Finding a win-win situation for salinity on the Liverpool Plains

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Abstract

The Liverpool Plains catchment faces a number of natural resource issues including dryland salinity, which has been attributed to removal of native vegetation, an increase in rainfall and the use of long fallow cropping systems. Opportunity cropping, where a crop is sown once the soil profile has been recharged to a suitable level, has been promoted as a more water use efficient system. In this paper, we present results from field trials and APSIM modelling to find if the recommended change to opportunity cropping systems can produce a "win-win" situation, that is increasing profitability whilst at the same time reducing recharge to the groundwater systems that are believed to contribute to dryland salinity.

Contributed Paper to the 46th Annual Conference of the AARES

13-15 February 2002

Canberra

1. Introduction

The Liverpool Plains region of northwest NSW comprises an area of highly productive agricultural land. Gunnedah is the largest town, located in the north of the catchment. It is an interesting farming region because of the historical development of cropping production technology – with regard to both the adaptation and adoption of new cropping systems. Production technologies have been developed to utilise the natural advantages of climate, soil types and soil fertility while overcoming problems of harnessing available moisture supplies (especially the patterns of distribution), maintaining soil fertility and structure, and countering crop weed and disease problems. As important, though, have been the production/environmental issues of minimising soil erosion and more recently addressing the problem of dryland salinity. While a technology package to overcome major soil-related issues (soil fertility/structure decline and soil erosion) appears to be in place and potentially successful, increased awareness of a dryland soil salinity problem has prompted further research and related activity.

The dryland salinity issues associated with changed land use in northern Australia typically derive from a change in vegetation cover (clearing of trees or changed vegetation patterns) and the imposition of more 'leaky' annual cropping systems. This means that more of the precipitation infiltrates into subsoil zones, rather than being used by vegetation. The effect of this increased 'deep drainage' is to mobilise salts present in the subsoil layers and to raise the water table, bringing the salts closer to the surface and hence to the roots of pastures and crops. The effects (rising water tables) may be spatially removed from the causes (increased infiltration) leading to an externality. One unknown factor has been the degree of deep drainage associated with different cropping systems – whether there are substantial differences between perennial vegetation, more traditional long-fallow crop systems and the newer opportunity cropping systems. Young (1999) reported agronomic and soil-water balance trials investigating this issue. The present analysis considers the profit and deep drainage levels associated with alternative cropping systems based on different crop planting rules or strategies. Questions emerge about the nature of the patterns of profits and deep drainage as cropping rules vary, whether there are trade-offs involved, and the possible existence of situations where less leaky crop systems can be more profitable.

Consulting work has been commissioned (URS 2001) addressing a number of natural resource management issues in the Liverpool Plains region. The issues identified were:

- dryland salinity and groundwater recharge;
- flooding;
- soil erosion;
- water quantity and quality (including river salinity);
- nature conservation and biodiversity; and
- riparian zone health.

These issues impact on the environmental and economic health of the region and a Catchment Investment Strategy has been developed to identify and integrate the important actions that need to be undertaken. A system of Land Management Units (LMU) was developed based on classifications according to soil type, slope and rainfall. Cropping systems management (especially opportunity cropping) was identified as an important strategy to potentially reduce groundwater intake (deep drainage), erosion and other problems. Changes in land use for each LMU were recommended in the Catchment Investment Strategy. A shift towards opportunity cropping was recommended for some

LMU's, based on the idea that it involves less surface runoff and deep drainage than conventional cropping (usually long fallow systems). However, there was no detail available for that analysis on potential differences in drainage between different opportunity cropping decision rules (based on soil moisture levels). Subsequent work and analysis presented here, enables a more detailed look at the possibility of optimising the soil water planting rules.

In this paper we concentrate on the issue of salinity hazards and soil water planting rules to minimise deep drainage. We briefly review information on salinity hazard in the northern NSW agricultural region, and then turn to a description of some agronomic trials aimed at the cropping/salinity interface. We review a paper by Burt and Stauber (1989) which considered this issue in the US, although those authors did not have information on deep drainage. They derived an economic response surface associated with alternative soil water planting rules for the Northern Great Plains using Montana data. The shape of this surface in comparison with our own results prompts a question about the flatness of economic response.

We present results from an agronomic simulation model based on paddock-level trial results. Because these simulation results provide predicted outcomes as distributions, the results are analysed and presented in two stages. First we calculated gross margins and deep drainage as the means of the distributions of 40-year simulations. This assumes that farm decision-makers relying on such results would consider the results 'on average' as a basis for action. Then we accounted for the whole distributions in making the same evaluations. In the first stage patterns of gross margins ($/ha) and deep drainage (mm/ha/year) are presented and discussed. Potential trade-offs are analysed in a relatively simple way. Then one particular case is analysed in more detail, first by assessing whether the distributions differ statistically and then by testing the selected sub-set for stochastic dominance. This comparison is still made for only one measure (paddock-level gross margin). Finally we consider the average figures for both measures in a multi-objective criteria analysis.

2. Salinity hazard

An Australian dryland salinity assessment was recently conducted and published (National Land and Water Resources Audit 2001). A focus on dryland salinity as a serious natural resource management issue in Australia has been building over the last decade. The aim of the audit was to gain an idea of the magnitude of change in soil, water and nutrient balances in the Australian landscape due to trends in land use, particularly agricultural development. The impacts of this process fall on farmers (through salinisation of agricultural land and waterways), on urban dwellers (through infrastructure such as water supply, roads and buildings), and on society more generally (through impacts on biodiversity).

The audit includes hazard and risk assessments. A hazard is defined in the audit as anything that can cause harm to an asset, eg. salt loads in land where ground-waters have potential to rise. Risk is defined there as estimation of the expected amount of harm that will occur to the asset when a condition occurs, eg. shallow saline groundwater under cropland. The audit includes regional-scale dryland salinity risk or hazard assessments undertaken by State agencies using:

- information on groundwater levels and trends;
- known incidence of salinity;
- soil characteristics; and
- topography.

The limitations and constraints in undertaking this audit are listed on pp. 5-6 in National Land and Water Resources Audit (2001). The audit includes an assessment of the risk in 2000, and a projection of risk to 2050. The risk map for New South Wales in 2000 is reproduced in Figure 1. In general, the northwest region of the state is not currently classed as high risk, nor is it substantially at risk in 2050. However, some areas of the northwest region do indicate salinity risk, and the Liverpool Plains area was the subject of a research study, which is detailed in the next section.

3. Agronomic and soil-water balance trials

Opportunity cropping systems have been developed in the highly variable summer-dominant rainfall climes of northern Australia based on the concept of using water when it becomes available. The process involves monitoring or measuring the accumulation of moisture in the soil profile until there is sufficient water to grow a crop at the next sowing window. Both summer and winter crops can be and are commonly grown. But how much is ‘sufficient’ water to grow a profitable crop, and how does this trigger level impact the amount of amount of deep drainage? The answers to these questions prompted the experiments described below.

Young (1999) reported trials conducted in the southern Liverpool Plains at two on-farm research sites, established in late 1994. The sites were considered typical of the highly productive farming country in the catchment and were representatives of areas previously identified as being significant areas of recharge of groundwater causing problems on the alluvial plains. Agronomic measures (yields etc.) were derived for the different cropping systems. The experimental design for cropping comprised 6 treatments: a wheat-sorghum-long fallow rotation (3 phased treatments), continuous winter cereal, and opportunity cropping (2 treatments: winter cereal-summer pulse and sorghum-winter pulse sown on a sowing rule of 0.5 m wet soil measured with a push probe).

In addition measures of precipitation, evaporation and surface drainage were taken so that an estimate of deep drainage was made (by differencing) for each cropping system in each year. The project also involved adapting and validating the APSIM model (McCown et al. 1996; Paydar et al. 1999) to represent the soil types and rainfall patterns of various locations across the Liverpool Plains. The aim was to quantify the production, nutrient movement and water balance of cropping systems with varying lengths of fallow and perennial pastures, spanning the range of the most ‘leaky’ to the least ‘leaky’ systems. The result is a comparative prediction of agronomic and deep drainage outcomes for the different cropping systems over a range of climatic zones and soil types from 1957 to 1998.

The APSIM cropping systems model was validated using data from the research sites, providing confidence that it could be used for both temporal and spatial extrapolation of the results. APSIM is a paddock-scale model that provides the management detail to allow different cropping systems to be modelled. Once this simulation model was validated against the trial data, further analysis was conducted with 40 years of climate records to simulate results for the various cropping systems in other soil types and rainfall distributions within the catchment.

