climate has a major influence on cropping systems (Kelleher 1990, Tow 1991). The soils near Wagga Wagga are finer textured than the sands in the west, greatly improving their water holding capacity. Wagga Wagga's soils are mostly Red Earths (Greater Soils Groups taxonomy), or Dn2.12 in Northcote's Factual Key (Northcote 1981). These Red Earths are neutral to slightly acidic, have good cation exchange capacity, and are usually deficient only in phosphorus and, for legumes, molybdenum. Potential yields of crops, and the subterranean clover and annual ryegrass pastures, are high compared with Merredin and the Australian cropping zone in general (see Table 1). These conditions give farmers a broad choice of crop rotations. Economic conditions also influence the range of activities at Wagga Wagga. Infrastructure has traditionally favoured cropping and sheep. Recent increases in the demand for beef cattle for feedlots and fluctuations in the wool price have lead to an increase in cattle numbers and the associated facilities for their management and trading.

The aims of this study are to develop a mathematical programming model for investigating the management of farms on the Red Earth soils in southern New South Wales, test the sensitivity of model results to changes in key assumptions, and analyse the effects of changed commodity prices on the most profitable management system for a typical mixed farm.

Methods

Mathematical modelling of a mixed farm

Modelling is essentially a process of abstraction of the physical system. Usefulness of the results from a model is dependant on both the quality of the abstraction, and the similarity between the systems that were the source of the information and the system in which the results are to be applied. For a review of some philosophical difficulties in the use of models, see Busch (1993). Malcolm (1990) discussed the concept of an "optimal degree of generality" in modelling, and concluded that one strength of budgeting methods was their depth and breadth, and presumably, the balance between the two. PRISM represents the whole farm at a similar level of detail as enterprise budgets. In fact, PRISM may be used as a budgetting tool by simply ignoring the mathematical programming capability. PRISM preserves or improves the resolution of biological and economic information contained in MIDAS (Morrison *et al.* 1986). All farming systems data was obtained from the local farms, merchants, *etc.*

Like MIDAS (Morrison *et al.* 1986), PRISM is an annual steady-state model. The passage of time is ignored for all purposes except the fixed intra-annual schedule of operations and calculation of bimonthly cashflows. Each year in the various crop and pasture rotations is proportionally represented on an annual basis: the yield of any enterprise per hectare per annum is multiplied by the hectares of each enterprise per hectare of rotation.

The problems considered here are concerned with allocating the available resources to maximise the farm profit, or the allocative efficiency (Menz and Longworth 1976, Drynan 1987). The objective function, given in Equation 1, is maximised. This objective includes total farm income and expenses, the opportunity costs of capital expenditure on machinery and other major items of equipment, the cost and returns from an overdraft or cash surplus, and the cost of depreciation of assets.

$$\text{Objective} = \Sigma(\text{Income} - \text{Expenditure} - \text{Opportunity Costs} - \text{Depreciation}) \quad ...(1)$$

This function includes the cost of servicing an overdraft, but not servicing a farm business debt nor personal expenses such as telephone bills or car expenses. Tax is not included due to the wide range of potential liabilities that may apply to a given farm business. These differences often arise through off-farm income or expenditure. Maximising farm profit is a common goal for farm managers, except in peasant and subsistence farming (Young *et al.* 1990). These farmers are likely to maximise their technical efficiency; to maximise their outputs for a given set of inputs, or minimise their inputs for a given level of output (Farrell 1957). The PRISM model may be reformulated to maximise a technical efficiency objective. Nevertheless, farmers commonly ignore advice designed to increase profit and technical efficiency. It seems that the factors involved in the non-adoption of efficient operations are complex (Buggie 1977) and beyond the scope of this work.

The PRISM model resides in a Microsoft Excel 4.0 for Windows* workbook and the objective function is maximised using the LINDO product What's Best*. There are 134 activities and 75 constraints in the model. Details of these are given in Appendix 1. There are three activities (ownership of various sized shearing sheds and yards) for which the solution is a binary variable. The model is therefore solved using a combination of integer and linear programming.

All biological and financial information in the model is linked to a master spreadsheet. The master sheet shows a traditional MP matrix with activities in columns and constraints in rows, as shown diagrammatically in Table 2. Details of the matrix activities and constraints are given in Appendix 1. The farm operation and management spreadsheets are; Crop production, Pasture production, Livestock production, Herbicide and fertiliser inputs, Overheads and labour requirements, Finance, and Miscellaneous costs. The farm representation in these spreadsheets is detailed in separate sections below. Other spreadsheets assist data input and analysis of results, Gross margins, Costs and prices, and Graphs. Two spreadsheets assist navigation through the system, Main and Macros. The model involves many sheet-to-sheet linkages and mathematical formulae. Non-optimising operation of the model involves solving approximately 6500 arithmetic and logical functions. Recalculation time on an Intel 80486DX based personal computer is approx. 10 seconds, and optimisation and updating results approx. 60 seconds.

Revenue is derived chiefly from grain, wool and livestock sales, and interest earned on positive cashflow. Grain is produced in the rotations and sold for cash or fed to animals. Monthly energy supply by pastures is a characteristic of rotations, and the energy is either used by the animals or transferred forward one month, in which case quantity and quality penalties apply. Wool is cut in September (rams are also shorn in May), and sold in a range of prices separated for breeds and wool classes (bellies, locks *etc.*). Autumn lambs, often born in May, are sold as prime lambs in late spring or early summer or sold in late summer as heavy lambs. The monthly liveweight values for each class of animal are inputs to the model. These determine the animal's energy requirements, and strongly influence the time of selling and price received for lambs.

PRISM represents a single soil type on the farm (Red Earth). Where soil quality varies, and crops are differentially affected, a site index may be used to adjust yields. It is also possible to represent factors that limit the extant of cropping and pasture activities within the soil unit, if this is necessary. An example of this would be the exclusion of barley and canola crops from an area representing paddocks with acid soils. Alternatively, the cost of the soil improvements needed to allow the use of affected crops, such as lime, could be incorporated into the relevant rotation costs

Crop and pasture rotations

Estimates of grain production from the crops in the rotations are obtained in PRISM from a submodel using growth indices of the style of Fitzpatrick and Nix (1970). This is different to the consensus, or expert knowledge-based yield assessments made in most farm models, such as MIDAS (Morrison *et al* 1986). Accuracy in the relative yield estimates is thought necessary because grain sales are known to provide much of the farm income on mixed farms (Davis *et al* 1979). Grain is used to feed stock through the autumn pasture feed gap. Bias in the ratios of pasture and grain yields or ratios of yields between grains may significantly alter the numbers of livestock and the proportions of pasture and crops.

