Integrating Economic Data with Spatial Biophysical Data to Analyse Profitability and Risks of Wheat Production on a Regional Basis

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(Received 24 July 1995; accepted 24 January 1997)

ABSTRACT

Production risks are an important factor in agricultural land use decision making due to the relative uncertainty associated with climatic variability, enterprise performance, and market returns. Profitability and risks of wheat production on the Canterbury Plains are related to variability in climatic, production, and economic factors. A spreadsheet-based risk analysis program (@RISK) was used to integrate data sets within a risk framework for wheat production. This is shown to be an effective tool for evaluating alternative management practices in relation to profitability and risk. Autumn sowing and irrigation were found to improve predicted economic returns whilst reducing risk when compared to commonly practised spring sowing of wheat under dryland conditions. Spring sowing is reliant on irrigation to reduce risk. Predictions that autumn-sown wheat under dryland conditions will achieve similar yields to irrigated spring-sown wheat indicate that increasing the proportion of autumn-sown wheat would promote more efficient use of scarce water resources. A geographic information System was used to identify and represent visually the spatial distribution of variability in wheat yields and the risk to economic returns. The authors foresee future application of these techniques to sustainable resource management issues because the integration of climate, soils, water balance, and land use performance data sets within a quantitative framework that accounts for social, economic, and environmental effects through time and space is central to resource management decision making. © 1997 Published by Elsevier Science Ltd
INTRODUCTION

Resource management legislation reform in New Zealand has placed increased weighting on sustainability of land use, including ecological, social, and economic dimensions of land use. Traditional land evaluation which assesses the suitability of land resources for specific land uses is rendered inadequate by the reformed legislation. Methods are now needed to integrate biophysical data sets with climatic, agronomic, and economic data sets. Integration can be achieved through crop yield models and risk simulation techniques being spatially integrated with climatic and land resource databases through a geographic information system (GIS). This paper reports on initial application of these techniques to wheat production on the Canterbury Plains. The Canterbury Plains, in the South Island of New Zealand, produce 55% of New Zealand's wheat production (Barr, 1985). Average wheat yield for the area is 3.5 tonnes/ha (Logan, 1985), well below the potential of 6.0 to 8.5 tonnes/ha. (P. D. Jamieson, personal communication, A. Davoren, personal communication). Suboptimal yields reflect effects of soil properties (e.g. water holding capacity, drainage, nutrients, and slope), climate (e.g. rainfall, evaporation), pest and disease, and inappropriate crop management. A major factor influencing wheat yield on the Plains is soil moisture deficit (SMD) in the later stages of the growing season (Wilson, 1985). The magnitude of SMD and its impact on wheat yield varies, both spatially and temporally, in response to soil, climatic, and management factors (Webb et al., 1985; Wilson, 1985).

In the past, land evaluation in New Zealand has been limited to physical land evaluations where the performance of specific land uses were assessed in terms of constraints imposed by the land. As pointed out by Dumanski and Onofrei (1989) such evaluations have been useful in identifying and comparing potential land use alternatives and for broad, regional land use planning. However, the outputs of these evaluations are static snap shot comparisons of different land uses, reflecting long-term average performance. If land evaluation is to provide a valid index of both suitability and sustainability of crop production, it will have to incorporate information on production risks that are crucial to the survival of many agricultural enterprises.

The New Zealand Resource Management Act 1991 (RMA) has created a requirement to include social, economic, and ecological dimensions of sustainability in resource management decision making. The lack of integration of social, economic, and biophysical data has been recognised as a major limitation in land use planning (Stomph et al., 1994); such integration will be needed for decision making under the RMA. Even with increased quantification of the biophysical attributes (van Diepen et al., 1991), these have not been integrated with economic and biophysical data sets, due to the fact that
Enterprise performance and the risks associated with competing land uses have not been considered to date (Smith and Capelin, 1984).