Agronomic results were generated from APSIM to compare long fallow wheat, continuous (short fallow) wheat, continuous sorghum and opportunity cropping systems (defined by a wheat/sorghum rotation) on a large range of soil types and climatic zones within the catchment. Water that is held in the soil below the wilting point (lower limit) is unavailable to plants. The water held between the wilting point and the field capacity (drained upper limit) is available to plants. This is the soil's available water capacity (AWC). The opportunity cropping rotations were divided into eight different soil water planting rules for both summer and winter. The rules were derived from discussions with local farmers and range from drier AWC ranges 10 cm – 30 cm (winter – summer respectively) to wetter 130 cm – 150 cm AWC triggers for planting (Table 1). The modelled long fallow and continuous wheat systems were the same as the experimental treatments except that in the latter only wheat was used, rather than wheat and barley.

Nine climate zones in total were defined in the catchment, along with 31 soil types. Six zones or locations were suitable for cropping and their parameters are outlined in Table 2. APSIM was run for each relevant climate zone, soil profile type and land use combination (Ringrose-Voase et al. 1999; Ringrose-Voase et al. 2001). Annual deep drainage and crop yield (as well as wheat protein) over the 40-year span 1957-1997 were calculated. This allowed investigation of the interactions between land use, soil type and climate.

Sowing dates for both wheat and sorghum were earlier in the northern part of the plains (the Gunnedah climate zone). In addition, less nitrogen was applied in the Gunnedah zone, in anticipation of lower yields due to drier conditions. Less nitrogen was also applied to non-Vertosols (Table 3) due to shallower possible plant root depth of 90 cm compared to 310 cm for Vertosols. For wheat, the Sunco variety was sown in the first third of the sowing window and Hartog in the latter two thirds.

3.1 Analysis on selected soil types

Four contrasting soil types were selected as illustrative for our purposes. The rules were tested for all six climate locations suitable for cropping on:

- a Black Vertosol, Lever Gully (Type 1);
- a Black Vertosol with a different available water content (AWC), Conadilly (Type 2);
- a Red Sodosol, Fullwoods Road; and
- a Red Kandosol, Stafford Gap.

Lever Gully is a self-mulching, black vertosol found in tertiary basalts on the lower slopes of the Liverpool Ranges. It has very high clay content throughout the profile, good water entry properties and high AWC. Conadilly (Type 2) is a episodic-epicalcareous, self-mulching, black vertosol. Its AWC is less than Lever Gully. Fullwoods Road is a subnatric, red sodosol found on the lower slopes of the Narrabeen Sandstone hills. It has a texture contrast profile with clay subsoil, which is mildly sodic, and a clay loam surface layer. It has a hard-setting surface and relatively poor water entry properties. Its AWC is also less than Lever Gully. Stafford Gap is a mellic, red kandosol found on the upper slopes of the Narrabeen sandstone hills. It has a gradational profile, with a gradual increase in clay from a sandy clay loam at the surface to sandy clay at depth. It is very stony throughout the profile and has very porous subsoil, with large hydraulic conductivity. Whilst its water entry properties are better than Fullwoods Road, it has lower AWC, because much of the porosity is drainable.

4. Previous economic analyses of crop returns and deep drainage

Interest in cropping decisions with implications for saline seep control was reported by Burt and Stauber (1989) for the US North Central States. These authors specified the crop planting decisions based on soil moisture content and set out a decision tree for the process of making crop choices. In their model they specified strategies based on an assumption that decisions were based on soil water at seeding time jointly with most recent land use. This is a Markov process (Howard 1960). They identified the choice of threshold soil water level (x) as important in such decisions. Controlling this parameter is an indirect way of controlling the probability of planting a crop or fallowing. In their model, if x was very low then continuous cropping was chosen and the probability of fallow was very low or zero. Vice versa held for high moisture trigger levels, although a constraint preventing consecutive fallows also operated. Conceptually there is some optimum x for each location.

They noted that for any specific choice of x the decision rule was completely determined. Using average net (farm-level) returns (ANR) for steady-state crop sequences as the appropriate financial measure, they noted that ANR is a function of x. Using input and output prices, experimental trial data and the Markov assumption, they graphed this relationship for spring wheat in Montana. Their graph is reproduced in Figure 2. They noted that economically the best farm decision was to avoid the threshold levels of plant available soil water of less than 2 inches (5 cm). The optimum was in the range 3.5 – 4.5 inches.

Burt and Stauber (1989) did not have data on saline seep associated with different levels of x. However, they noted that the smaller the level of x, the less hazard from saline seep and vice versa. US farmers had to weigh direct economic returns against the saline seep problem, and come up with a reasonable compromise. 'The farmer will avoid the interval on x between 0 and 2 if he has knowledge of a graph like Fig. 2 which applies to his region of farming' (Burt and Stauber 1989 p. 50). These authors concluded that the increase in expected ANR per acre under these strategies in relation to the best fixed rotation were rather modest. However, the potential gains were substantial for areas facing productivity losses from saline seeps.

In the results for northwest NSW presented in this paper graphs similar to Figure 2 are presented with alternative soil water planting rules on the horizontal axis. In addition there are estimates of deep drainage for the same cases, so that an analysis of the trade-offs involved can be undertaken.

5. Methodology

Two approaches to the analysis are presented. The simulated predictions for each crop strategy or soil-water planting rule are presented as a distribution of annual values based on the (daily) climatic sequence from 1957 to 1998. This is one sequence of a population of possible sequences, but it does give a distribution of each factor. The long fallow crop management system is considered to be the historical or default against which others are compared. Many farmers in the region have switched to opportunity cropping in recent years, but there are substantial groups who may be interested in the results when considering whether they should change from long fallow.

The initial analysis uses the mean values of these distributions in making comparisons of alternative management strategies. Financial budgets (described below) are developed based on annual outputs (yield, protein content) and inputs (fertiliser, other inputs). These are compared with average deep drainage figures and a simple classification of win-win cases is made. This is a deterministic or average-value evaluation of crop alternatives.

The second stage of analysis involves looking at the whole distribution of agronomic responses and the resultant spread of financial returns. Unfortunately the distribution of deep drainage values was not available for this analysis. The distributions of gross margins are first compared to see if they are statistically different, using the Kolmogorov-Smirnoff test (Hien *et al*, 1997; Steel and Torrie, 1980). Then the remaining distributions are tested for stochastic dominance (McCarl 1988,1990). A sub-set of management options are then evaluated in a multi-objective criteria analysis, which incorporates the (deterministic) range of responses in both profits and deep drainage. It aims to investigate how the trade-offs between these objectives can be reconciled. This approach makes use of a hypothetical elicited utility function.

This paper is a heuristic exercise, so the analyses are undertaken for one case (the Parraweena climate with Level Gully Vertosol soil). The aim is to generate discussion amongst the research and advisory group regarding methods that could be usefully applied to questions of technology evaluation and adoption.

5.1 Gross margin analysis

Ideally, it would be preferable to compare these systems on a whole farm level, as Burt and Stauber (1989) used average net (farm-level) returns in their analysis. However, a gross margin level analysis of this type is also useful, in terms of being able to generalise, since growers are able to compare this information with their soil type and climatic location. In addition a farm level study may be difficult to interpret, since many farms have different cropping areas, capital investment and objectives.

The budget results for one of the trial sites from 1995 to 1999 were used to estimate the average wheat and sorghum variable costs (excluding nitrogen fertiliser and contract harvesting) as well as summer and winter fallow costs (Table 4). For example, the average cost of all of the winter fallow periods during the trial was used for winter fallow costs. Machinery assumptions and costs and levies are those appropriate to each enterprise under commercial conditions as outlined in Scott (1997 a, b). A gross margin may be defined as the gross income from an enterprise less the variable costs incurred in achieving it. Variable costs are those costs directly attributable to an enterprise and which vary in proportion to the size of an enterprise. The gross margin is not gross profit because it does not include fixed or overhead costs such as depreciation, interest payments, rates or permanent labour which have to be met regardless of enterprise size (Scott 1997 a, b).

The same commodity and individual input prices were used over the whole period. This was to prevent fluctuations in commodity prices and input prices obscuring rotation effects on the gross margins. Wheat prices used were $140 per tonne for 10% protein, $155 per tonne for 11.5% protein, and $175 per tonne for 13% protein with an increment of $0.50 per tonne for every 0.1% increase in protein within each class. Wheat with less than 10% protein was classed as feed wheat with a price of $110 per tonne. The sorghum price used was $124 per tonne.

Nitrogen fertiliser and contract harvest costs were added as part of the gross margin calculation process. For example on Vertosols at the locations ‘Weblands’, 'Quirindi', ‘Parraweena’, ‘Berwicks’ and ‘Roscrae’, it was assumed 100 kg of nitrogen per hectare per crop would be applied. This was equivalent to 217 kg per hectare of urea, which at $410 per tonne of urea resulted in a nitrogen cost of $89.13 per hectare (Table 4). For Gunnedah, it was assumed that 70 kg per hectare of nitrogen for wheat would be applied, and 80 kg per hectare of nitrogen for sorghum. This equated to $62.39 per hectare and $71.30 per hectare respectively.