Grain production in PRISM is estimated from crop water use, an approach developed by de Wit (1958), reviewed by Tanner and Sinclair (1983), and investigated in southern Australia by French and Schultz (1984). The model is given in Equation 2

$$G = T \cdot TE \cdot NI \cdot WDI \cdot USI \qquad \text{.........(2)}$$

where G is grain production (kg/ha/year), T is crop transpiration (mm) and TE is the transpiration efficiency for grain (kg/mm), NI is an index of nitrogen availability, WDI is an index of weed and disease limitations to grain production and USI is an index of grain yield potential as affected by undersowing the crop with pasture species. Crop density is usually decreased to approximately half the usual value when an annual pasture is undersown. Undersown pastures grow concurrently with the crop, and undersowing is widely adopted in favour of either sowing pastures in the year following the cropping phase or allowing volunteer species to establish on fallow ground following cropping.

Transpiration is estimated from the soil water budget given in Equation 3 (Monteith 1960). Although it is rare for all parameters of this equation to be estimated or measured over a growing season, several authors have estimated T, usually from measurements of P and estimates of Es, δQ, r_t, and q_r. Estimates of T/(T+Es) for spring wheat (cv. Banks) at Werribee reported by Connor *et al.* (1992) ranged from 0.52 to 0.54 for crops sown in May and June, while July sowing gave 0.43 and 0.45, reflecting suboptimal water expenditure by the crop. Doyle and Fischer (1979) found that T/(T+Es) ranged from 0.60 to 0.77, with a mean of 0.70. Huda (1994) found that the range of wheat yields encountered on the Eyre peninsula were simulated when the proportion of precipitation transpired (T/P) ranged from 0.60 to 0.80. T/P is likely to be slightly less than T/(T+Es), as small amounts of runoff and deep drainage occur during the growing season at Wagga Wagga (K. Helyar, pers. comm.). If T/(T+Es) ranges from 0.50 to 0.75 and runoff and drainage losses are 10 percent of P, T/P will range from 0.45 to 0.67. In PRISM T/P equals 0.56 for wheat crops.

$$P = T + Es + \delta Q + r_s + q_z \qquad \text{............(3)}$$

where P is precipitation (rain, fog and dew), T is transpiration and evaporation of intercepted precipitation, Es is soil evaporation, δQ is the change in soil water storage, r_s is runoff, and q_z is the net loss due to drainage out of, and conduction into the root zone (all units mm).

Transpiration efficiency for grain yield in wheat varies with factors such as evaporative demand during the growing season and genotype (de Wit 1958, Connor *et al.* 1992). Although evaporative demand varies little between years at a given location, variation in the time of sowing and the length of stages of crop development lead to large differences in TE. Connor *et al.* 1992 found that the TEs of spring wheat sown in May were about 22 kg/ha/mm (range 21.3 to 23.3), while June and July crops were about 29 (range 26.5 to 31.6). Assuming a harvest index of 0.38, the TE of wheat crops grown at Tamworth, described by Doyle and Fischer (1979), ranged from 12.4 to 33.2 kg/ha/mm, and had a mean of 20.4 kg/ha/mm. Huda (1994) used TEs of 10.5 and 14.8 kg/mm for wheat grown on the Eyre peninsula. These data may reflect overestimates in Huda's estimates of T/P; reducing the T/P ratios to 0.5 would increase the TEs for equal yield to 12.6 and 23.7 kg/mm for average and good managers, respectively. The yield estimates for wheat grown at Wagga Wagga are based on a TE of 24 kg/ha/mm.

The TEs of crops other than wheat are calculated from the ratios of water use efficiency (WUE, kg grain/mm growing season rainfall) for various crops relative to wheat. WUEs are readily calculated, and are used as a crude estimate of the efficiency of rainfall use. The assumption made in estimating TE for crops other than wheat is that WUE and TE ratios between two crops are equal. There is meagre data to support or reject such an assumption, though consideration of the main physiological determinants of these ratios, such as harvest index, suggests that they are likely to mutually affect WUE and TE. Data colleted by local farmer groups and reported by Mead (1992) and Butler and Laycock (1994) were used to estimate the crop conversion factors from WUE to TE. These data are shown in Table 4.

Table 5 shows the actual and potential yields for the five grains, and the growth indices used in equation (2) to estimate the actual yields. A wide range of data sources has been used to estimate the growth indices. Preliminary estimates were refereed by four local experts. The refereeing process resulted in some minor changes incorporated into the data shown in Table 5.

Pasture production

The metabolisable energy (ME, MJ/kg) available from pastures is based on monthly estimates of the dry matter production reported by Reeve and Sharkey (1980) at Rutherglen, Stockdale (1983) at Kyabrum, and Wolfe and Southwood (1980) and Collins *et al.* (1983) at Wagga Wagga. Table 6 shows the component pasture growth rates used to derive the standard set. The growth rates based on the data of Reeve and Sharkey (1980) are much higher than the other data, though there is no clear reason for these differences. Data based on Collins *et al.* (1983) and Stockdale (1983) compare well, especially in terms of a likely annual total dry matter production in the range of 6 to 8 t/ha/year. However, the annual total for Wolfe and Southwood's (1980) data is much lower. This is not simply due to competition between lucerne and clover in the pastures, because even when the lucerne component of the pasture is included, Wolfe and Southwood's (1980) annual totals were 6.7, 5.2 and 2.8 t/ha/year in three years at the lowest lucerne density. The low yield data agrees with the results of Robinson *et al.* (1993), who found the mean annual production from 35 irrigated sub clover paddocks was only 5.9 t/ha/year. The standard deviation for these 35 paddocks was 2.1 t/ha/year, indicating high variability, even among irrigated paddocks. Given this level of production from irrigated pastures, the total of 3.4 t/ha/year in the Wolfe and Southwood data seems feasible. The sensitivity of the model to changes in pasture production assumptions is tested below.

Monthly values of the *in vitro* digestibility of dry matter (IVD) was based on Stockdale's (1983) data. The ME of pasture was estimated from IVD using Equation 4 (Standing Committee on Agriculture 1990).

$$ME = IVD * 0.17 - 2.0 \qquad ...(4)$$

Grazing of any pasture may be defered by one month, with quantity and quality discounts applying. This is a common practice to maximise the utilisation of the spring forage surplus.

Fodder conservation

The dominance of spring forage production has lead to the widespread adoption of fodder conservation as hay and silage in the Wagga Wagga area. Haymaking from pastures or oat cropsis almost universal. The PRISM model represents haymaking from pasture in mid-September, mid-October and early November. The hay is stored as small square bales (26kg dry matter), and either large round bales (490 kg) or large square bales (450 kg). Feeding out of the two bale sizes of hay is represented every month from January to May. The losses in dry matter and ME content are estimated from the data of Curll and Kaiser (1985, Temperate pastures).

As well as the direct loss of ME through the removal of dry matter, pasture growth is decreased in subsequent months. This effect is widely observed. Losses are estimated from Equation 5.

$$Me_{loss} = ME_{cut} * Area_{cut} * K_{time} \qquad ...(5)$$

where Me_{loss} is the reduction in ME available due to haycutting (MJ/month), ME_{act} is the normal ME available from the area cut (MJ/month), $Area_{cut}$ is an estimate of the area cut (ha), and K_{time} is the loss constant, equal to 0.8 for the month after cutting and 0.5 after two months. The area cut for hay is estimated from one month's carry forward of feed and cutting of 80% of the dry matter production. Later versions of the model are likely to constrain haymaking to include feed carry-forward and ensure that a sufficient area of well-established pasture is available. All of the results presented here conform to these principles without formally constraining the model.

