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Productivity differences across New South Wales rice farms

Links to resource quality

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Productivity indices were calculated for rice farms across New South Wales using data envelopment analysis (DEA) techniques. These revealed distinct geographic patterns. Preliminary work showed these geographic patterns were consistent with differences in resource quality, including depth from watertables, soil types and salinity levels. If differences in measured productivity are influenced by the quality of land and water resources used to produce rice, isolating this influence may provide a way of quantifying the costs associated with resource quality issues such as rising groundwater tables and soil salinity.

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Introduction

Most Australian rice is grown in the Murrumbidgee and Murray Valleys in New South Wales, located in the southern Murray Darling Basin (figure 1). Land salinisation has become a problem across parts of the southern Murray Darling Basin as deep rooted native vegetation has been removed and replaced by shallow rooted annual crops — including rice — and pastures which use less water, resulting in the watertable being maintained closer to the surface. In irrigation areas this has been compounded by the application of large additional quantities of water, often without sufficient drainage facilities to remove excess water. Over large parts of the Murray Darling Basin's irrigated land, watertables are less than 2 metres from the surface, resulting in salinisation and waterlogging, affecting the productivity of agricultural activities.

Land and water management plans for the Murrumbidgee and Murray irrigation areas have been developed to manage rising watertables and subsequent salinity. In the process of developing these plans, data on soil types, the distance of watertables from the surface and salinity levels of both the soil and groundwater have been collected for each region. The availability of such data has enabled this preliminary investigation into the relationship between productivity and resource quality.

A measure of farm productivity — in relation to best practice technology — can be calculated using data envelopment analysis (DEA) techniques based on the quantities of

Figure 1: **Rice growing regions in New South Wales**

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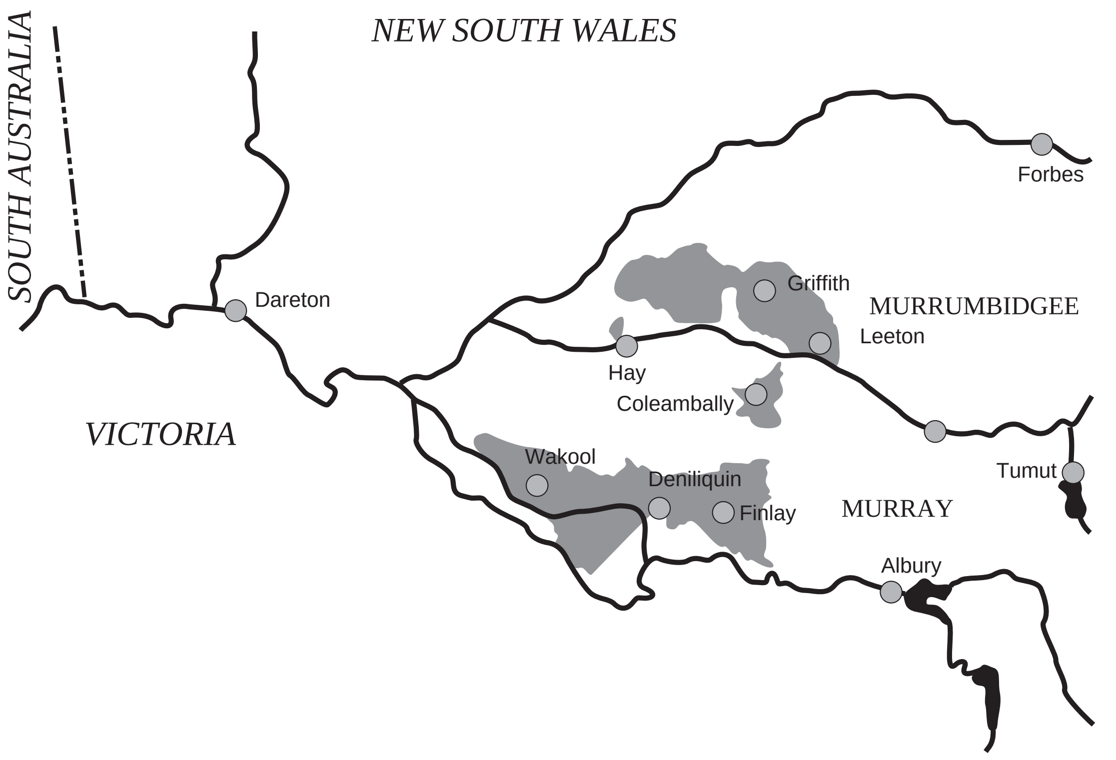