Additionally, a rule was used that if the yield was so low that income would be less than the cost of harvest, then the crop would not be harvested. The costs incurred (ie. the resultant negative gross margin) would not include harvest costs.

5.2 Stochastic dominance analysis

In order to address the issue of risk, the stochastic dominance technique was used to determine the levels of risk of each option. Observation of the mean, maximum and minimum mean annual gross margins indicated that the various opportunity cropping soil water planting rule options may be more “risky” than the long fallow, continuous cropping wheat or sorghum rotations. This was because the maxima and minima of the opportunity cropping options appeared to be respectively higher and lower than those of the long fallow or continuous wheat or sorghum options (Figure 3).

Cumulative distributions were derived for mean annual gross margin ($/ha) using the “Histogram” data analysis tool in Excel®. There was some concern that the distributions may not be statistically different, due to the fact that the yields and gross margins were derived from 40 years of non-randomised historical rainfall data.

One criticism of stochastic dominance analysis is that it is subject to sampling error due to small sample sets. The sample size in the data set is not large (40 years) so the Komolgorov-Smirnov (K-S) test is used to determine whether the distributions are statistically different, and valid to use stochastic dominance to rank the alternatives according to risk characteristics (Hien *et al*, 1997). The K-S test is a non-parametric test used on two data samples to test whether the sample cumulative distributions are describing the same population. The null hypothesis is that the two distribution being compared are estimators of the same distribution, and the differences in them are due to estimation error. The K-S test statistic is the maximum vertical distance between the two distributions. If the distance is greater than the critical value at the selected significance level, then the null hypothesis may be rejected and concluded that the data indicates the two distributions are statistically different.

As an example of the technique for this paper, the K-S test was applied (with a 5% significance level) to the mean annual gross margin results for the Lever Gully soil type at the Parraweena location. This is the most common climatic location for this soil type.

Stochastic dominance analysis was then undertaken on the selected cropping systems using the “Riskroot” program (McCarl, 1988). The program generates results showing which distributions of mean annual gross margin are dominant for ranges and values of risk aversion coefficients (RACs). This is to facilitate interpretation of the results from a farmer's point of view, and answer the question “Which set rotation or opportunity cropping planting rule would a risk-averse profit-maximising farmer choose?”

5.3 Multi-criteria analysis

Because the crop management decisions in this analysis involve two objectives or attributes – gross margin and deep drainage, an evaluation using multiple objectives was undertaken. Methods from Hardaker, Huirne and Anderson (1997) were used. This type of analysis is not new, but it was pursued here partly for our own learning experience. The elicitation of utility functions and attribute weights was conducted by interviewing an individual who owns and manages an agricultural enterprise, although not located on the Liverpool Plains. The decision analysis was conducted in terms of the 'art of the possible', the spirit of decision analysis underlying Hardaker et al. (1997).

Possible crop management actions were considered to include long fallow wheat (the traditional crop rotation) and the alternatives of continuous sorghum, opportunity cropping 90W_110S and opportunity cropping 50W_70S. The objectives or criteria were presumed to be to increase profit and reduce deep drainage, these being measured by gross margin ($/ha/year) and deep drainage (mm/ha/year). The average measures of these attributes for each action are shown in Table 5.

For this analysis distributional measures of deep drainage were not available. Hence although distributions of gross margins were available, only mean values for these attribute measures were considered and a deterministic analysis conducted. The process involved interviewing the respondent/manager to elicit a utility function for the two attributes based on the figures in Table 5. Then a questioning process determined the weights that could be applied to individual attributes to develop a multi-objective utility function.

6. Results

Initial results are presented graphically in Figures 4 (Mean annual gross margins), 5 (Mean annual deep drainage), 6 (Productivity and crop frequency – Vertosol soil types) and 7 (Productivity and crop frequency – Red soil types), and are discussed in sections 6.1 to 6.3. These results are for the case where mean (point) responses for each climate x soil type case are taken as the certain outcomes.

6.1 Crop sequence gross margins

The gross margins in Figure 4 show a high degree of variability between the shallowest/driest (10W_30S) and the deepest/wettest (150W_170S) planting rule for both vertosol soil types (Lever Gully and Conadilly). This is due to crop frequency declining (Figure 6) as required subsoil moisture increases, whilst productivity (in terms of yield per crop) increases. For the 'deeper' planting rules, the decline in crop frequency outweighs the increase in productivity and the trend for mean annual gross margin per hectare is lower.

On the red soils, the planting rules were only analysed up to 70W_90S, due to a maximum plant root depth of 90cm. For Stafford Gap, the mean annual gross margins are all below zero, indicating that continuous cropping would be unlikely to be profitable on this soil type. On Fullwoods Road the mean annual gross margins are relatively flat, although there is some decline towards the higher planting rule as a result of lower crop frequency (Figure 6) outweighing the increase in productivity per crop.

It is interesting to consider the shape of the opportunity cropping gross margin graphs in Figure 4 compared to Burt and Stauber's Figure 2. Their graph illustrates a more 'classical' response function from which an optimal decision rule can be derived. The simulated responses in Figure 4 indicate that the optimal rule varies more between the climatic locations than between the broad soil types. There appears to be an optimal sowing rule which differs between climates, however there is reasonable imprecision or flatness around each optimal point.

6.2 Deep Drainage

For almost all soil types and climate zones, the APSIM results showed that mean annual deep drainage under opportunity cropping is less than that produced by long fallowing or continuous wheat (Figure 5). Continuous sorghum usually contributes the least deep drainage of all. This is likely to be due to sorghum actively growing during the periods of highest rainfall during the year. For example, in the Parraweena climate zone 62 percent of average annual rainfall occurs from October to March (inclusive). The rainfall distribution for the other climate zones are similar.

6.3 Win-win payoffs

Combining the previous results allows an answer to the question 'Are there cases where a change in cropping strategy leads to greater gross margin and less deep drainage?' The answers are presented in Table 6. The analysis compares all other cropping strategies with long fallow, which is considered the ‘traditional’ system against which alternatives are considered. Because the gross margin calculations are a paddock-level measure, an additional $100/ha requirement has been included as the minimum gross margin required to cover overhead costs. This level will vary from farm to farm, since the level of overhead costs (administration, permanent labour, machinery replacement needs) varies between farms also.

The results in Table 5 indicate that for Vertosol soils and a $100/ha buffer, apart from the cases of drier rainfall combined with shallower/drier sowing rules, there are generally doubly positive benefits associated with changing from long fallow systems to opportunity crop systems. The continuous sorghum and continuous wheat strategies are also generally favoured. This is not the case for the red (Fullwoods Road) soil, where profits are generally not sufficiently higher apart from the wetter climates.

6.4 Komolgorov-Smirnov test results

The K-S test statistic was derived from pairwise comparisons of the mean annual gross margin cumulative distributions for the Lever Gully soil type at the Parraweena location.

The data are specified in the general form $GM_{rotation1,1}$, …..$GM_{rotation1,40}$ and $GM_{rotation2,1}$, …..$GM_{rotation2,40}$ and so the hypotheses are;
H_0: F_1 (GM) = F_2 (GM)
H_1: F_1 (GM) ≠ F_2 (GM)
where F_i is the cumulative distribution function (Steel and Torrie, 1980)

This is a two-sample, two-tailed test, and for n = 40 at the 5% level of significance the critical value is 0.325 (Steel and Torrie, 1980). We reject the null hypothesis if the K-S statistic is greater than the critical value.

On this basis, a relatively small number of pairwise combinations (six out of 55, Table 7) were found to have statistically different cumulative distributions. This indicates that the small number of data points (40, since 40 consecutive years of rainfall data were used) should be increased to better define the rotations and their associated distributions.

6.5 Stochastic Dominance results

Figure 8 shows the cumulative distributions of the mean annual gross margin for each of the selected crop sequences. We are looking at stochastic dominance with respect to a function in this case. The amount of overlap in these distributions requires systematic comparison, and this was done using the Riskroot program (McCarl, 1988). The program generates results showing which distributions of mean annual gross margin are dominant for ranges of risk aversion coefficients (RACs).

Composite results from Riskroot are shown in Figure 9, showing that there were breakeven risk aversion coefficients found. These are RAC ranges over which a given distribution dominates (McCarl, 1988). So only exceedingly risk averse decision makers with an absolute risk aversion coefficient above 0.026 would prefer the 90W_110S planting rule, whilst more moderately risk averse decision makers would prefer long fallow, followed by the 110W-130S planting rule. On this basis, a risk averse decision maker would not select the 10W-30S and 130W-150S planting rules.