Chemical and fertiliser costs

This spreadsheet includes information on chemical use for the 37 rotations. The chemicals include 22 herbicides and 7 insecticides. Chemicals are selected for the economic control of important weeds at opportune times in the rotations. There are large differences in strategies between the rotations due to important influences of crop sequence on the types and density of weed species in the rotations. The chemical use strategies in PRISM are the local agronomist's recommendations, revised to a remove some minor internal inconsistencies. Due to the large number of possible combinations of chemicals, it appears infeasible to test the biological ramifications of choosing an alternate strategy. Three methods of application are represented; farmer applied spray, contractor applied spray, and tank mixed with another chemical. Repeated chemical use within one year is also allowed. Table 8 shows the chemical usage and costs associated with the Pasture-Pasture-Canola-Wheat rotation.

Fertilisers

A fertiliser maintenance budget is calculated for phosphorus. The fertiliser requirement balances the export of P due to grain sales, based on standard P concentrations in the grain. The pasture fertilisation rate is dependant on stock numbers, with an allowance of 1 kg of P per DSE per year. The pasture fertilisation rate allows for fixation of some phosphate into sparingly soluble forms in addition to product export.

Livestock

Four activities are based on the common enterprises in the Wagga Wagga area. These enterprises are similar to those used across southeastern Australia. They represent flocks of either; wethers, self-replacing merino ewes, first cross Border Leicester-Merino ewes, or second cross Border Leicester-Merino ewes. Costs and returns for each unit is calculated from typical numbers of followers, rams *etc.* for the ewe. Production estimates and costs and prices were based on Walker's (1993) review of livestock data for the Riverina and southwest slopes.

Figure 1 shows the standard liveweight curves for groups of animals of similar age and sex. The energy demand for the enterprise unit is the mean requirement for the flock. Requirements for each class are calculated from Equation 6, as previously used by Morrison *et al* (1986) in MIDAS.

$$ME_{req} = a + b.LW + c.LWC + d.LWC^2 \qquad \ldots(6)$$

where ME_{req} is the energy requirement per month (MJ/month/head), LW is the liveweight (kg/head) and LWC is the liveweight change per month (kg/head/month). To modify the metabolic energy requirements for maintenance and production allowing for environmental conditions, values of a, b, c, and d vary according to the time of year. Values of a are 0.0479 in the winter months and 0.39 otherwise. Similarly, values of b, c and d are 0.0141/0.0119, 0.125/0.1305 and 0.0094/0.0102 respectively. As above, these values are based on the MIDAS method of estimating metabolisable energy demand. While all ME requirements in PRISM are based on the standard liveweight curves, differences between breeds and enterprise management generate minor liveweight, fertility and other differences that need to be taken into account. This is achieved by adjusting the Me_{req} for the enterprise by the relative DSE (dry sheep equivalents) rating of the enterprise units. For example, the first cross prime lamb system is rated at 2.1 DSE while the second cross system equals 2.3 DSE.

Stubble and Grain Feeding

The metabolisable energy available from stubble is calculated separately for cereal and legume crops. It uses the harvest index, proportions of grain unharvested and spilt in the field, and the proportion of edible non-grain biomass. Default values for cereal stubble provide 30kg of grain and 540 kg of leaf for grazing per tonne of cereal grain produced. This is based on a harvest index of 0.38, and 2 and 1 percent of grain unharvested and spilt respectively. It is assumed that 33 percent of the unharvested biomass is leaf, and is therefore available and palatable to sheep, while the remaining 67 percent is unavailable due to poor palatability, grazing losses or other factors. The composition of lupin stubbles is based on a harvest index of 0.30, 90% of grain is harvested and 1% of harvested grain is spilt. The available metabolisable energy from cereal and legume stubbles is shown in Table 9. The high quality component of stubbles consists of unharvested and spilt grain, and the low quality component is leaf. Metabolisable energy from stubble and hay is available on an either/or basis between months The available energy decreases over time in stubbles due to weather damage, physiological changes, microbial attack and other effects. These affect both the quantity and quality of grain and leaf residues in the paddock The rate of quantity decline is typically 10% per month for both cereal and lupin stubbles The rate of decline in the ME content in cereal stubble is 10% per month, and in lupin stubble commences at 5% per month and rises to 20% per month late in the season.

Intake of stubble and hay is limited by its quality A linear relationship is assumed, ranging from zero intake at 2 MJ/kg to maximum intake at 12 MJ/kg Equation 7 shows the method of calculation of maximum intake per head of stubbles and hay

$$MI = 0.093 * LW^{0.73} \qquad ...(7)$$

where MI is the maximum intake (kg/head/day) and LW is the liveweight (kg./head). Therefore, a 45kg wether has a maximum intake of 1.5 kg, but is limited to an intake of 0.9 kg where the feed quality is 6 MJ/kg Adjustments are also made for pregnancy and lactation in females.

Machinery Costs

Although the machinery options are potentially complex, farmers' choices usually hinge on owning a tractor and header that allow timely sowing and harvesting operations. Late sowing and late harvest carry large economic penalties through grain yield reductions and weather damage to grain. Timeliness of sowing and harvest is most affected by the power output and reliability of the machines. The model allows selection from four models of tractor ranging from 64kW to 280 kW engine capacity. There are three header options, ranging from 92 to 198 kW. Some characteristics of these machines are shown in Table 10.

The costs of machinery are separated into three groups; operating, repairs and maintenance and depreciation. Depreciation is an overhead cost, and is detailed below. Fuel use associated with the headers and tractors operating various implements is calculated from the engine power output (kW), an efficiency rating (L/kW) and the percentage of maximum power used during operation (usually 75%). Oil costs are calculated from fuel costs (nominally 15%). The fuel price used ($0.35/L) is the price quoted for diesel at Wagga Wagga in January 1995, net of State and Federal government rebates. A working rate (hours/ha) allows calculation of costs per hectare of rotation.

Annual costs of repairs on all machines and implements are a percentage of the new value. For the implements the value chosen is 1.5% per annum, while for the tractor and header, the cost is 3% p.a.

Maintenance for tractors is itemised and total costs estimated from usage. Table 11 shows the maintenance schedule for a 129 kW tractor.