Land users face uncertain outcomes where climatic events, markets, and inputs are variable and result in a range of expected yields and net returns. Methods of representing risk and uncertainty have been reviewed (Newman et al., 1990). Most techniques involve intensive calculations which require large data sets and are costly (Johnson and Cramb, 1991). Recent developments in simulation modelling have reduced data requirements and the associated costs of risk simulation modelling. Sources of risk for wheat production have been categorised into business risk (production and price variability and financial risks), the risk to residual farm incomes, and the ability to service financial commitments (Newman et al., 1990). In a study of arable farmers in Canterbury (Martin, 1993), 42% rated production and price variability as being either large or very large in a risk scaling task. Changes in product prices and rainfall variability were ranked as the most important sources of risk. Although these sources of risk were considered to be most important, farmers perceived few opportunities to manage them (Newman et al., 1990). To formulate recommendations for investment in crop production (such as irrigation), there is a need to provide land users with an analysis of the economic risks associated with the enterprise, and management options to minimise risks.

Crop models predict yields that can be used to link the biophysical and economic data sets and to perform land evaluations that include spatial and temporal variation in crop performance (Dumanski and Onofrei, 1989). Most crop yield models have been developed and validated at point locations (Wilson, 1985). Their use at a regional scale is constrained by the need to collect quantitative input data at many locations and the need to validate models under a range of environmental and management conditions. These constraints have limited the application of crop yield models using GIS (Johnson and Cramb, 1991; Johnston, 1989). Dumanski and Onofrei (1989) alleviated this constraint by simplifying a mechanistic crop growth model to include only those processes that were critical to variations in yield. In this paper we use a simple wheat yield prediction model that adjusts maximum potential yield according to a single variable (the risk and degree of soil moisture deficits). Soil moisture deficits were derived from a water balance model and a spatial database of soil water storage characteristics (Barringer et al., 1995). The predicted yield is then used to develop an economic model of the expected gross margin for a range of management options.

GIS technology provides an effective tool to store, combine, process, and retrieve information on a spatial dimension. One of the primary uses of GIS is the combination and evaluation of disparate data layers from which new layers can be derived. GIS is used to combine soil and climate layers and to
display the output from the crop yield model and the economic models. The mean expected yields and returns can also be displayed in probabilistic terms to represent the risks associated with particular land uses.

This paper describes a method for integrating economic and biophysical data sets quantitatively in a manner that incorporates the uncertainty and risks associated with a single land use.

The method consists of the following steps:

1. Assess the spatial variation in mean wheat yield, resulting from spatial variability in soil properties and moisture deficits based on monthly climate data for thirty years in the northern part of the Canterbury Plains (Fig. 1).

2. Evaluate the impact of monthly variability in soil moisture deficits across years on wheat yields for crops sown in both spring and autumn.

3. Evaluate the spatial variation of wheat yields and expected economic return from wheat production for two sowing dates (representing autumn and spring) both with and without irrigation.

4. Apply @RISK software to model risk within a framework that integrates the economic and biophysical data associated with a wheat yield model.

5. Assess the impact of production and price risks as inputs to evaluating land for growing wheat in Canterbury.

6. Apply GIS technology to present this information spatially for decision makers.

STUDY AREA

The study area covers 2500 km² and is a representative segment of the Canterbury Plains (total area 7500 km²). It extends from the coastline to the foothills of the Southern Alps, and from the Waimakariri River in the north to the Rakaia River in the south, comprising flat to gently undulating broad alluvial outwash fans, flood plains, and terrace systems of Pleistocene and Holocene age. The soils of the Plains are variable in depth, texture (from very shallow stony loamy sands to deep clay loams), stoniness, rooting impediments, drainage class, and permeability (Kear et al., 1967). These factors contribute to variation in available water holding capacity (AWC), the key soil factor influencing moisture deficit.