As outlined in Parton and Carberry (1995), estimation of the critical value of R, the absolute risk aversion coefficient, would allow us to determine between the 90W_110S planting rule, long fallow and the 110W-130S planting rule. If the range of R values are given by $1/w < R < 3/w$, where w is the wealth of the decision maker (Parton and Carberry, 1995), then the highest level of risk aversion for a farmer with a property worth $1 million is 3×10^{-6}. On this basis the 110W_130S planting rule would be selected.

During farmers discussions to ascertain the planting rule range to analyse, the 50W_70S and 90W_110S rule were the rules more commonly in use. So the 110W_130S rule is a little higher than expected.

In order to investigate this further, an ordering of the five selected alternatives using the E,V (mean-variance) efficiency criterion is shown in Figure 10. Since the degree of risk aversion isn't known, the rule that one alternative dominates another if it has a higher mean and a lower variance (Hardaker *et al*, 1997). According to Figure 10 the E,V efficient set is 90W_110S ,110W-130S and 130W_150S. The choice between them would depend on the individual farmers risk preference.

6.6 Multi-criteria analysis

An elicitation of utilities for each attribute was attempted based on the measures in Table 7. The utilities of gross margin and deep drainage were assumed to be independent, so elicitation was undertaken separately. Questioning for the gross margin utility was straightforward, but the deep drainage case proved difficult. This was because of problems interpreting the meaning of the attribute measures with respect to management actions.

First, deep drainage in the salinity context means that greater drainage levels may be associated with more salinity. But this may impact on the individual manager or for others lower in the catchment, and this probability is unknown. Also the time frame of any impact is unknown. Second, more deep drainage implies that water use for crop growth is less efficient, but unless there is a constraint on water availability the degree of inefficiency is unknown. Third, the respondent noted that the greater deep drainage levels might be associated with less risky enterprises that are easier to manage, although this risk may be associated with lower returns. Because only point estimates were used, because the management choices associated with each attribute level were not identified, and because the utility for gross margins was assumed to be independent of that for deep drainage, the interpretation of what is a 'good' and a 'bad' level of drainage was very difficult.

For these reasons, and because the elicited utility function for gross margins did not exhibit much curvature, it was judged that linear preferences were suitable and proportional scoring was used to evaluate the attribute measures. Following Hardaker et al. (1997) Chapter 8, the best and worst levels for each attribute were assigned utilities of one and zero respectively. Then the proportional scores of intermediate attribute measures were calculated by linear scaling. Implied linear utility functions for deep drainage (U_D) and gross margins (U_G) were derived as follows:

$$U_G = -1.99 + 0.01GM$$

$$U_D = 1.06 - 0.02DD\,.$$

The method of swing weights was used to find appropriate attribute weights allowing the above attribute utilities to be combined into estimates of the decision maker's overall preferences for the management alternatives. The respondent was asked about the relative importance of changing an attribute from its least preferred level to its most preferred. He indicated that if either attribute could be improved from its worst to its best case (from Table 7), he would choose the gross margin attribute to be most important. Further, for him the importance of improving deep drainage from its worst to its best level was only 50% compared to improving gross margin.

Given this information, and assuming the utility weights sum to unity, the relative importance of each attribute utility for this respondent was calculated to be 0.67 and 0.33 for U_G and U_D respectively. Applying these weights to the proportional scores calculated previously and used to derive the linear utility functions above, the weighted utilities for the four management actions were zero for long fallow, 0.82 for continuous sorghum, 0.89 for opportunity cropping 90W_110S, and 0.84 for opportunity cropping 50W_70S. Based on these figures, the elicited preferences for this manager/respondent indicate a preference for the wetter opportunity cropping strategy.

To show the sensitivity of these results to the input information, if the respondent had said that reducing deep drainage was 70% as important as improving gross margins then the overall preference would change to opportunity cropping 50W_70S. This accounts for the better performance on average deep drainage for the drier opportunity cropping planting rule.

7. Discussion and conclusion

With rising interest in ways to mitigate salinity risk, the issue of likely deep drainage levels under alternative crop management practices is important for the Liverpool Plains (and other) regions of northern NSW. Burt and Stauber (1989) proposed that there is an economic response (and an optimum) to different soil water planting rules in the US, but many farmers on the Liverpool Plains have discovered this for themselves and developed opportunity cropping systems.

Although the relationships between recharge at some point and discharge somewhere else are in general unknown, and so salinity causes and effects are somewhat conjectural, the general idea of reducing deep drainage by more efficient use of water appeals in a crop efficiency sense. That there may be increased profits associated with systems under which drainage is reduced is the question asked here. This is only answerable when a visionary and meticulously-performed project has been completed to provide the basic data. The use of an agronomic simulation model to extend field results beyond the tyranny of site and season has allowed much of our analysis to proceed.

In this paper we have looked at a range of economic analyses and tools to begin the evaluation task. Point (deterministic) estimates of gross margin and deep drainage for combinations of crop management, soil type and climatic pattern were developed and presented. Combining these measures in a 'win-win' table showed that there appear to be many opportunities for the traditional long fallow wheat rotation to be improved in terms of both increased profits and reduced deep drainage.

An investigation of the distributions of paddock-level financial returns was undertaken. The statistical tests for differences and the stochastic dominance analysis provide some indicative results, but more work is needed to hone these analyses. In general this analysis showed that opportunity cropping could improve the distribution of profits, although long fallow has advantages in terms of lower management inputs. This component of the analysis did not account for the deep drainage outcomes.

The last analysis included both financial and drainage outcomes in a multi-criteria analysis which tried to develop a joint utility function. We concluded that some of the opportunity cropping strategies did appear to be superior to long fallow.

The use of some of these methods was included and presented in an attempt to 'learn by doing', and we hope that further refinement of our analyses will follow discussion and criticism of the work presented here.

References

Burt, Oscar R. and Stauber, M.S. (1989), 'Dryland Cropping Decision Theory with Application to Saline Seep Control', *Journal of Production Agriculture* 2(1): 47-57.

Hardaker, J.B., Huirne, R.B.M. and Anderson, J.R. (1997) *Coping with Risk in Agriculture*, CAB International.

Hien,V., Kabore, D., Youl, S. and Lowenberg-DeBoer, J. 1997, "Stochastic dominance analysis of on-farm trial data: The riskiness of alternate phosphate sources in Burkina-Faso", *Agricultural Economics*, Vol. 15, pp 213-221.

Howard, R.A. (1960) *Dynamic programming and Markov processes*, Technology Press and John Wiley and Sons, New York.

McCarl, B.1988, *Riskroot Program Documentation*, Texas A&M University, College Station, Texas, USA.

McCarl, B.A. (1990), 'Generalised Stochastic Dominance: An Empirical Examination', *Southern Journal of Agricultural Economics* 20(2): 25-33.

McCown, R,L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P. and Freebairn, D.M. (1996), 'APSIM: a novel software system for model development, model testing and simulation in agricultural systems research', *Agricultural Systems* 50: 255-271.

National Land and Water Resources Audit (2001), *Australian Dryland Salinity Assessment 2000: Extent, impacts, processes, monitoring and management options* Commonwealth of Australia.

Parton, K.A., and Carberry, P.S. (1995), 'Stochastic Dominance and Mean-Standard Deviation Analysis: Some Critical Issues', *Australian Journal of Agricultural Research* 46: 1487-91.

Paydar, Zahra, Neil Huth, Anthony Ringrose-Voase, Rick Young, Tony Bernardi, Brian Keating, Hamish Cresswell, John Holland and Ian Daniells (1999), 'Modelling Deep Drainage Under Different Land Use Systems. 1. Verification and Systems Comparison', *Proceedings of International Congress on Modelling and Simulation*, Hamilton, New Zealand, 6-9 December.

Ringrose-Voase, Anthony, Zahra Paydar, Neil Huth, Robert Banks, Hamish Cresswell, Brian Keating, Rick Young, Tony Bernardi, John Holland and Ian Daniells (1999), 'Modelling Deep Drainage Under Different Land Use Systems. 2. Catchment Wide Application', *Proceedings of International Congress on Modelling and Simulation*, Hamilton, New Zealand, 6-9 December.

Ringrose-Voase, A.J., Young, R.R., Huth, N.I., Paydar, Z., Bernardi, A.L., Banks, R.G., Johnson, R.M., Cresswell, H.P., Keating, B.A., Scott, J.F., Holland, J.F. and Daniells, I. (2001), 'A Tool to Aid Development of Land Use Strategies at a Catchment Scale to Reduce Dryland Salinity Risk', *Proceedings of International Congress on Modelling and Simulation*.