Labour

Labour requirements in PRISM are estimated only during the peak demand periods of sowing and harvesting. This is due to difficulties in estimating the total labour requirement on a monthly or bimonthly basis when jobs are of a low priority and easily deferred. Tree planting and road maintenance are typical of the many deferrable demands on labour. During harvest it is likely that labour is only committed to jobs with direct and significant economic impact The results in this study do not include any limitations on labour availability or the cost of labour It is assumed that sufficient unpaid labour is available during sowing and harvesting for the efficient operation of all enterprises This assumption will hold for most family-operated mixed farms in southern NSW

Overhead Costs

The cropping machinery portfolio of a farm is fixed in PRISM No attempt is made to optimise machinery selection. However, there are some differences in costs between crops and rotations allowed for in machinery and implement usage. Cropping overheads are calculated from the depreciation and interest costs of the tractor, header and implements The tractor and header are depreciated according to usage (hours), while implements are a fixed cost, depreciating over a working life (mostly nine years). Depreciation of all machinery is based on the difference between the new and salvage prices. Salvage prices of the tractor and header were set at 35% of the new price.

The opportunity cost of capital investment in machinery iscalculated on a variable interest rate. The annual rate of 10.5% is based on a fixed term deposit of $50,000 for 5 years, quoted in Wagga Wagga in January 1995. Separate interest rates are used in the calculation of the credit costs of an overdraft for operating expenses.

Overhead costs in the livestock enterprises are based on the shearing and handling capacity of various infrastucture options. Three levels of capacity are represented in PRISM; plant, shearing stands and yards to handle up to 400 sheep, 401 to 2,000 sheep or 2,001 to 12,000 sheep. Total costs and the types of units involved are, respectively, a $9,000 portable unit, a $43,000 three stand shed and yards, and an $82,000 five stand shed and yards. Depreciation, opportunity cost of capital and insurance are included in annual overhead costs. It is assumed here that owner-financed replacement of the equipment will occur on a period of approximately 20 years, so a depreciation rate of 5% is applied. Opportunity costs of capital are calculated in the same way as for cropping equipment, above. The total overhead costs (depreciation + opportunity) per sheep for the three units are \$3.84, \$3.26 and \$1.54 respectively, when used at full capacity. PRISM optimises livestock overhead capacity in each solution.

Cashflow and finance

Bimonthly cashflow is calculated. Where cashflow is positive, additional returns are achieved, based on the available rates for short-term deposits in January 1995 (6% p.a.). Negative cashflow attracts a cost based on overdraft rates (12% p.a.). The finance activities are essentially the same as those used in MIDAS (Morrison *et al.* 1986)

Results

Table 12 shows some operating costs and grain yields for the various rotations. There is clearly a degree of complexity of the patterns in grain yield through the various rotations. Some short rotations have high grain yields, but produce a limited range of grains, and they generally incur high herbicide and pesticide costs, as pastures have low variable costs compared with crops.

Annual tractor and header depreciation costs ranged from \$8.75/ha/year for the cheapest rotation (PPCaW) to \$13.88/ha/year for the most expensive (PPPWLW). Depreciation of implements cost \$6.92/ha/year and the opportunity cost of this capital was \$6.79/ha/year. Opportunity costs for the 106 kW tractor and 110 kW header are \$7.23/ha/year and \$13.03/ha/year respectively. These figures agree with local approximations of \$50/ha/year total machinery depreciation and opportunity cost (Wall pers. comm.). Our figures range from \$42.72/ha/year to \$47.85/ha/year.

There are large differences in the annual cost of the pest control strategies between the rotations. The lowest costs were less than \$15/ha/year to more than \$35/ha/year. This is primarily due to the influences of crop sequence on the types and density of weed species present. Some important weeds are readily controlled by strategic use of selective chemicals in alternating cereal and broadleaf crops, especially when highly competitive varieties are used. Pastures also help in the control of important weed species.

The optimum under standard conditions

Table 13 summarises the results. The maximum value of the objective function is \$137, 000. Two short-term, cropping oriented rotations were selected; 825ha of PPCaW and 175ha of PPCaWB. The shadow costs of alternative rotations, shown in Table 14, indicate that rotations such as PPWLW, PPPCaWLW and

PPPPCaWLW(W,Bor O) are also highly profitable Grain production and sales are dominated by wheat and canola. The wheat yield is much lower (2.51 t/ha/year) than in other rotations, but the profitability of canola more than compensates for this

The optimum livestock system consists of 3130 second cross ewes The effective stocking rate is 14.9 DSE/ha This is high by local standards, where the usual range is 9 to 12 DSE/ha for good quality annual pastures. It also slightly exceeds a rule of thumb that says that the relationship between pasture production and practical stocking rates is 0.5t/ha/year/DSE. The gross margins and shadow costs of the alternative livestock enterprises are shown in Table 15. This table shows that the shadow prices reflect neither the gross margin per unit nor the gross margin per DSE. For example, the shadow cost of a first cross ewe is $1.88, or $0.90/DSE, while the difference in the gross margin is $0.63/DSE In the case of merino wethers, the shadow cost is 94% greater than the difference in gross margin per DSE ($0.62 *vs.* $1.20).

Pasture hay is made in large, round bales A total of 450 bales, or 220 tonnes, of hay made and fed, equal to 70 kg per ewe or 31 kg/DSE. Also, 53 tonnes of barley, produced in the PPCaWB rotation, is fed over the summer months. The area of this rotation is determined by the animal feed requirements, as no barley is sold, and the small difference between production and feeding (about 1.5 t) is the seed requirement for re-sowing the 35 ha crop on an annual basis.

Sensitivity to changes in critical values:

(i) grain yields

The TE figures for each crop were decreased by 4 kg/ha/mm transpiration. Poor crop management can result in reductions in TEs of at least this order, as indicated in the results of Connor *et al.* (1992) for late sown wheat crops. The optimal sytem under these conditions is summarised in Table 13 under Low TE.

There are some extraordinary results from this change. The objective function declined by $41,000, or 34%. The area of canola declined drammatically, from 241 ha to 29 ha. Apparently, at the new, low yield of 1.43 t/ha/year, canola is less profitable than wheat in a high yielding rotation. In spite of the reduction in potential yields of all crops, the actual yield of wheat increased to 2.66 t/ha, through the selection of a pasture-wheat-lupins-wheat rotation. Wheat grown after pasture and wheat-lupins have higher relative yields than wheat after pasture-canola (70% *vs.* 86 and 72% of potential, not allowing for undersowing effects).

Livestock numbers were reduced under low TE conditions, though the effective stocking rate (15.1 DSE/ha) remained similar to the standard (14.9 DSE/ha), due to reductions in pasture area. Not surprisingly, there were small reductions in the quantities of hay and grain fed to livestock.

(ii) pasture growth rates

The effect of varying potential growth rates was investigated by optimising with the data based on Reeve and Sharkey (1980) and Wolfe and Southwood (1980). The results are sumarised in Table 22 under R & S pasture and W & S pasture. The R&S simulation used the standard 100 kg/ha/month for the December to March period, as Reeve and Sharkey (1980) did not report growth over this period.

The solution for R&S pasture growth rates (high) is very similar to the standard solution in most respects. The major change was a large reduction in haymaking. This result reflects the limitations on stocking rate imposed by the annual cycle in feed availability, including the availability and profitability of stubble and grain feeding options for the summer-autumn period.