a given set of inputs used to produce a given quantity of output. Differences in productivity indices across farms may reflect differences in the quality of those inputs, in particular land and water resources.

This work is an investigation into the link between the level of productivity and the quality of land used to grow rice in southern New South Wales. The quality of land is assumed to be influenced by different soil types across the region, the distance of watertables from the soil surface and the salinity levels of both soils and groundwater. It is assumed that the quality of the irrigation water used to grow rice is not associated with differences in productivity. This was because data on the varying quality of irrigation water across the region were generally not available.

If the measured productivity indices are shown to be heavily influenced by resource quality, DEA techniques may provide a way of quantifying the costs associated with resource quality issues such as rising groundwater tables and soil salinity.

Productivity indices for each of the farms surveyed have been calculated and mapped, revealing distinct geographic patterns. The productivity maps have then been compared with maps of soil types, groundwater contours and groundwater salinity in each of the regions.

Method

Charnes, Cooper and Rhodes (1978) coined the term ‘data envelopment analysis’ when they reformulated Farrell’s (1957) initial work on the measurement of technical efficiency into a mathematical programming problem. Since then, the application of DEA techniques has been well documented and the technique extended in a number of ways (Fare, Grosskopf and Lovell 1985; Charnes and Cooper 1985). One such extension has enabled the measurement of productivity indices encompassing both technical efficiency and technical change (Arnade 1998).

DEA techniques have been used to define a productivity frontier representing the smallest amount of each variable input required to produce a given quantity of output. Empirical work on frontier analysis has traditionally been dominated by parametric frontier production function analysis and its variants, which fit a surface over the data to identify the ‘best practice technology’. DEA techniques use linear programming (LP) methods to construct a nonparametric surface over the data, enabling the calculation of productivity indices relative to this surface.

Assuming constant returns to scale technology and using an example with two inputs (X_1 and X_2) required to produce an output (Y), a scatter diagram of farms with each farm’s location determined by the quantity of X_1 and X_2 required to produce one unit of Y is presented in figure 2. The piecewise convex line extending from *P* to *T* is constructed, using LP techniques, by finding a linear combination of farms, for each farm *k*', that matches its output, while minimising the variable input combination required. If the amount of variable inputs cannot be reduced using a linear combination of other farms, *k*' is considered to be one of the most productive farms and takes a position on the frontier.

Farms away from the frontier are considered less productive because by moving to the frontier — along the radial — they could produce the same level of output using less inputs. The productivity of farm B, for example, is represented by the distance 0*A*/0*B*. If 0*A*/0*B* was 0.90 then all inputs could be proportionally reduced by 10 per cent without a reduction in output. Farms on the frontier are therefore assigned a productivity index of one and farms away from the frontier assigned productivity indices of less than one. It follows that the further farms are from the frontier the lower their productivity index.

Different estimation techniques are applied depending on the returns to scale assumption. For a complete algebraic specification of the mathematical programming formulation of the model see Chavas and Aliber (1993).