Scott, F. (1997a), Farm Budget Handbook 1997, Winter Crops, Northern NSW, NSW Agriculture Tamworth, January 1997, 66 pp.

Scott, F. (1997b), Farm Budget Handbook 1997, Summer Crops, Northern NSW, NSW Agriculture Tamworth, September 1997, 80 pp.

URS. (2001), *Liverpool Plains Catchment Investment Strategy for the Liverpool Plains Land Management Committee*, May 2001, URS Australia Pty Ltd

Young, R.R. (1999), 'Cropping and pasture systems to manage rising water tables and dryland salinity on the Liverpool Plains' Final Report to the Grains Research and Development Corporation on Project DAN 159N [1993 – 1999]. NSW Agriculture, Tamworth.

Table 1: Opportunity cropping planting rules

Sowing rule (Includes rules for all shallower depths)	Available soil water to trigger sowing wheat		Available soil water to trigger sowing sorghum	
	Depth, cm	Proportion of available water	Depth, cm	Proportion of available water
			10	0-99%
OP 10W_30S ➚	10	50-99%	30	≥75%
OP 30W_50S ➚	30	≥75%	50	≥75%
OP 50W_70S➚	50	≥75%	70	≥75%
OP 70W_90S ➚	70	≥75%	90	≥75%
OP 90W_110S ➚	90	≥75%	110	≥75%
OP 110W_130S➚	110	≥75%	130	≥75%
OP 130W_150S➚	130	≥75%	150	≥75%
OP 150W_170S➚	150	≥75%	170	≥75%

➚ *For any rule (***eg.** *OP50w/70s) use the rules in the same row and all previous rows*

Table 2. Summary of rain, evapotranspiration and frost data for cropping locations

Location	Mean annual:			Last	Proportion of
	Rain mm/year	**ETp** mm/year	**Frosts** days/year	**frost** 95^{th} %ile	**Catchment** represented
Gunnedah SCS[1]	626	1,884	11.9	14 Sep	31.7%
'Weblands'	627	1,725	22.3	24 Sep	10.9%
Quirindi PO[1]	652	1,699	24.5	30 Sep	20.6%
'Parraweena'[2]	680	1,718	23.3	26 Sep	13.0%
'Berwicks'	718	1,669	26.2	30 Sep	5.4%
'Roscrae'[2]	744	1,630	27.2	30 Sep	10.3%

Locations are named after a Bureau of Meteorology weather station ([1]) or rainfall station ([2]) within the same grid square, or after a nearby property or landmark. Etp is evapotranspiration.

Table 3. Sowing rules used in the long-term APSIM simulations

	Climate zone: Gunnedah	Climate zone: Others
Wheat		
Window for Sunco	1-31 May	1-14 June
Window for Hartog	1 June-31 July	15 June-31 July
Available soil water requirement to trigger sowing		
0-10 cm depth	50-99%	50-99%
10-30 cm depth	≥75%	≥75%
30-50 cm depth	≥75%	≥75%
Nitrogen fertiliser applied for Vertosols	70 kg/N/ha	100 kg/N/ha
Nitrogen fertiliser applied for Non-Vertosols	42 kg/N/ha	60 kg/N/ha
Sorghum		
Window	21 October-10 January	7 November-10 January
Available soil water requirement to trigger sowing		
0-10 cm depth	0-99%	0-99%
10-30 cm depth	≥75%	≥75%
30-50 cm depth	≥75%	≥75%
50-70 cm depth	≥75%	≥75%
Nitrogen fertiliser applied for Vertosols	80 kg/N/ha	100 kg/N/ha
Nitrogen fertiliser applied for Non-Vertosols	50 kg/N/ha	60 kg/N/ha

Table 4. Average costs used in the economic analysis of the APSIM results

	Costs, $/ha						
	Basic	Nitrogen				Harvest	
		Gunnedah zone		Other zones		Up to 2.5 tonnes grain/ha	Increase per tonne grain/ha over 2.5
		Vertosols	Non-Vertosols	Vertosols	Non-Vertosols		
Wheat	126.34	62.39	37.43	89.13	53.48	35.00	15.00
Sorghum	141.80	71.30	44.57	89.13	53.48	40.00	6.30
Winter fallow	39.70						
Summer fallow	45.50						

Table 5. Deterministic estimates of attribute levels for management actions

Management action	**Deep drainage mm/ha/year**	**Gross Margins $/ha/year**
Long fallow	50	183
Continuous sorghum	3	250
Opp Crop 90W_110S	18	275
Opp Crop 50W_70S	6	260

Table 6: Win-win scenarios for paddock profits and deep drainage

Minimum mean gross margin required $ 100 per ha per year (default is zero)

Soil: Lever Gully (Type 1)

	OP 10w 30s	OP 30w 50s	OP 50w 70s	OP 70w 90s	OP 90w 110s	OP 110w 130s	OP 130w 150s	OP 150w 170s	Sorghum	Wheat
Mean annual gross margin $/ha/year										
Gunnedah	NO	NO	YES	YES	YES	YES	YES	NO	NO	NO
Weblands	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
Quirindi	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
Parraweena	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Berwicks	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Roscrae	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Soil: Conadilly 2

	OP 10w 30s	OP 30w 50s	OP 50w 70s	OP 70w 90s	OP 90w 110s	OP 110w 130s	OP 130w 150s	OP 150w 170s	Sorghum	Wheat
Mean annual gross margin $/ha/year										
Gunnedah	NO	NO	YES	YES	YES	YES	YES	NO	NO	NO
Weblands	NO	NO	NO	YES	NO	YES	YES	YES	YES	NO
Quirindi	NO	NO	NO	YES	YES	NO	YES	YES	YES	NO
Parraweena	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Berwicks	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
Roscrae	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Soil: Fullwoods Road

	OP 10w 30s	OP 30w 50s	OP 50w 70s	OP 70w 90s	OP 90w 110s	OP 110w 130s	OP 130w 150s	OP 150w 170s	Sorghum	Wheat
Mean annual gross margin $/ha/year										
Gunnedah	NO	NO	NO	NO	-	-	-	-	NO	NO
Weblands	NO	NO	NO	NO	-	-	-	-	NO	NO
Quirindi	NO	NO	NO	NO	-	-	-	-	NO	NO
Parraweena	NO	NO	NO	NO	-	-	-	-	NO	NO
Berwicks	YES	YES	YES	NO	-	-	-	-	NO	NO
Roscrae	YES	YES	YES	YES	-	-	-	-	NO	NO

Table 7: Statistically different pairwise combinations for Lever Gully at Parraweena location

Comparison	Against
10W-30S	90W_110S
	110W_130S
	130W_150S
	Long fallow
90W_110S	Long fallow
110W_130S	Long fallow

Figure 1: Dryland salinity risk 2000
Source: National Land and Water Resources Audit 2001

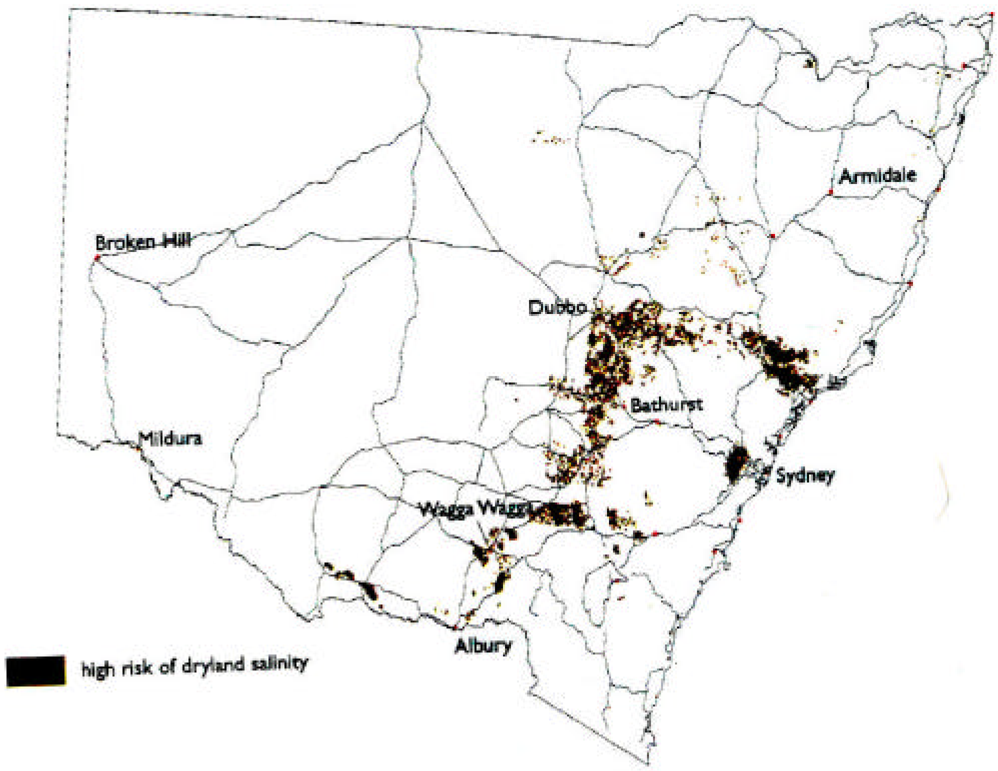

Figure 2: Threshold level of plant available soil water
Source: Burt and Stauber 1989