The W&S pasture (low) solution was very different from standard. Livestock numbers were reduced by 1720 ewes, or 55%. The effective stocking rate was only 7.5 DSE/ha, and the quantities of grain and hay fed decreased significantly. The decrease in pasture profitability (per ha) gives advantage to the lupins-wheat and pasture-wheat rotations, and the wheat yield increased for the reasons described above for these rotations.

(iii) haymaking

Haymaking is normally included in solutions. The effect of removing the haymaking option was investigated by removing the costs and benefits of haymaking from the LP matrix. The results of this change are shown in Table 13.

Removing the costs and benefits associated with haymaking increased the objective to $140, 000, partly due to the costs savings available through less investment in machinery. This comparison is a little unrealistic, as ownership of haymaking equipment is virtually universal. The benefits of haymaking in terms of climate and financial risk are likely reasons for farmer's commitment to haymaking under average year conditions.

There was a switch to cropping under these conditions. Not only was the pasture area reduced, but the stocking rate fell to 10.5 DSE/ha (or 30%). The total quantity of stubble fed to livestock increased moderately (from 51 to 72 kg/DSE), while grain feeding increased substantially (doubling). This indicates that the alternative grazing strategy of either utilising more stubble is less profitable than grain feeding. Given the availability of crop stubbles, this is somewhat surprising, though as the proportion of potential stubble utilisation increases, the quality decreases. Also, by late summer the yield and quality penalties applied to stubbles have reduced their availability and quality to relatiely low levels.

The increase in the area, and yield, of barley in this system is proportional to the increase in the demand of livestock for grain. Again, the wheat-lupins-wheat rotations result in higher wheat yields, a greater area of wheat, and a reduction (37%) in the area of canola.

Discussion

How reasonable are these results?

Unfortunately, each of the solutions for a set of conditions may be accompanied by a group of sub-optimal, but relatively desirable alternatives. The mathematical programming methods used in PRISM can only hint at the alternatives, mainly through analysis of the shadow costs. Given this limitation, however, there appears to be no major flaws in the modelled results given above. In particular, the sensitivity of the model to changes in key data revealed the responsiveness and adaptability of the model. Although it seems impossible to test the accuracy of the gross output from the model, the strategies selected for the various sets of conditions were unable to be faulted from a theoretical point of view.

What are the potential applications of PRISM in its current form?

The results indicate that the model, and probably the profitability of the farming systems on the Red Earths, are sensitive to factors such as; decreases in total quantity and seasonal distribution of pasture yield, and the potential yields of crops as determined by their transpiration efficiency. Conversely, there was little response in profit to increased pasture yields and elimination of haymaking.

Two quite different types of rotation strategies are within small margins of each other in terms of profit. In broad terms, one relies on large returns from canola and a modest return from wheat, while the other relies on a large return from wheat and a modest return from lupins. There is great potential for the model to highlight trade-offs like this in the farming systems. This analysis appears to be the first to reveal these relationships.

What are the improvements needed to widen the applicability?

Some relatively common activities and enterprises on farms on the Red Earths include; lucerne-based perennial pastures and beef cattle growing and fattening. There is no reason why lucerne-based rotations and enterprise-based beef production activities cannot be included in PRISM to widen its applicability. Also, to the south of Wagga Wagga in areas around Albury and Rutherglen, it is common for farms to include an area of less fertile podzolic, or grey duplex soils. These are often acidic, sometimes to depth, and have a much more limited range of cropping options than the Red Earths Ideally, to be used in this area, a version of PRISM for these soils would separately represent the areas and activities of these two soils.

To increase the realism of the model's representation of livestock management, the sheep enterprise activities could be segregated into animal class-based activities. This would allow the flock structure to vary, and solutions would offer management changes within the livestock enterprises. The solution might, for example, offer a strategy for avoiding low prices for cull-for-age ewes or maximise the benefits from high prices for light lambs.

Risk and sustainability

It is also an unfortunate fact that although multiple goals, such as minimising riskiness and maximising sustainability, are necessary to succeed in farm management, profitability is the most readily quantified objective, and the focus of most effort in mathematical programming models.

Conclusion

Is it useful? Will PRISM or other models be used to affect farm management?

This may be addressed by asking; Where are the simple computer-based tools that were passed over by most agricultural economists in the 1960s? Although they have disappeared many years ago, as predicted by the harbingers of doom, they have evolved into the excellent tools that are in wide use today, such as enterprise budgets on spreadsheets. Cases of radical conservatism abound in the economic, as well as scientific literature (eg Gloom and doom in ???, Rev. Market and Ag Econ., Hardaker and Anderson).

Although it has been argued that farm management tools have delivered bugger all in the fifty yearsto 1990, (Malcolm 1990) there is little evidence that they will not deliver major benefits in the 1990s and beyond. In fact, it may be that a considerable time is required for adoption and thoughtful implementation, and perhaps even for generational change to occur, before tools such as mathematical programming are used without reference to their usefulness. PRISM seems well positioned to answer meaningful questions about farming systems in the 1990s.

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Table 1. Climate, soils and crop yield data affording a simple comparison of mixed farms at two loactions in the southwestern and southeastern cropping regions of Australia. Climate data from the Bureau of Meteorology (1988)

Factor		Merredin West Australia	Wagga Wagga New South Wales
Location (latitude longitude)		31° 31'S 118° 12'E	35° 15'S 147° 20'E
Annual rainfall (mean, mm)		309	570
Growing season rainfall[1] (mean, mm)		253	321
Evaporation (Class A pan, mm)	April	175	120
	July	80	40
	October	230	200
Soil types		Yellow loamy sands, red-brown loams, clay loams	Red loams, red-brown loams
Pasture production (dry matter t/ha/year)[2]		3.5	6.0
Crop yield range (t/ha/year)			
cereals		1.0-2.0	1.5-3.5
legumes		0.5-1.0	1.0-2.0
oilseeds		0.5-1.2	1.2-1.8

[1]The growing season is April to October, based on annual C_3 metabolism species
[2]Data from MIDAS (Morrison *et al.* 1986) and Wolfe and Southwood (1980)

Table 2. A summary of the linear programming matrix, showing the sub-matrix structures. Return (+/-) indicates whether activities generate (+) or consume (-) capital. Constraint names are shown on the left and their formulas are shown on the right hand side (RHS). Supply and demand, and transfer in time of various farm commodities are shown as S, D and T coefficients respectively. The usual goal is to maximise the sum of the returns

Activity	Rotations	Grain sales	Grain feeding	Grain sowing	Fertiliser use	Stubble grazing	Pasture deferal	Make hay	Feed hay	Live-stock	Interest on cash[1]	RHS
Return	-	+	-		-	-	-	-	-	+	+/-	
Constraint	(ha)	(t)	(t)		(t)	(t)	(t)	(bales)	(bales)	(head)	($)	
Land area (ha)	D											∑D=1000
Grain balance (t)	S	D	D	D		S						∑S>=∑D
Nutrient balance (kg)		D	D		S					D		∑S>=∑D
Feed balance (MJ/month)	S		S			S/T	T	D	S	D		∑S>=∑D
Cash balance ($/month)	D	S	D	D	D	D	D	D	D	S	S/D	

[1]Interest is earned and payed when cashflow is positive and negative, respectively.