Mean annual rainfall ranges from about 600 mm near the coast to about 1000 mm at the head of the Plains (Ryan, 1987). Although rainfall is

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Fig. 1. Climate and soil impacts on predicted mean yields.
approximately evenly distributed throughout the year, evapotranspiration (ET) is significantly higher during October to March, resulting in marked soil moisture deficits during November to March. Mean annual open water evaporation exceeds 1000 mm in a band through the central Plains, due to lower cloud frequency relative to both the coast and high Plains, where evaporation is correspondingly lower (900–1000 mm). Variability in rainfall may be expressed in coefficients of variation (CV). The CV for annual rainfall for four climate stations on the Canterbury Plains varied from 19 to 23% and the CV for spring and summer rainfall varied from 34 to 44% (Ryan, 1987). Mean monthly temperatures range from about 6°C in July to 16°C in January, with growing degree days (base 5°C) of about 2400 (Ryan, 1987).

METHODS AND TOOLS FOR ANALYSIS

A range of models has been applied to determine water balance, wheat yield, and economic returns and to integrate and link outputs from these models into a spatial dimension via GIS. This section briefly details the nature of the models and their linkages.

Water balance model

Thirty climate stations, each with between 20 and 30 years of rainfall records, are located within or immediately adjacent to the study area. A water balance model (New Zealand Meteorological Service, 1986) was used to determine soil moisture deficits on a 5 day time step for the period (20–30 years) mean data. Potential evapotranspiration (PE) was determined using Penman’s method (Penman, 1956). Good correlations were found between measured and estimated moisture deficit data over a range of available water holding capacities and deficit conditions (Barringer et al., 1995).

Representing moisture deficit values relating to individual climate stations (points) as area based deficit zones across the study area was achieved by modelling soil moisture deficits for the 20–30 year period mean data, assuming a single homogeneous AWC across the entire study area. Boundaries for 10 'deficit zones' were identified from isopleths defining soil moisture deficit at 50 mm intervals. These zones are reported in Barringer et al. (1995).

The soil type and deficit zone polygons were overlain to create a new set of polygons comprising soils with a given AWC class and deficit zone. A total of 80 possible soil moisture deficit unit (SMDU) polygons resulted from the eight AWC classes (Barringer et al., 1995) and 10 moisture deficit zones. A simple coding routine was used to create a code between 1 and 80 indentifying each SMDU.
The water balance model was then rerun for output of wilting point deficits (WPD) for the 80 SMDU using the 20–30 year period mean data. WPD is a climatic deficit, in mm, accrued after the available water storage in the soil has been extracted by plant growth (New Zealand Meteorological Service, 1986). The appropriate mean monthly deficit values for each analysis were assigned to each SMDU using the coding routine. Spatial and temporal data are reported in Barringer et al. (1995).

**Wheat yield prediction**

A simple regression model (P. D. Jamieson, personal communication) was used to predict wheat yield from soil moisture deficit data across the region for period mean climatic data.

\[
\text{Actual yield} = \text{Potential yield} - (\text{WPD} \times 0.003 \times \text{Potential yield}) \tag{1}
\]

where yield values are expressed in tonnes/ha and the wilting point deficits in mm. The model has been well validated for the Otane (autumn) wheat cultivar in the Canterbury region (Baird, 1985; Baird and Gallagher, 1985) and is widely used by the wheat industry for yield prediction.

Potential yields under optimum management are estimated to be 6.0 tonnes/ha on the upper part of the Plains and 8.5 tonnes/ha on the lower Plains (P. D. Jamieson, personal communication, A. Davoren, personal communication). The lower potential yield for the upper Plains results from higher evapotranspiration rates during northwesterly föhn wind conditions which result in stomatal closure restricting water uptake (A. Davoren, personal communication). Such winds are more frequent in the upper Plains than near the coast.

A WPD database comprising monthly deficit data spanning the 30 years of records was established for each of the 80 SMDUs. The wheat model (eqn (1)) was run using cumulative moisture deficit data derived from the deficit database for two growing seasons representing spring (mid August to 31 January) and autumn (mid May to 31 December) sowing under both dryland and irrigated management. The mean wheat yields from these calculations were displayed spatially through GIS (see Fig. 1).