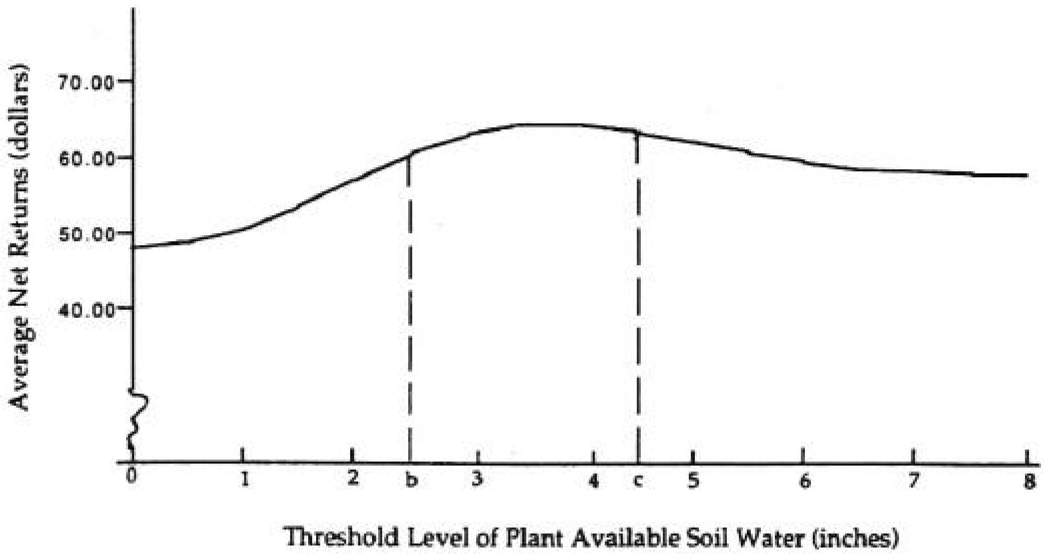

Figure 3: Variation in gross margin at one location and soil type

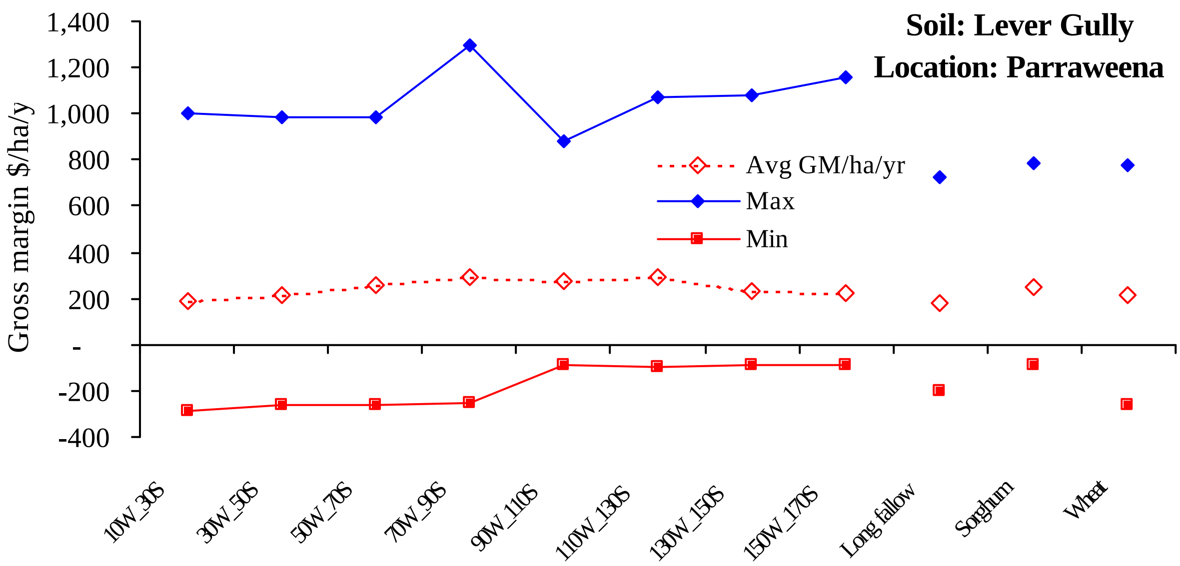

Figure 4: Mean annual gross margins

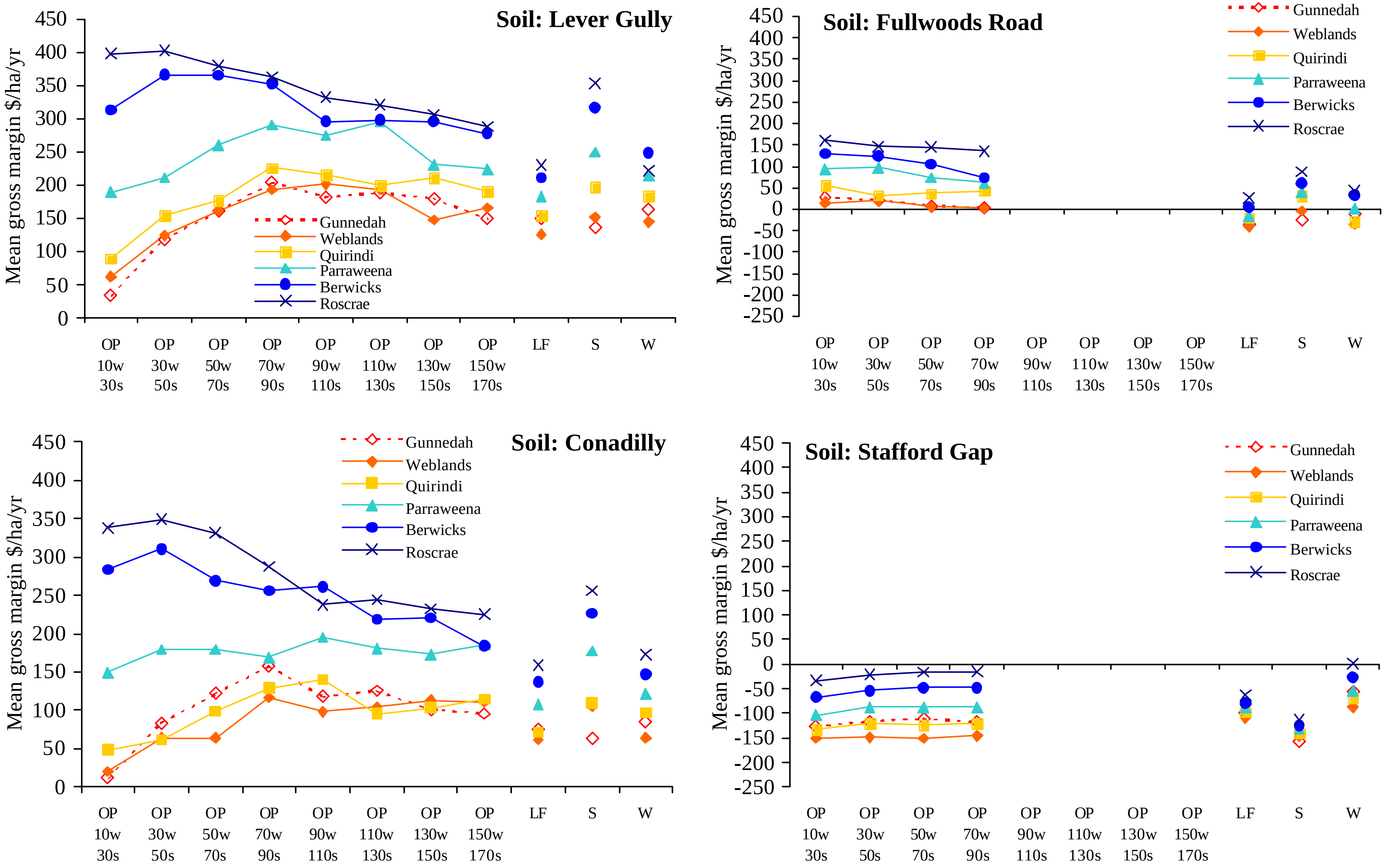

Figure 5: Mean annual deep drainage