In this paper, productivity indices have been calculated for farms producing rice in the southern Murray Darling Basin. Once the productivity indices were calculated for each farm they were smoothed spatially, using a kernel smoother (Cowling and Shafron 1992), to produce local averages and then mapped as contours using the mathematical software package MATLAB (The MathWorks Inc 1998). This revealed geographic patterns that

Figure 2: **Input based efficiency frontier**

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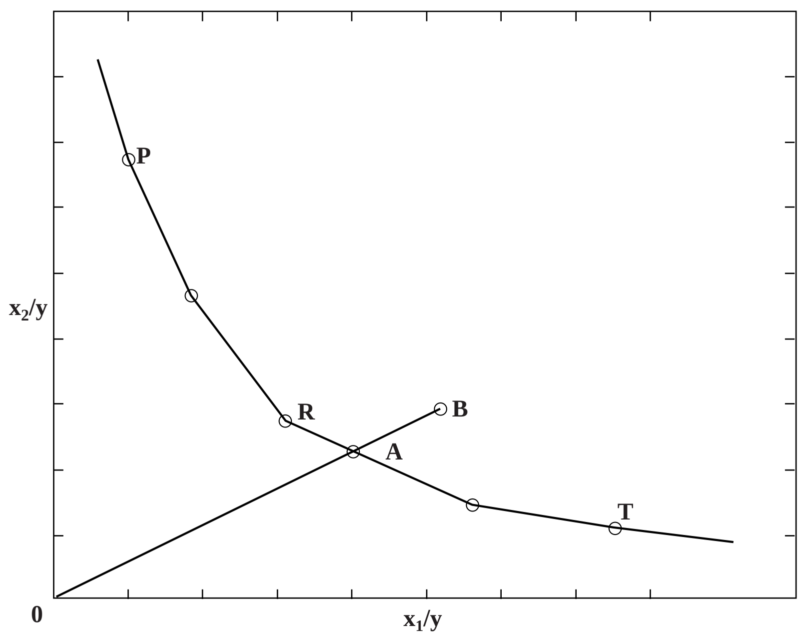

could then be compared with maps of groundwater tables, soil types and salinity levels to explore the links between productivity across farms and measures of resource condition.

The calculation of productivity indices using DEA techniques is specified in the theory in terms of quantities of inputs and outputs. The number of inputs and outputs specified in this model is limited by the relatively small sample which has required the use of aggregate cost and receipt variables as dollar value surrogates for input and output quantities. The variables used are as follows:

- ***variable inputs***: volume of water used (megalitres), quantity of fertiliser used (kilograms) and other variable costs incurred ($);
- ***fixed inputs***: area planted to rice (hectares), other farm area (hectares) and other fixed costs incurred ($); and
- ***outputs***: total rice receipts ($) and receipts from other farm activities ($).

The model was specified with the assumption of non-increasing returns to scale implying that all farms in the sample operate with either constant or decreasing returns to scale.

The study region

The Murrumbidgee and Murray valleys are located in the southern Murray Darling Basin and agriculture forms the basis of the local economy in each region. Irrigation began in the Murrumbidgee valley following the construction of Burrinjuck Dam. While production initially centred on horticulture, dairying and other pasture enterprises, rice has since become the major commodity produced on the larger (nonhorticultural) farms (MIA and Districts Land and Water Management Plan Working Group 1997). Irrigation in the Murray valley did not occur until some years after irrigation was established in the Murrumbidgee valley (Berriquin Land and Water Management Plan Working Group 1995). The major agricultural activities across the Murray valley are rice production, dairying and wool production.

Rice growing is likely to be most productive under several resource conditions (table 1). Medium to heavy clay soils and transitional red brown earths are the most suitable for rice growing. The distance of the watertable to the surface of the soil is also important, with land where the watertables are less than 4 metres from the surface less suitable for rice growing. Similarly the salinity of the soil is an important factor, with some loss of yield on mildly saline soils (class B soils). Rice is not a suitable crop to be grown on extremely saline soils (C and D class soils).

Table 1: **Associations between productivity and resource condition**

	Low productivity	High productivity
Watertables	Close to the soil surface	More than 4 metres from the soil surface
Groundwater	Saline	Less saline
Soils	Sandy soils, loam soils and deep cracking or self mulching clays	Medium to heavy clay or red brown transitional earths
	Mildly saline (class B soils)	Less saline (class A soils)

Both the Murrumbidgee and Murray valleys have a range of soils and are affected by high watertables and the associated problems of salinity and waterlogging which have been exacerbated by the use of irrigation water.