**Economic model**

Gross revenue was calculated from the predicted yield and expected return (NZ$272/tonne in 1992 terms). No price adjustment was made for seasonal differences (i.e. between autumn and spring) or changing inputs (i.e. impact of nitrogen on protein levels). The expected return was calculated from the
TABLE 1
Production Cost Data for Wheat Based on 1992 Dollars

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>Cost/unit (NZ$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avadex (fungicide)</td>
<td>5 litre/ha</td>
<td>13.57</td>
</tr>
<tr>
<td>Herbicides (contract application)</td>
<td>per application</td>
<td>15</td>
</tr>
<tr>
<td>Cultivation</td>
<td>h/ha</td>
<td>15.14</td>
</tr>
<tr>
<td>Freight</td>
<td>per tonne</td>
<td>17.50</td>
</tr>
<tr>
<td>Glean (fungicide)</td>
<td>20 g/ha</td>
<td>1.25</td>
</tr>
<tr>
<td>Harvesting</td>
<td>per tonne</td>
<td>42</td>
</tr>
<tr>
<td>Seed</td>
<td>0.125 tonne/ha</td>
<td>600</td>
</tr>
<tr>
<td>Tilt (herbicide)</td>
<td>1 litre/ha</td>
<td>78.97</td>
</tr>
<tr>
<td>Cropmaster 20 (fertiliser)</td>
<td>0.125 tonne/ha</td>
<td>445</td>
</tr>
<tr>
<td>Urea</td>
<td>calculated</td>
<td>421.2</td>
</tr>
<tr>
<td>Irrigation</td>
<td>mm water applied per ha</td>
<td>0.36</td>
</tr>
</tbody>
</table>


A time series of annual wheat price returns (J. Prasad, personal communication) adjusted by the primary producers output index to constant dollar terms.

Input data for production of Otane wheat on a typical intensive cropping farm were obtained from the Lincoln University Financial Budget Manual (Burtt and Fleming, 1991). It was assumed that all cultivation work was undertaken by the farmer, with spraying and harvesting completed under contract (Table 1). A marginal return model based on the above assumptions was developed in LOTUS 123.†

Costs of production were then calculated from the details in Table 1 to provide a net gross margin per ha for each of the 80 SMDUs. Costs associated with freight and harvesting are yield dependent; irrigation costs are a function of WPD with a maximum irrigation application of 200 mm per annum (i.e. the WPD was reduced by up to 200 mm under the irrigated scenario and the yield recalculated); whilst nitrogen inputs are calculated from eqn (2) as a function of expected yield and nitrogen index (Ministry of Agriculture and Fisheries, Advisory Services Division, 1987). The nitrogen index was held constant in this study, representing a first year wheat crop out of pasture.

\[
\text{Nitrogen (kg/ha)} = (7.5 \times \text{NI}) + 75 + ((\text{TY} - 4.5) \times 25) \quad (2)
\]

where
NI = nitrogen index as a function of past cropping and fertiliser effects
TY = expected yield

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Analysis of profitability and risks of wheat production

@RISK model

The economic and yield models reported above are based on single estimates of uncertain and variable model parameters which reduce expected outcomes to mean values and limit information for planning and decision support purposes.

An alternative approach is to provide decision makers with information on the expected range of future outcomes and the probability of their occurrence. @RISK software is a quantitative risk analysis tool that uses spreadsheet capabilities. @RISK provides modellers with the opportunity to specify input parameters as distributions of possible values dependent on the nature of the variable and knowledge of its statistical form. Each run of the model represents a series of "what if" scenarios where the output of expected values is represented as probability functions and associated statistics.