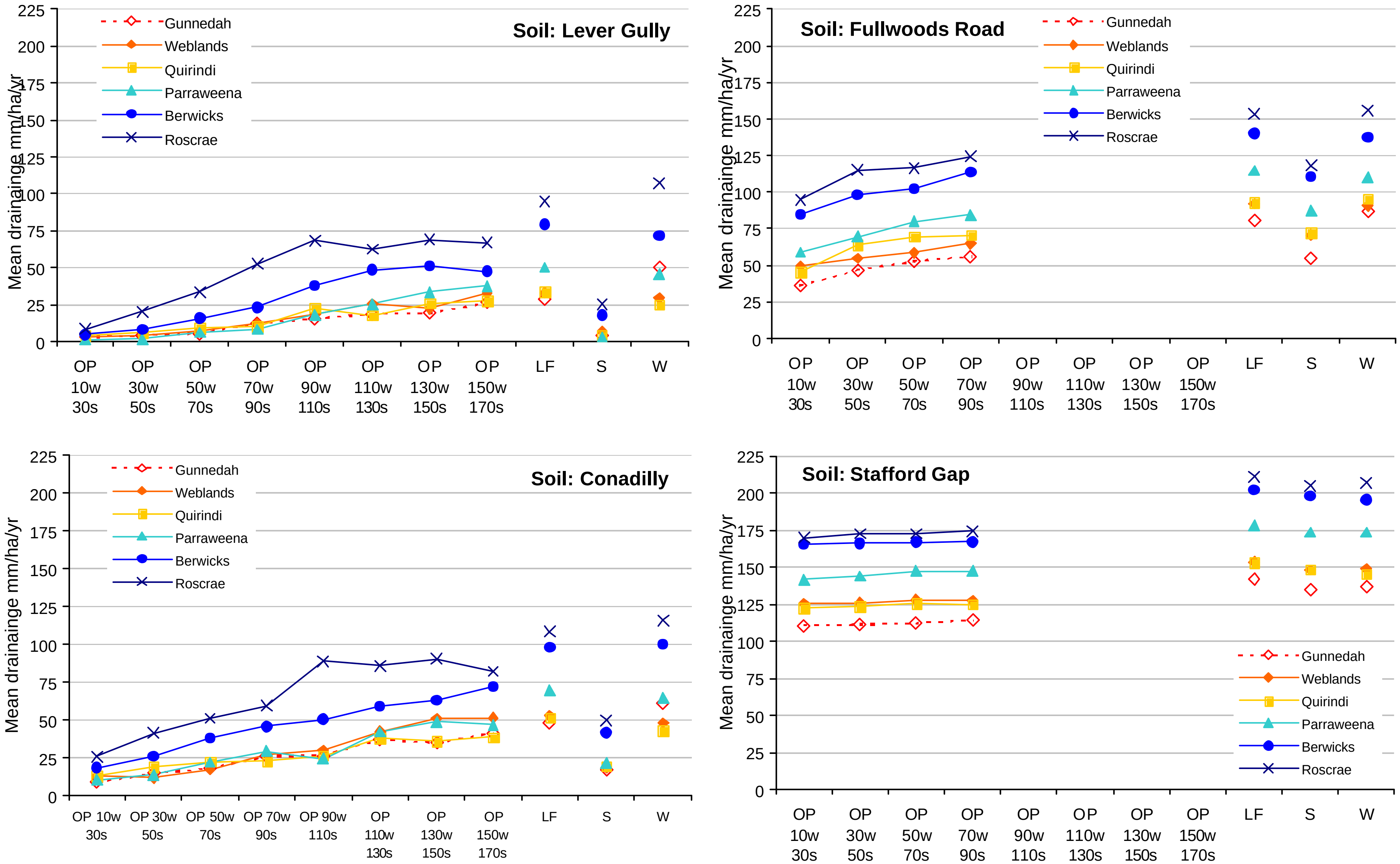

Figure 6: Productivity and crop frequency-Lever Gully and Conadilly soil types

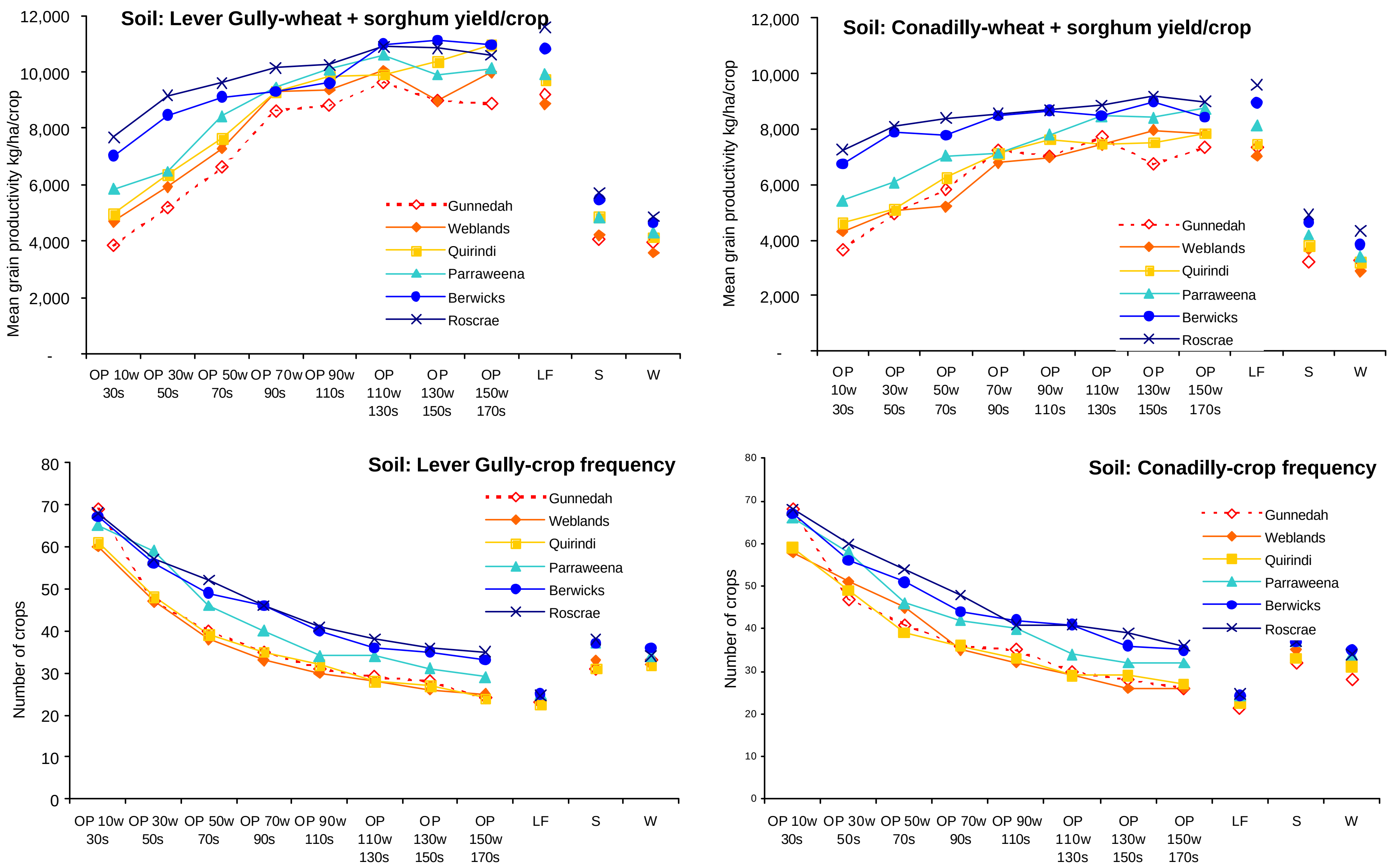

Figure 7: Productivity and crop frequency-Fullwoods Road and Stafford Gap soil types