Table 3 Crop water use efficiency (WUE, kg grain/mm growing season rainfall) and transpiration efficiency (TE, kg grain/mm transpiration) data used to estimate the TE of barley, oats, canola and lupin crops grown near Wagga Wagga

Crop	WUE[1] kg/ha/mm	WUE[2] kg/ha/mm	TE[3] kg/ha/mm	standard TE in PRISM kg/ha/mm
Wheat	14	15 7	24	24
Barley	17			29
Oats (grain)		14 8		23
Canola	7 5	9 0		14
Lupins	9 5	8 3		16

[1] Data from Mead (1992)

[2] Data from Butler and Laycock (1994)

[3] Estimated from the data of Doyle and Fischer (1979), Connor *et al* (1992) and Huda (1994)

Table 4 Standard values for growing season rainfall (GSR[1]) and transpiration (T) and transpiration efficiency (TE) for various crops

Crop	GSR (mm)	GSR[2] losses (mm)	Transpiration (mm)	Transpiration efficiency (TE) (kg/ha/mm)
Wheat	340	170	190	24
Canola	340	170	170	14
Barley	310	170	140	29
Lupins	340	205	135	16
Oats (grain)	300	130	170	23
Oats (grazing+grain)	320	120	200	16

[1] Median precipitation during the crop's growing season (mm) For wheat, this is the median rainfall at Wagga Wagga from 1 May to 15 November As anthesis and harvest in barley is typically two weeks earlier than wheat, barley's growing season ends 1 November Oats may be sown earlier than wheat (up to eight weeks, typically two weeks), and the growing season is 15 April to 15 November

[2] GSR losses are increased 20% for lupins due to extra early season soil evaporation associated with low leaf area indices GSR losses for oats are lower due to rapid soil coverage.

Table 5 Crop site potential, growth index and actual yield data for a range of paddock histories[1]

Crop	Paddock history	Potential yield t/ha/year	Weed and disease index	Nitrogen index	Actual yield t/ha/year	Undersowing index	Yield if undersown t/ha/year
Canola	PP	**2.94**	0.90	0.75	**1.98**	-	-
	PW	**2.94**	0.80	0.50	**1.18**	-	-
Lupins	PW	**2.72**	0.90	0.90	**2.20**	0.25	1.65
	PP	**2.72**	0.95	0.95	**2.45**	0.25	1.84
	PO	**2.72**	0.90	0.90	**2.20**	0.25	1.65
	WW	**2.72**	0.85	0.80	**1.85**	0.25	1.39
	CaW	**2.72**	0.90	0.80	**1.96**	0.25	1.47
Barley	WW	**4.06**	0.60	0.60	**1.46**	0.25	1.10
	LW	**4.06**	0.80	0.75	**2.44**	0.25	1.83
	CaW	**4.06**	0.85	0.60	**2.07**	0.25	1.55
Oats (grain)	PP	**3.91**	0.90	1.00	**3.52**	0.25	2.64
	PW	**3.91**	0.80	0.80	**2.50**	0.25	1.88
	CaW	**3.91**	0.70	0.70	**1.92**	0.25	1.44
	LW	**3.91**	0.80	0.80	**2.50**	0.25	1.88
	WW	**3.91**	0.65	0.65	**1.65**	0.25	1.24
Oats	PP	**3.20**	0.90	1.00	**2.88**	0.25	2.16
(graze/grain)	PW	**3.20**	0.80	0.80	**2.05**	0.25	1.54
	CaW	**3.20**	0.70	0.70	**1.57**	0.25	1.18
	LW	**3.20**	0.80	0.80	**2.05**	0.25	1.54
	WW	**3.20**	0.65	0.65	**1.35**	0.25	1.01
Wheat	CaW	**4.56**	0.85	0.50	**1.94**	0.25	1.45
	PCa	**4.56**	1.00	0.70	**3.19**	0.25	2.39
	PO	**4.56**	0.90	0.75	**3.08**	0.25	2.31
	PP	**4.56**	0.90	0.95	**3.90**	0.25	2.92
	PW	**4.56**	0.80	0.70	**2.55**	0.25	1.92
	WL	**4.56**	0.80	0.90	**3.28**	0.25	2.46
	WO	**4.56**	0.65	0.55	**1.63**	0.25	1.22
	WW	**4.56**	0.50	0.50	**1.14**	0.25	0.86
	PL	**4.56**	0.95	0.95	**4.12**	0.25	3.09
	LW	**4.56**	0.80	0.70	**2.55**	0.25	1.92
	OL	**4.56**	0.90	0.80	**3.28**	0.25	2.46

[1] Crop history refers to the previous two years of the rotation, where the following annual options are indicated: P=pasture, Ca=canola, W=wheat, O=oats, L=lupins, B=barley

- Not applicable as canola is never undersown

Table 6 PRISM standard pasture growth rates and estimates based on data from various sources

Month	Growth rates (kg/ha/month)				
	Standard	Stockdale 1983	Collins *et al* 1983	Reeve and Sharkey 1980	Wolfe and Southwood 1980*
Jan	100	160	-	-	60
Feb	100	160	-	-	70
Mar	100	160	-	-	60
Apr	100	160	-	800	140
May	400	450	700	900	200
Jun	600	900	700	700	300
Jul	400	900	600	300	200
Aug	700	1500	1200	500	400
Sep	1500	1500	2000	1700	800
Oct	1500	1200	-	2500	1000
Nov	100	160	-	750	100
Dec	100	160	-	-	70
Total (t/ha/year)	5 7	7 4	5 0 +	8 15 +	3 4 +

* Wolfe and Southwood (1980) gave seasonal totals for a mixed lucerne/clover pasture Lucerne production was excluded and the intra-seasonal distribution infered from other data

Table 7 Some of the pasture and crop rotations evaluated in PRISM.

Number	Acronym	Features
2	PPOW	Short rotation Oats reduce grass weed incidence and provide autumn grazing
3	PPWW	Short version of traditional rotation of subterranean clover pasture with wheat rotation.
12	PPPOW	As for PPOW, but with more grazing potential.
14	PPPCaWW	Uses canola to reduce grass weed incidence in the subsequent wheat crops and provide high value grain
15	PPPWLW	Lupin crop improves weed control for subsequent wheat crop and increases nitrogen availability
16	PPPWOW	As for PPOW, but longer cropping phase.
17	PPPWWW	Traditional pasture-wheat rotation.
21	PPPWLWB	As for PPPWLW, but with an extra barley crop. Barley is grown in situations with low nitrogen availability.
23	PPPCaWLW	As for PPPCaWW, and extends cropping phase with lupins to increase nitrogen availability and grass weed control
36	PPPCaWLWB	Maximum length of cropping phase. Barley is grown in situations with low nitrogen availability.