Only business risks were included in the risk model. Consideration of financial risk was excluded due to the limitations of using a marginal analysis as the economic model where net income is a return to fixed charges, interest, debt, and labour. The grower was also assumed not to have contracted the sale of the crop (i.e. removed the market risk); rather the crop was considered to be sold on the open or spot market. The impact of contracting could be tested by restating the price distribution as a point estimate representing the contract price.†

Factors that influence production and price variability within the economic model for each of the 80 SMDUs were wilting point deficit (WPD), wheat price, freight, harvesting costs, nitrogen, and irrigation costs. Expenses for weed and pest control are other variables dependent on seasonal conditions but are not developed within this model due to the scarcity of data.

The levels of most input variables are dependent on expected wheat yield, the value of which is a function of the WPD data. Irrigation costs were considered to be a function of three variables: availability of water, efficiency of water use, and cost of water. For each irrigation variable, irrigation consultants were asked to specify the minimum, most likely, and maximum values, from which triangular distributions were defined. The specification of type of distribution applied to each variable was determined by available information. Distribution statistics for WPD were calculated from the 30 year records of monthly deficits. Wheat price records were collated for the 30

†The impact of growers contracting for a fixed price was tested for the AWC 90, SMD zone 5 combination. This impact was relatively small, increasing the mean gross margin by NZ$/ha, reducing the range of expected values by a reduction of the maximum, and increasing the probability of a positive economic outcome by 3%.
year period and converted to 1992 dollar values using the producer input index (J. Prasad, personal communication). Both wheat price and WPD were then entered into the model as normal distributions defined by mean and standard deviation.

For each SMDU, 1500 iterations of the model were run to create distributions of output variables. Output distributions of predicted yields and gross margins under both dryland and irrigated conditions and for spring and autumn sown wheat were created. The risk simulation outputs were used to assess the magnitude of risk associated with growing wheat within the 80 SMDUs and the impact of alternative management strategies on both expected returns and the associated level of risk.

**Spatial model**

Land use investment decisions often require the selection of sites to undertake production, either through contract growing or direct investment. Land use planning decisions and resource management decisions, however, are concerned with allocation of land to the best uses based on predicted impacts of alternate uses. Both land use planning and investment have a spatial dimension within the decision process that needs to be reflected within decision support systems. To represent the spatial nature of decisions, yield and gross margin estimates for different sowing dates and management strategies were attached as database attributes to each SMDU polygon. For risk assessments, probabilities of specified outcomes for yields and gross margins were also attached to each of the 80 SMDU polygons. Probability ranges were then used to aggregate land types into similar risk categories which were spatially portrayed using Terrasoft GIS. Maps were also made for component attributes, e.g. AWC, soil data, irrigation availability, etc.

**RESULTS**

**Mean differences across AWC–WPD combinations**

Predicted mean yields for spring sown crops ranged from 0.06 to 6.42 tonnes/ha (Table 2), highlighting the importance of soil and climatic influences on the spatial distribution of wheat production (Fig. 2). Gross margins based on these yield data indicate a negative mean gross margin in 18 of the 80 SMDUs, suggesting that these units, on average, are not suitable for spring-sown wheat crops (Table 3). About half of the SMDUs have a 90% or lower probability of a positive gross margin. Hence, dryland spring wheat is a very uncertain and risky enterprise within these units.
TABLE 2
Mean Predicted Spring Yields (tonnes/ha) for Different Available Water Holding Capacity (AWC) Classes and Soil Moisture Deficit (SMD) Zones