The data used in the model were collected in ABARE's 1996-97 Australian agricultural and grazing industries survey. Data collected in 1996-97 have been used because an extended survey of irrigation districts was undertaken in that year, increasing the number of farms surveyed in the region. A sample of 74 rice growers in the Murrumbidgee and Murray valleys were used in this analysis.

Results

Productivity indices for farms across the region as a whole ranged between one, the most productive, and 0.34, the least productive. The distribution of productivity indices revealed that the majority of farms had very high productivity indices and very few farms had very low productivity indices (table 2).

As a guide to interpreting the indices, farms with a very low productivity index — less than 45 per cent — use more than double the variable inputs used by farms on the productivity frontier. Differences in variable input use appear to be influenced by quality differences in the resources between the most productive and less productive farms. This implies that in rice production, resource quality may be valued in dollar terms. For instance, if lower productivity indices can be attributed to soil salinity, then the variable input costs associated with operating away from the productivity frontier — where soils are not saline — may, in part, reflect the costs associated with soil salinity.

Table 2: **Distribution of productivity indices**

		Proportion of farms (n=74)
Very high	Greater than 90%	58%
High	Between 75 and 90%	15%
Moderate	Between 60 and 75%	11%
Low	Between 45 and 60%	12%
Very low	Less than 45%	4%

The productivity indices were smoothed spatially to produce local averages. These were mapped and the major irrigation districts, towns and rivers were overlaid to provide reference points. Distinct geographic patterns both within and between regions were observed when the productivity indices for each survey farm were mapped (figures 3–5).

The Murrumbidgee valley

Rice farms in the Murrumbidgee valley are concentrated in two main areas, the Murrumbidgee Irrigation Area and Districts (MIA&D) located around Griffith and Leeton (figure 3), and the Coleambally Irrigation Area (CIA) located around the township of Coleambally (figure 4). The MIA&D is itself made up of a number of smaller irrigation districts which are not referred to specifically in this paper, with the exception of the Wah Wah irrigation district which is situated to the west of Barren Box Swamp (figure 3).

Rice farms located around Griffith had generally high productivity indices. Farms in the Wah Wah irrigation district and the CIA, however, had relatively lower productivity indices. In the CIA, productivity indices deteriorated the further south farms were in the region.

Groundwater tables

Rising watertables are the biggest problem facing rice producers in the Murrumbidgee valley. Already, watertables are within 2 metres of the soil surface over more than 70 per

Figure 3: **Productivity indices across rice farms in the Murrumbidgee Irrigation Area**

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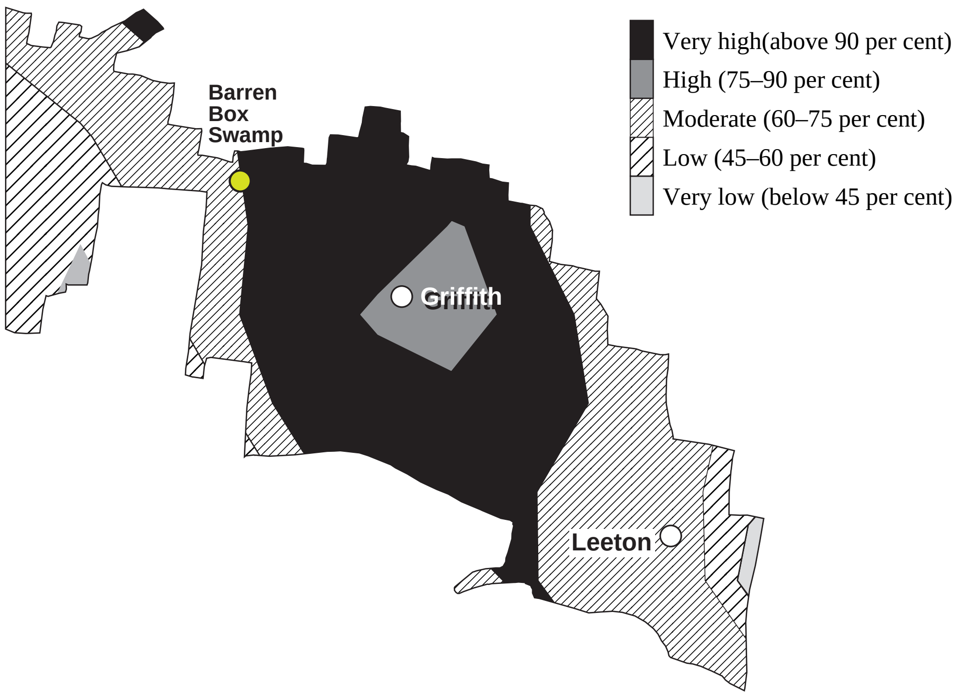