Table 8 An example of the chemical usage and costs associated with a rotation. The defaults for the pasture-pasture-canola-wheat rotation (rotation 1) are shown

Rotation	Crop/ pasture	Spray	Rate[1]	n[2]	Method[3]	Cost ($/ha)	Spray	Rate	n	Method	Cost ($/ha)
PPCaW	Pasture	Roundup	0.35	1	f	$5.80	Lemat	0.05	1	f	$1.60
	Pasture	Roundup	1.00	1	f	$14.25	Lemat	0.05	1	f	$1.60
	Canola	Fusilade	0.25	1	f	$19.25	Endosulphan	0.50	1	f	$4.75
		Lontrel	0.30	1	f	$13.85					
		Trifluarin	2.00	1	f	$15.25					
	Wheat	Roundup	0.50	1	f	$7.75					

[1] Rates are in L or g of product per hectare of crop or pasture
[2] n = number of applications per year
[3] f= farmer application, cost = $1.25/ha
c=contractor, cost = $5.00/ha
i=incoporated in another costed spray (at no cost).

Table 9 Available metabolisable energy from cereal and legume stubbles per tonne of grain harvested basis.

Feed period	Cereals		Legumes	
	High quality	Low quality	High quality	Low quality
	Available energy (MJ/month/tonne)		Available energy (MJ/month/tonne)	
January	292	1980	607	1980
February	250	1693	519	1604
March	214	1447	421	1299
April	183	1238	303	935

Table 10 Tractor and header options (data from Anon 1994).

	Option			
Tractors	1	2	3	4
Engine power output (kW)	63	82	106	146
New price ($)	61,000	81,000	102,000	115,000
Headers				
Engine power output (kW)	92	110	198	
New price ($)	117,800	183,900	194,900	

Table 11. Standard maintenance costs for a 129 kW tractor

Item	Application	Number required per annum	Cost per unit $	Expected life hours
Filters	Air - inner	1	68	500
	Air - outer	1	57	500
	Fuel	1	34	500
	Hydraulic oil	1	81	1000
	Engine oil	1	13	250
	Trans. oil	1	52	1000
	Transmission	1	22	1000
Tyres	Large	2	990	3500
	Small	2	220	3500
Tubes	Large	2	135	6000
	Small	2	25	6000
Batteries		2	140	2400

Table 12. The 37 PRISM rotations and some of their annual costs and grain yields. The dashed lines separate rotations with 2, 3 and 4 year pasture phases in the rotation.

Rotation	Herbicide and pesticide costs $/ha/year	Machinery operating costs $/ha/year	Grain yields (t/ha/year)					
			Wheat	Barley	Oats grain	Oats grazing + grain	Canola	Lupins
PPCaW	21.03	15.12	0.60				0.50	
PPOW	25.82	15.84	0.58		0.88	0.72		
PPWW	27.59	15.84	1.45					
PPWO	23.36	15.84	0.97		0.47	0.30		
PPCaWW	25.16	16.81	0.93				0.40	
PPCaWB	25.16	16.81	0.64	0.31			0.40	
PPWLW	26.55	15.51	1.27					0.44
PPWOW	21.99	17.38	1.02		0.50	0.41		
PPOLW	23.55	15.51	0.49		0.70	0.58		0.44
PPWWW	22.08	14.53	1.16					
PPPCaW	16.82	13.96	0.48				0.40	
PPPOW	20.66	14.53	0.46		0.70	0.58		
PPPWO	22.58	14.53	0.78		0.38	0.31		
PPPCaWW	20.97	15.55	0.77				0.33	
PPPWLW	24.12	14.47	1.06					0.37
PPPWOW	18.32	16.03	0.85		0.42	0.34		
PPPWWW	36.87	16.03	1.22					
PPPCaWB	24.33	15.55	0.53	0.26			0.33	
PPPCaWO	22.15	15.55	0.53		0.24	0.20	0.33	
PPPOLW	19.63	14.47	0.41		0.59	0.48		0.37
PPPWLWB	25.7	15.77	1.03	0.26				0.31
PPPWLWO	25.35	15.77	1.03		0.27	0.22		0.31
PPPCaWLW	19.79	15.36	0.81				0.28	0.28
PPPOLWB	16.53	15.77	0.47	0.26	0.50	0.41		0.31
PPPOLWO	16.53	15.77	0.47		0.77	0.63		0.31
PPPPWLW	21.74	14.2	0.91					0.31
PPPPCaWB	17.97	14.88	0.46	0.22			0.28	
PPPPCaWO	14.44	14.88	0.46		0.21	0.17	0.28	
PPPPOLW	16.82	14.2	0.35		0.50	0.41		0.31
PPPPWLWB	22.49	14.95	0.90	0.23				0.28
PPPPWLWO	22.49	14.95	0.90		0.23	0.19		0.28
PPPPCaWLW	17.29	14.6	0.71				0.25	0.24
PPPPOLWB	14.46	14.95	0.41	0.23	0.44	0.36		0.28
PPPPOLWO	14.46	14.95	0.41		0.67	0.55		0.28
PPPPCaWLWW	16.82	15.52	0.93				0.22	0.22
PPPPCaWLWB	16.82	15.52	0.72	0.20			0.22	0.22
PPPPCaWLWO	16.82	15.52	0.72		0.21	0.17	0.22	0.22

Table 13 Summaries of the optima selected under a range of conditions.

Variable	Units	Conditions of optimisation				
		Standard	Low TE	Nil hay	R&S pasture	W&S pasture
Objective	$1000	137	90	140[1]	137	115
Pasture area	ha	482	410	423	483	428
Wheat area (yield)	ha (t/ha)	241 (2.51)	353 (2.66)	270 (2.85)	241 (2.51)	284 (2.80)
Oats area (yield)	ha (t/ha)	-	-	-	-	-
Barley area (yield)	ha (t/ha)	35 (1.55)	29 (1.59)	44 (1.58)	34 (1.55)	14 (1.55)
Canola area (yield)	ha (t/ha)	241 (1.98)	29 (1.43)	153 (2.01)	241 (1.98)	144 (2.02)
Lupin area (yield)	ha (t/ha)	-	176 (1.62)	110 (2.00)	-	131 (2.00)
Grain fed	t	53	44	67	52	20
Hay fed	bales[2]	450	390	-	200	110
Stubble grazed	t	374	363	322	329	233
Wethers	head	-	-	-	-	-
SR Merino ewes	units[3]	-	-	-	-	-
First X ewes	units	-	-	-	-	-
Second X ewes	units	3130	2700	1940	3090	1410

[1] higher than standard due to savings from not owning haymaking eqipment.
[2] large round bales (approx. 490 kg of dry matter) were chosen each time.
[3] a unit is a breeding ewe and her followers and associated stock (eg. rams).

Table 14 Shadow costs ($/ha) for alternative rotations, from the standard solution.