<table>
<thead>
<tr>
<th>SMD zone</th>
<th>AWC 15</th>
<th>AWC 30</th>
<th>AWC 45</th>
<th>AWC 60</th>
<th>AWC 75</th>
<th>AWC 90</th>
<th>AWC 120</th>
<th>AWC 150</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.79</td>
<td>3.80</td>
<td>4.39</td>
<td>4.7</td>
<td>4.96</td>
<td>5.26</td>
<td>5.73</td>
<td>5.90</td>
</tr>
<tr>
<td>2</td>
<td>2.35</td>
<td>3.35</td>
<td>4.01</td>
<td>4.39</td>
<td>4.56</td>
<td>4.91</td>
<td>5.31</td>
<td>5.60</td>
</tr>
<tr>
<td>3</td>
<td>1.72</td>
<td>2.72</td>
<td>3.34</td>
<td>3.72</td>
<td>3.93</td>
<td>4.29</td>
<td>4.73</td>
<td>5.14</td>
</tr>
<tr>
<td>4</td>
<td>1.11</td>
<td>2.10</td>
<td>2.67</td>
<td>3.04</td>
<td>3.31</td>
<td>3.66</td>
<td>4.15</td>
<td>4.68</td>
</tr>
<tr>
<td>5</td>
<td>0.88</td>
<td>1.76</td>
<td>2.50</td>
<td>3.01</td>
<td>3.65</td>
<td>3.88</td>
<td>4.63</td>
<td>5.25</td>
</tr>
<tr>
<td>6</td>
<td>0.68</td>
<td>1.52</td>
<td>2.08</td>
<td>2.52</td>
<td>2.92</td>
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<td>4.17</td>
<td>4.63</td>
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<tr>
<td>7</td>
<td>0.42</td>
<td>1.10</td>
<td>1.63</td>
<td>2.06</td>
<td>2.51</td>
<td>2.76</td>
<td>3.43</td>
<td>3.98</td>
</tr>
<tr>
<td>8</td>
<td>0.06</td>
<td>0.58</td>
<td>0.85</td>
<td>1.25</td>
<td>1.55</td>
<td>1.83</td>
<td>2.39</td>
<td>3.59</td>
</tr>
<tr>
<td>9</td>
<td>0.82</td>
<td>1.86</td>
<td>2.49</td>
<td>2.92</td>
<td>3.29</td>
<td>3.67</td>
<td>4.42</td>
<td>5.10</td>
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<tr>
<td>10</td>
<td>1.83</td>
<td>2.98</td>
<td>3.66</td>
<td>4.63</td>
<td>5.04</td>
<td>5.77</td>
<td>6.42</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3
Mean Predicted Spring Gross Margin (NZ$/ha) for Different Available Water Holding Capacity (AWC) Classes and Soil Moisture Deficit (SMD) Zones

<table>
<thead>
<tr>
<th>SMD zone</th>
<th>AWC 15</th>
<th>AWC 30</th>
<th>AWC 45</th>
<th>AWC 60</th>
<th>AWC 75</th>
<th>AWC 90</th>
<th>AWC 120</th>
<th>AWC 150</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>177.9</td>
<td>387.4</td>
<td>502.3</td>
<td>556.1</td>
<td>606.1</td>
<td>661.7</td>
<td>756.9</td>
<td>790.8</td>
</tr>
<tr>
<td>2</td>
<td>84.1</td>
<td>294.1</td>
<td>426.8</td>
<td>501.4</td>
<td>530.7</td>
<td>600.3</td>
<td>668.4</td>
<td>729.1</td>
</tr>
<tr>
<td>3</td>
<td>-49.5</td>
<td>163.7</td>
<td>291.1</td>
<td>367.8</td>
<td>409.8</td>
<td>482.1</td>
<td>565.9</td>
<td>641.4</td>
</tr>
<tr>
<td>4</td>
<td>-181</td>
<td>29.6</td>
<td>155.3</td>
<td>227.6</td>
<td>283.2</td>
<td>356.9</td>
<td>452.2</td>
<td>556.4</td>
</tr>
<tr>
<td>5</td>
<td>-231</td>
<td>-41.4</td>
<td>107.9</td>
<td>219.1</td>
<td>337.9</td>
<td>387.2</td>
<td>538.8</td>
<td>664.8</td>
</tr>
<tr>
<td>6</td>
<td>-271</td>
<td>-92</td>
<td>24.31</td>
<td>111.3</td>
<td>197.4</td>
<td>280.3</td>
<td>448.9</td>
<td>545.6</td>
</tr>
<tr>
<td>7</td>
<td>-326</td>
<td>-183</td>
<td>-73.9</td>
<td>23.46</td>
<td>112.6</td>
<td>164.7</td>
<td>299.8</td>
<td>417.5</td>
</tr>
<tr>
<td>8</td>
<td>-403</td>
<td>-290</td>
<td>-240</td>
<td>-147</td>
<td>-86.5</td>
<td>-32.8</td>
<td>88.4</td>
<td>326.7</td>
</tr>
<tr>
<td>9</td>
<td>-239</td>
<td>-18.2</td>
<td>107.8</td>
<td>194</td>
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<td>354</td>
<td>499.9</td>
<td>634.7</td>
</tr>
<tr>
<td>10</td>
<td>-24</td>
<td>216.6</td>
<td>351.3</td>
<td>328.8</td>
<td>543.5</td>
<td>630.1</td>
<td>768.2</td>
<td>897</td>
</tr>
</tbody>
</table>