Figure 4: **Productivity indices across rice farms in the Coleambally Irrigation District**

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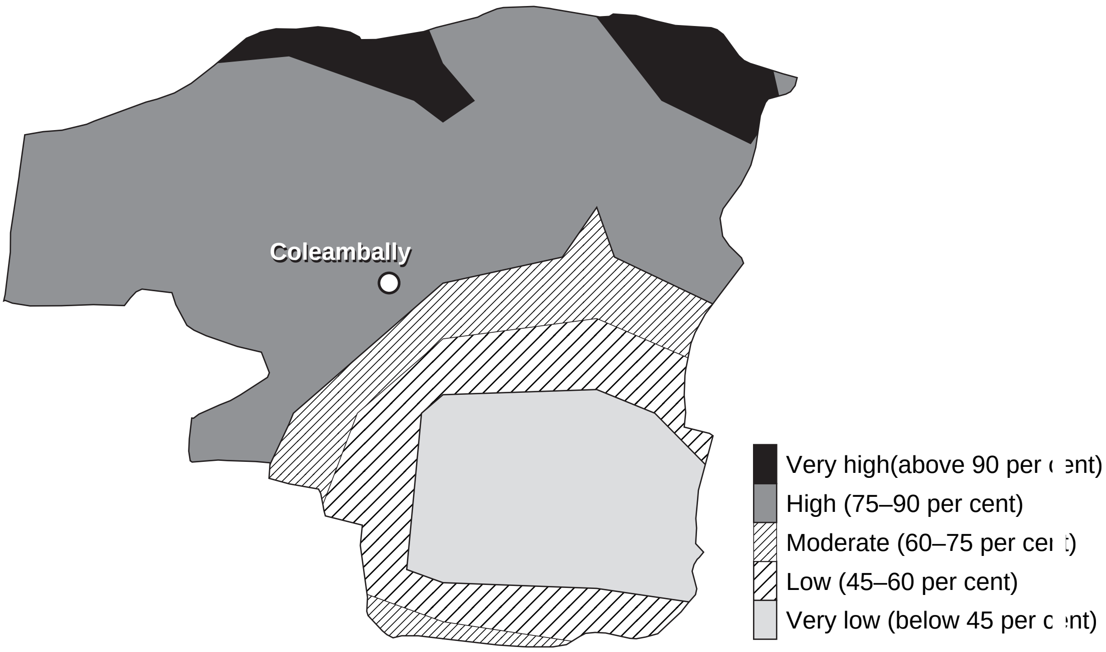

cent of the MIA&D (MIA & Districts Land and Water Management Plan Working Group 1997), and over half of the CIA (Coleambally Land and Water Management Plan Committee).

In the MIA&D the watertable is closest to the surface — within 1–2 metres — in the area north of Leeton at the south east end of the district (MIA & Districts Land and Water Management Plan Working Group 1997, p.11). This is consistent with the productivity indices which were lower for farms in the south eastern part of the region compared with farms around Griffith.

Maps of the watertable across the CIA in 1991 showed that the watertable was within 2 metres of the surface to the south east of Coleambally. This was consistent with the productivity indices that show farms at the northern end of the region with higher productivity indices compared with farms at the southern end (Coleambally Land and Water Management Plan Committee, p. 19).