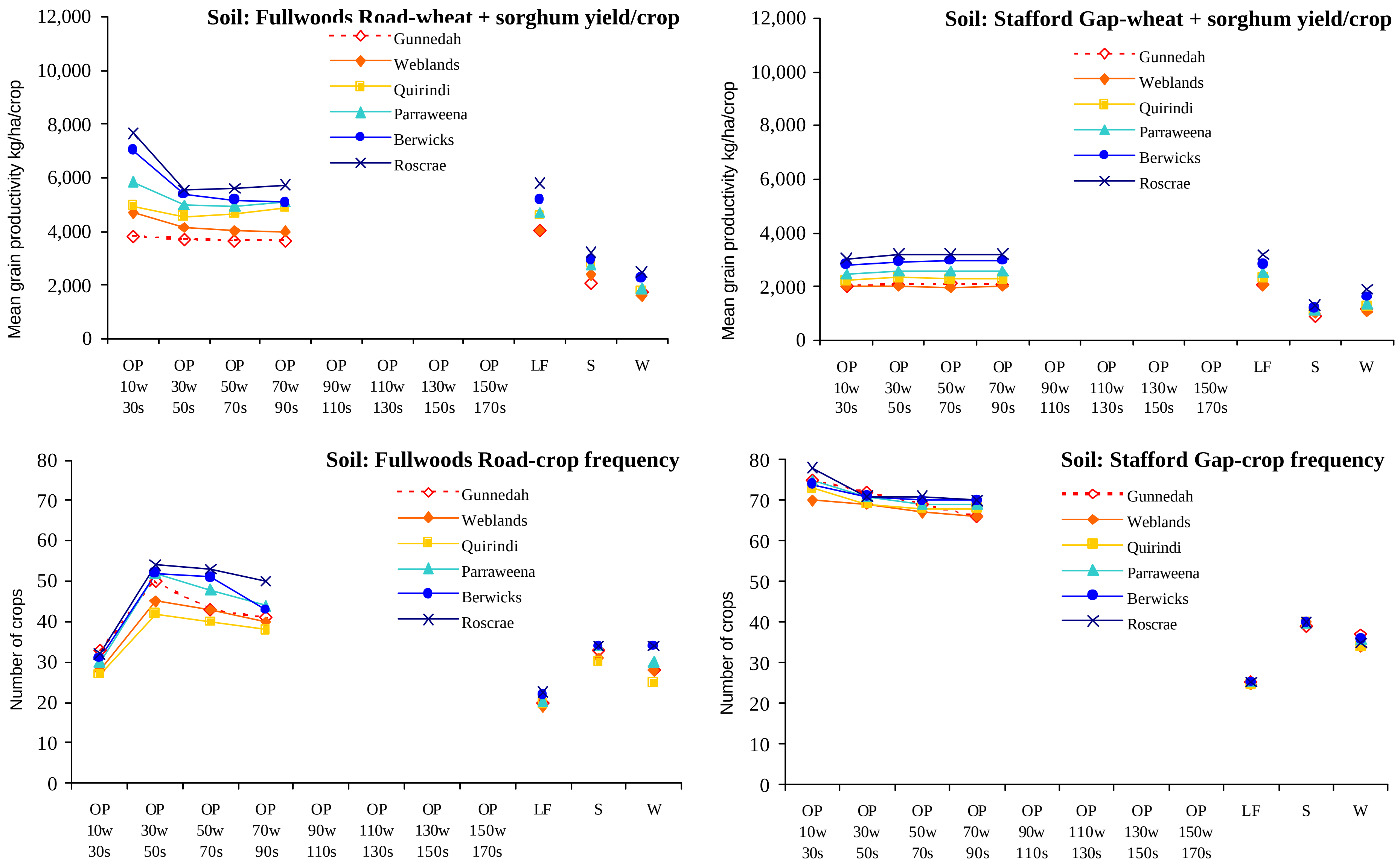

Figure 8 : Comparisons for Lever Gully soil type at Parraweena

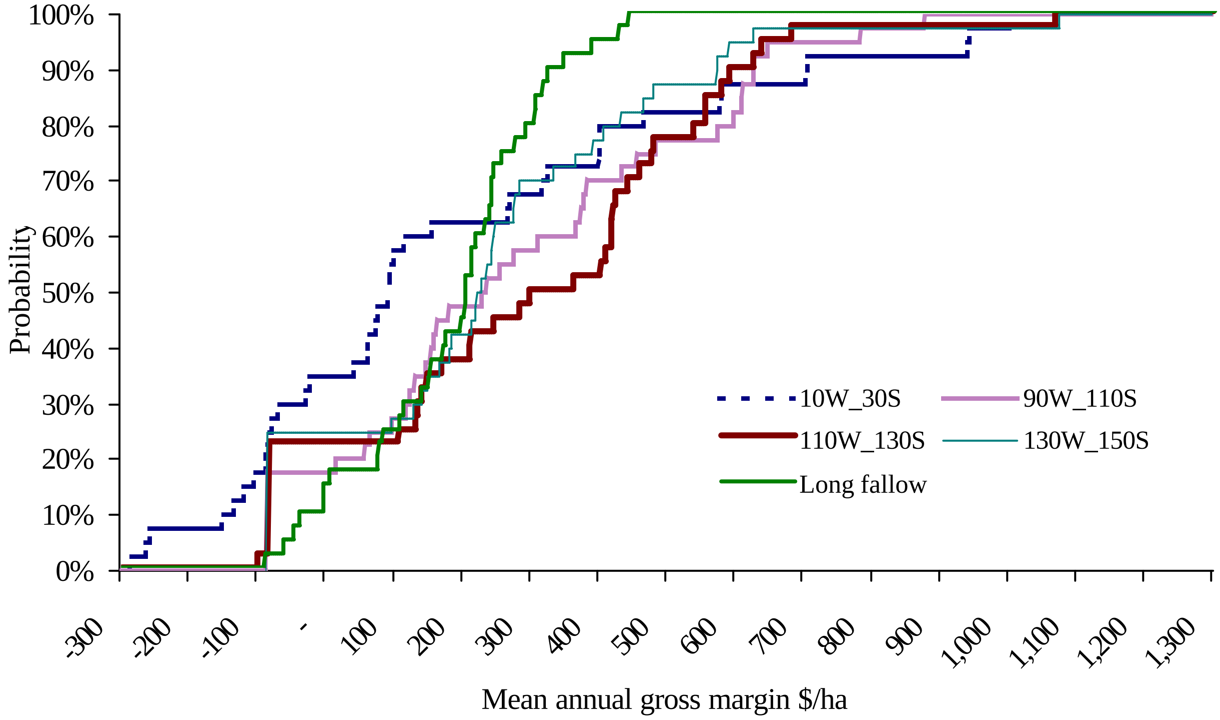

Figure 9 : Risk Aversion Coefficients for selected crop sequences

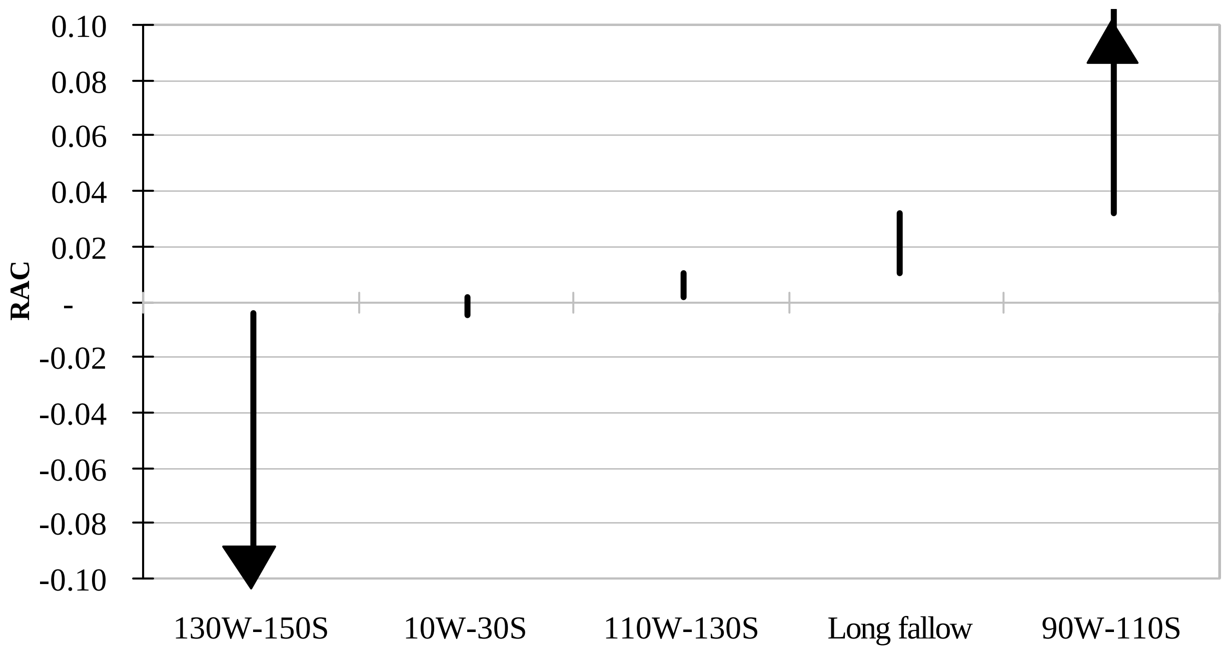

Figure 10: Five selected crop sequences in E,V space