Risk simulations

Mean predicted values provide only limited information about expected wheat yields and gross margins, explaining only 8 to 15% of their variability. For land evaluation or farm management decision making, such a limited set of occurrences will potentially result in overallocation of land to wheat production, because no account is taken of outcomes below the mean values. Ignoring risk will overestimate the economic value of growing wheat, which will have potential resource impacts and associated negative socioeconomic impacts. The variability of yield and gross margins for spring-sown crops is...
TABLE 4
Management Impacts on Yield and Gross Margin for Soils with AWC 90, Climate Zone 5

<table>
<thead>
<tr>
<th></th>
<th>Spring sown</th>
<th>Dryland autumn sown</th>
<th>Spring irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (tonnes/ha)</td>
<td>3.88</td>
<td>5.58</td>
<td>7.09</td>
</tr>
<tr>
<td>Range (tonnes/ha)</td>
<td>8.91</td>
<td>9.1</td>
<td>6.2</td>
</tr>
<tr>
<td>CV(%)a</td>
<td>66</td>
<td>40</td>
<td>27</td>
</tr>
<tr>
<td>Probability positive (%)</td>
<td>96</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Gross margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (NZ$/ha)</td>
<td>395</td>
<td>652</td>
<td>996</td>
</tr>
<tr>
<td>Range (NZ$/ha)</td>
<td>2224</td>
<td>2673</td>
<td>2529</td>
</tr>
<tr>
<td>CV (%)b</td>
<td>383b</td>
<td>256</td>
<td>215</td>
</tr>
<tr>
<td>Probability positivec</td>
<td>79</td>
<td>93</td>
<td>97</td>
</tr>
</tbody>
</table>

*aCoefficient of variation.

*bReduces to 264% with the removal of market risk.

*cProbability of result greater than NZ$50/ha.

high, as evidenced by the output range and the coefficient of variation (CV in Tables 4 and 5). For spring-sown wheat—the AWC 90, climate zone 5 combination (Table 4)—the probability of no yield is 4% and the predicted variance of yield is relatively high (CV = 66%). For gross margin, the risk is magnified due to price uncertainty, resulting in a 21% (i.e. one year in five) chance of a negative net return, compared with a 7% (i.e. one year in 14) chance for the autumn-sown option. The variability of the gross margin is extremely high (CV = 383%), which reduces to 264% when market price risk is removed. Adoption of autumn sowing is predicted to increase the gross margin while reducing the level of uncertainty. A risk-averse farmer growing dryland wheat would therefore be expected to adopt autumn-sown wheat.

The impact of sowing date options for the combination of AWC 90, climate zone 5 (Table 4) is significant, with autumn sowing providing higher mean returns (i.e. 40% increase in gross margin) with lower risk (i.e. CV = 256%) and increased certainty (i.e. 7% probability of a negative result). The opportunity to manage these risks highlights the need to develop an integrated biophysical and economic modelling approach that includes risk. The disadvantages of spring sowing can be overcome with irrigation, which provides the highest net return with a risk level similar to that for the dryland autumn-sown crop.