Soil types

Soils in the MIA&D generally consist of transitional Mallee soils with few areas of clay. Larger areas of deep cracking clay soils less suitable to growing rice are located in the Wah Wah irrigation district, and soils more generally in the district are more naturally saline than soils in the rest of the MIA&D (Wah Wah Land and Water Management Plan Working Group 1997). The lower productivity indices observed in the Wah Wah irrigation district relative to the rest of the MIA&D are consistent with the less suitable and more saline soils.

While the irrigation water across the Murrumbidgee and Murray valleys is generally of a similar quality, one exception is the irrigation water in the Wah Wah irrigation district. The irrigation water used in this region is typically drainage water collected in Barren Box Swamp from irrigation further upstream and is therefore more saline (MIA & Districts Land and Water Management Plan Working Group 1997).

Around a quarter of the soils in the CIA are semi self-mulching grey clays, the rest of the soil consists of transitional red brown earths (Hulme 1994).

The Murray valley

The Murray valley is made up of the Murray Valley East, located to the east of Deniliquin, and the Murray Valley West, centred around Wakool. The Murray Valley East is made up of two smaller irrigation districts, the Berriquin irrigation district located to the east of Deniliquin, and the Denimein irrigation district located to the north west of Deniliquin. The Murray Valley West is also made up of two smaller districts, the Wakool irrigation district located north west of the township of Wakool and Cadell to the south east of the town.

Farms in the Murray Valley East generally had higher productivity indices than those in the Murray Valley West (figure 5). Within the Murray Valley West, however, productivity

Figure 5: **Productivity indices across rice farms in the Murray Valley**

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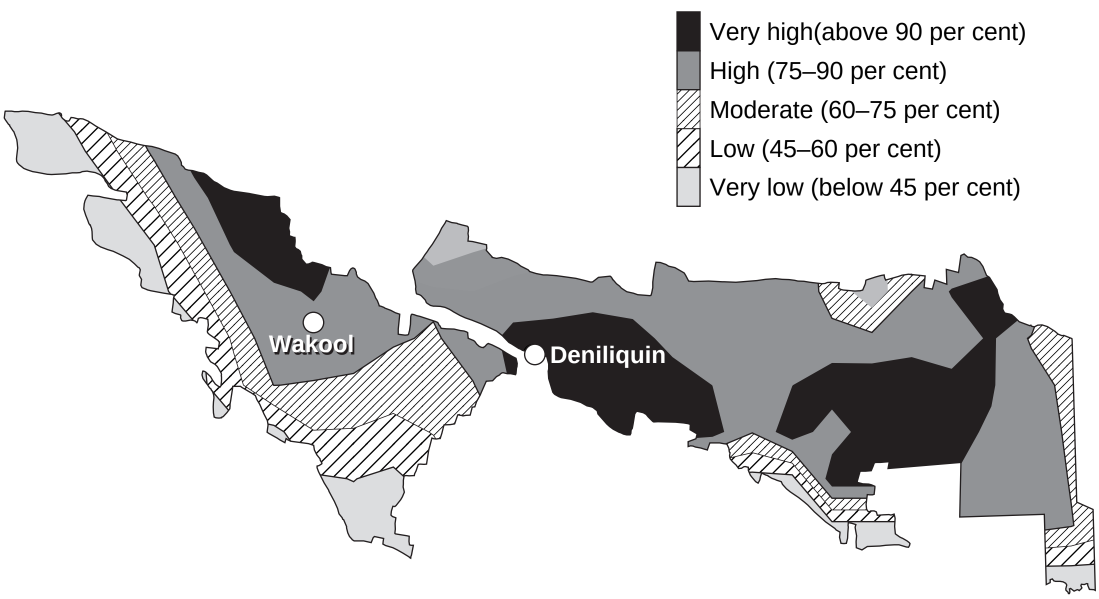

indices ranged from very high in the north east part of the Wakool irrigation district to very low at the southern end of Cadell.