Rotation	Shadow cost	Rotation	Shadow cost	Rotation	Shadow cost
PPCaW	-	PPPWO	$40	PPPOLWO	$8
PPOW	$23	PPPCaWW	$21	PPPPWLW	$31
PPWW	$30	PPPWLW	$21	PPPPCaWB	$25
PPWO	$23	PPPWOW	$40	PPPPCaWO	$25
PPCaWW	$8	PPPWWW	$68	PPPPOLW	$30
PPCaWB	-	PPPCaWB	$16	PPPPWLWB	$20
PPWLW	$5	PPPCaWO	$19	PPPPWLWO	$22
PPWOW	$31	PPPOLW	$21	PPPPCaWLW	$11
PPOLW	$8	PPPWLWB	$11	PPPPOLWB	$16
PPPWW	$41	PPPWLWO	$12	PPPPOLWO	$18
PPPCaW	$17	PPPCaWLW	$0	PPPPCaWLWW	$4
PPPOW	$36	PPPOLWB	$6	PPPPCaWLWB	$2
				PPPPCaWLWO	$3

Table 15. shadow costs for livestock enterprises, from the standard solution.

Sheep enterprise		Gross margin/unit $/ewe	Gross margin/DSE $/DSE	Shadow cost $/unit
SR Merino Ewes		$26.60	$12.67	$1.43
Merino Wethers		$14 08	$12.80	$1.32
First-X Ewes		$26.87	$12.79	$1.88
Second-X Ewes	3130	$30.87	$13.42	

FIGURES

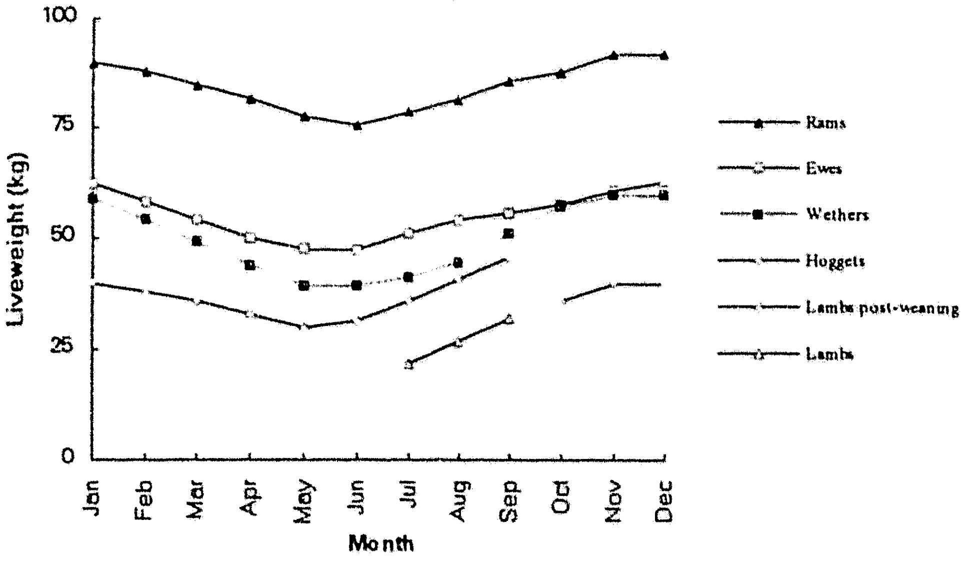

Figure 1. Liveweight curves for the major groupings of livestock in the PRISM model.

APPENDIX 1. Details of the mathematical programming matrix in the PRISM model .

Table A 1 A summary of the constraints in the PRISM farm model

Constrain name	units	Purpose
Total area	ha	To set the farm size
Total DSEs	head	For estimating effective stocking rate
Sheep numbers	head	For estimating overhead costs (e.g. shearing shed)
Sheep overhead systems	number	To limit farm to one set of overheads (ie sheds, *etc.*)
Crop area	ha	To count and/or limit the arable area.
Pasture area	ha	To count and/or limit the pasture area.
Barley area	ha	To count and/or limit the crop area.
Canola area	ha	"
Lupin area	ha	"
Oats area	ha	"
Wheat area	ha	"
Barley production, sales *etc*	tonnes	To balance crop production, usage and sales.
Canola production, sales *etc*	tonnes	"
Lupins production, sales *etc*	tonnes	"
Oats production, sales *etc*	tonnes	"
Wheat production, sales *etc*	tonnes	"
Hay making and usage[1]	bales	To balance hay making and usage.
P requirements and purchases	kg P	To balance P requirement and supply.
N application	kg N	Not used in this version.
January - December feed[2]	MJ/month	To balance animals' metabolisable energy requirements.
Cereal stubble - high	kg	To balance supply and demand of stubble.
Cereal stubble - low	kg	"
Lupin stubble - high	kg	"
Lupin stubble - low	kg	"
Jan stubble intake restriction	kg/month	To limit the intake of low quality feed.
Feb stubble intake restriction	kg/month	"
Mar stubble intake restriction	kg/month	"
Apr stubble intake restriction	kg/month	"
Seed requirement[3]	kg	To provide for seed to be sown.
Overdraft limit	$	To set a maximum overdraft.
Labour supply and usage[2]	hours/month	Not used in this version.
Cashflow[4] Jan-Feb to Nov-Dec	$/2 months	To estimate and/or limit cashflow.
Herbicide and pesticide costs	$	To estimate and/or limit input costs.
Fertiliser (P) costs	$	"
Cropping machinery overhead costs	$	To estimate cropping machinery overheads.
Haymaking machinery overhead costs	$	To estimate maymaking overheads.
Total income/cost	$	To estimate totals and solve matrix.

[1] Hay bales are made in three sizes (= three constraints).
[2] Calulated separately for each month (= twelve constraints).
[3] Calculated separately for wheat, barley, oats, canola and lupins (= six constraints).
[4] Calculated on a bi-monthly basis (= six constraints).

Table A 2 A summary of the activities in the PRISM farm model

Activity type	Units	Number	Typical activity represented
Rotate pastures and crops on land	ha	37	Grow Pasture-Pasture-Pasture-Canola-Wheat-Barley in sequence
Fertilise crops and pastures	tonnes	3	Apply superphosphate
Sell grain	tonne	5	Sell wheat to the Wheat Board
Provide seed to sow crop	tonne	5	Provide seed to sow wheat crop
Defer pasture grazing	ha	6	Defer grazing pasture from September to October
Graze crop stubles with sheep	tonne	18	Graze low quality wheat stubble in February.
Feed grain to sheep	tonne	12	Feed barley in March.
Livestock enterprises	head	4	Run a Merino cross ewe and followers[1]
Livestock overheads	na[2]	4	A three stand shearing shed, yards and gear.
Finance	$	12	Fund March-April cashflow from overdraft.
Labour	hours	4	Employ casual assistant at harvest[3]
Haymaking	bales	9	Make round bales in October
Feeding out hay	bales	15	Feed out small bales in April.

[1] Enterprises are based on the breeding unit (eg. a breeding ewe has 0 03 rams built into costs and returns).
[2] Livestock overheads include sheads, yards, shearing machinery *etc*
[3]Not used in this version of PRISM