Details on the risky nature of growing dryland spring-sown wheat as affected by deficit zone are given in Table 5. Zones with lower mean yields are more risky (CV = 383% and 701% cf. 158%), which contributes to a high probability that a net loss will result (i.e. one year in three). Adoption of
autumn sowing effectively leads to a similar risk among deficit zones, while significantly improving gross margins. With autumn sowing there is a chance of loss in one year out of 15.

Spatial models

Spatial representation of yield and economic risk are given in Figs 1 and 3 respectively. These spatial patterns indicate a number of spatial representations that could be used for land evaluation at regional scales. The central zone of shallow and stony soils is differentiated from other deficit zones by the gross margin risk of a 30% to 80% probability of a negative economic return.
Fig. 3. Spatial pattern of positive economic return probabilities.
CONCLUSIONS

Integration of biophysical data and economic data within a risk assessment framework has identified spring wheat growing to be a risky investment for specific locations within the Canterbury Plains. In the central region of the Plains the likelihood of economic loss is high, due to a combination of shallow and stony soils and variable rainfall. Wheat production is less risky on the western region of the Plains, where rainfall is more reliable for spring-sown crops, and the eastern margin where soils are deeper.

The growing of autumn-sown wheat reduces risk and has higher economic returns. Growers in the region tend to manage risk through the use of irrigation and additional inputs such as nitrogen, weed, and pest control. Given the increasing and competing demands for water resources, adoption of autumn sowing could also be promoted on the basis of minimising the use of limited water resources. This study has indicated that reducing water use demand by changing sowing dates from spring to autumn can be achieved without reduction in crop production potential.

Linking crop models with temporal and spatial climatic variability and spatial soil variability can provide additional confidence to future land evaluation. The inclusion of production and market risks with climatic risk within the @RISK based model enables future development of land evaluation criteria that include both physical and economic information. The demonstration of an increasing probability of a negative outcome by changing from a yield-based criterion (5% probability) to an economic criterion (20% probability) is a step towards linking planning to sustainable resource management.

The application of GIS enables linkage of results of crop models to spatial databases of climate and land resources to determine variability in yield and profitability in a spatial context. Conflicts between biophysical and economic objectives can be identified spatially by comparing soil, yield and profitability assessments. Spatial analysis of data has highlighted that areas with low mean yields are associated with high levels of risk due to climate-soil interactions.

Future research should move from a crop model to the modelling of crop sequences and prediction of environmental impacts of cropping systems. A need has been identified (Stomph et al., 1994) to move beyond the single crop model within a biophysical context, whilst crop sequences have been modelled using CROPS, a knowledge-based decision support system (Buick et al., 1992). Linking CROPS to a risk inclusive framework incorporating biophysical and economic data is a priority. Within the resource management context there is a need to extend the basic production models to include the effects of production on the resource base. These effects include nutrient leaching, agrochemical usage, and water demand.
We envisage application of these models at farm and regional scales. Potential applications for these models at farm level include farm management planning and investment decision support. At regional level, spatially integrated decision support models may help to improve the management of increasingly scarce resources, such as water. For effective resource management the link between the objectives of society and resource allocation procedures needs to be improved. The variety of land use options, along with the uncertainties that surround biophysical/economic/social environs, make resource management a challenging task. Resource management is fundamentally a risk management process (Barr, 1994) and data sets should continue to incorporate risk so the resource manager can deal effectively with uncertain and complex interactions.

ACKNOWLEDGEMENTS

The authors wish to acknowledge advice on wheat production received from Drs P. D. Jamieson and D. R. Wilson of Crop and Food Research, data on the time series on annual wheat prices received from J. Prasad of MAF policy and the helpful comments of the anonymous reviewer. Funds for this research were provided by the Foundation for Research, Science and Technology under Contract C09222.

REFERENCES