Groundwater tables

The watertable is closer to the surface across more of the Murray Valley West than the Murray Valley East, which is consistent with the lower productivity indices achieved on average by farms in the west of the valley relative to those in the east (Wakool Land and Water Management Plan Working Group 1995, p. 20; Cadell Land and Water Management Plan Working Group 1995, p. 28; Berriquin Land and Water Management Plan Working Group 1995, p. 40).

In 1994, the watertable was within 4 metres of the surface over more than half of the Murray Valley West district and the groundwater was generally very saline. In the Wakool irrigation district, the groundwater table is closest to the surface to the north west of the township of Wakool (Wakool Land and Water Management Plan Working Group 1995, p. 20). However, a subsurface drainage scheme, involving groundwater pumping, built between 1979 and 1988 has assisted in some of the worst affected areas.

Compared with the Wakool irrigation district, Cadell has minor watertable problems. Less than a quarter of the region is over watertables within 4 metres of the surface and the watertable is closest to the surface in the north west of the region (Cadell Land and Water Management Plan Working Group 1995, p. 28). This is not consistent with the productivity data which show farms in the Wakool irrigation district with higher productivity indices on average compared with farms in Cadell.

In the Murray Valley East, the watertable in the Berriquin irrigation district is closest to the surface in roughly the middle of the district (Pope and Solomon 1989, p. 6) which is where the productivity indices are lower. In the Denimein irrigation district the watertable is within 2 metres of the surface at the northern edge of the district where productivity indices are the lowest.

Soil types

A large proportion of the soils in the Murray Valley West, particularly in the Wakool irrigation district, were naturally saline prior to farming and the development of high watertables. A large proportion of the soils in the district consist of either grey soils subject to inundation or grey and brown soils of the treeless plains which have been shown to have a high salt content. The soils more suited to rice growing — transitional red brown earths — are located to the north west of Wakool, where some of the highest productivity indices in the region are observed (Wakool Land and Water Management Plan Working Group 1995, p. 17).

Soils in Cadell are mainly loam, but there is some clay. The clay soils, more suitable for rice growing than the loam soils, are concentrated at the northern end of Cadell where farms had higher productivity indices than farms further south (Cadell Land and Water Management Plan Working Group 1995, p. 13).

Testing robustness

The same model was run using 1993-94 survey data to test the robustness of the productivity patterns observed. While the sample size was considerably smaller — less than half — some of the more general patterns seen in the 1996-97 data were duplicated in the 1993-94 data. Farms in the Murray Valley West had on average much lower productivity indices than farms in the Murray Valley East. In particular farms in the Cadell region, especially further south, had generally low productivity indices. Similarly, in the Murrumbidgee Valley farms in the Wah Wah irrigation district had lower productivity indices than farms in the rest of the MIA&D.

Before pursuing the possibility that this technique may provide a way of quantifying the costs associated with resource quality issues it is necessary to determine the influence that other factors such as differences in farm management practices may have on productivity. For instance, it has been shown that Landcare membership is positively associated with the presence of degradation problems on farms, suggesting that farmers have ways of managing these problems (Mues, Chapman and Van Hilst 1998). It is therefore necessary to determine the influence that the adoption of farm management practices has on the productivity of farms experiencing problems with groundwater tables and soil salinity.

Conclusion

Mapping the productivity indices of rice farms across southern New South Wales creates patterns that appear to be explained in part by the depth of watertables from the surface and, to a lesser extent, the soil types across the regions and the salinity of both the soil and the groundwater.

The collection of quantitative data on resource condition, however, is required to test the hypothesis that resource condition provides a satisfactory explanation of the variability in measured productivity using more rigorous statistical analysis.

Initial further work will involve increasing the number of sample farms to enable the model to be run under an assumption of variable returns to scale and the collection of a more ideal data set that includes water and fertiliser application rates for rice alone. A detailed investigation into the ability of different farm management practices to explain productivity differences is also necessary, but requires the collection of specific data on farm management practices.

Following this, further investigation is required to determine whether or not the technique can be used to quantify the costs associated with resource quality issues such as rising groundwater tables and soil salinity.

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