How profitable are perennial pasture phases in Western Australian cropping systems?

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Summary Previous research has indicated that, in most parts of Western Australia, it is not currently profitable to plant lucerne (*Medicago sativa* L.) on the scale required for salinity abatement. However, these investigations have not incorporated the long-term benefits that accrue from the use of lucerne to enhance management of weeds, especially for those growers facing the threat or actual presence of herbicide resistance. This work is an investigation of the economics of lucerne when these various benefits are considered simultaneously. An existing model for analysing herbicide resistance in annual ryegrass (*Lolium rigidum* Gaud.) in Western Australia (Ryegrass Resistance and Integrated Management – RIM) is extended to include lucerne and recharge. It is demonstrated that crop rotations involving a regular pasture phase increase long-term profitability, relative to that of continuous cropping, because of improved weed management, reduced chemical use and through increasing yields in subsequent cereal crops. The first two benefits help reduce the evolution of herbicide resistance. In addition, the incorporation of lucerne in a rotation can significantly reduce recharge. These results indicate that lucerne pasture phases have increased value when implications for long-term productivity are considered, suggesting adoption on a greater scale with consequent benefits for salinity mitigation.

Keywords Lucerne, soil salinity, herbicide resistance.

INTRODUCTION

Secondary soil salinity affects over 1.8 million hectares of agricultural land in Western Australia, representing around three-quarters of the total area affected by dryland salinisation on this continent (McFarlane and Williamson 2002). The primary cause of this degradation has been the clearance of deep-rooted native vegetation and its replacement with farming systems based on annual plants across 20 million hectares (Hatton and Nulsen 1999, Latta *et al.* 2001). The shallow rooting depth of annual species reduces their capacity to dry the soil to depth and their senescence over summer reduces the period of transpiration. A higher proportion of rainfall consequently drains through the soil profile, compared with that under native vegetation, and mobilises ancient salt deposits. Low land gradients limit discharge across a significant proportion of the landscape (Ward and Asseng 2002) and therefore the saline water table gradually rises, eventually reaching the root zone of agricultural plants and restricting their growth through waterlogging and salt toxicity.

Deep-rooted perennials can reduce deep drainage by growing in response to out-of-season rainfall and by creating a buffer of dry soil that absorbs the recharge of subsequent crops. A large proportion of the landscape must be planted in perennial plants if significant reductions in recharge are to be achieved (Clarke *et al.* 2002). Indeed, George *et al.* (1999) estimates that as much as 70 to 80 percent of the landscape may need to be planted to such species. Deep-rooted perennial pasture is a viable means of reducing recharge on a large-scale (Latta *et al.* 2001, Latta 2003), particularly in light of the expense of agroforestry (Cacho *et al.* 2001) and the off-site impacts of engineering options (Pannell *et al.* 2001). Lucerne (*Medicago sativa* L.) is the species most suited to wide scale adoption because it provides valuable out-of-season feed for livestock and uses significantly more water than annual species (Latta *et al.* 2001). This legume can also be productive in acid soils in areas of low rainfall (300–400 mm) (Latta 2003) and is therefore suited to reducing recharge across a significant proportion of the Western Australian wheatbelt, a region in which the area of salinised land is expected to double over the next 20 years (McFarlane and Williamson 2002).

Adoption of perennial pastures, especially at the scale at which the catchment effects of salinisation are to be significantly reduced, depends primarily on their profitability (Bathgate and Pannell 2002). This includes the value of production forgone by the inclusion of a pasture phase, a concept described as opportunity cost in economic theory. The opportunity cost of pasture has been significant in recent decades as there have been extended periods in which the profitability of cropping has been high relative to that of livestock. This opportunity cost is higher with lucerne compared with annual pastures, as phases are generally longer because of the high cost of establishment and the need to establish a dry soil buffer of sufficient size. The value of the pasture phase to subsequent crops has also diminished with technological development. The use of fertiliser, selective herbicides, and the introduction of a number of pulse crops, such as lupins (*Lupinus* spp.), has reduced the reliance on pasture for nitrogen provision and weed control. These factors have all decreased the perceived profitability of the pasture phase and have favoured extended cropping cycles.

Such decisions are rational responses to short-term economic signals. However, the optimal management of natural resources requires consideration of long-run effects as current decisions often incur a user cost, a foregoing of future income accruing to a decline in quantity or quality of a base resource. Extended cropping cycles can have detrimental long-term consequences for agricultural productivity, even though appearing economic in the short-term. An important cost is that of increased salinisation risk in agricultural systems based on annual species. Another is that associated with the development of herbicide resistance in major cropping weeds (Powles and Holtum 1990).

An important benefit of a perennial pasture phase that has the potential to contribute to its profitability is an ability to delay the onset of herbicide resistance. To date this feature has been omitted from economic analyses of dryland salinisation. A perennial pasture like lucerne permits the use of a wider range of control strategies in an integrated weed management approach (Powles *et al.* 1997) to exhaust weed seed banks. These include grazing, competition from pasture plants, the use of a broader range of herbicides, spray-grazing, spray-topping, green-manuring, pasture topping through mechanical means, burning, and hay or silage making.

The objective of this research is to investigate the profitability of a perennial pasture phase, in relation to continuous cropping, when benefits for soil salinisation and herbicide resistance management are considered simultaneously. This work uses bioeconomic modelling to provide valuable insight into the long-term implications of cropping and weed management decisions. It is demonstrated that incorporating lucerne, and pasture phases in general, in crop sequences increases long-term profit when herbicide resistance and hydrological benefits are accounted for.

METHODOLOGY

The Ryegrass RIM (Resistance and Integrated Management) model is designed for analysing the management of herbicide resistant annual ryegrass (*Lolium rigidum* Gaud.) in Western Australia (Pannell *et al.* 2003). This is a deterministic simulation model describing the multiple-cohort dynamics of both plants and seeds and their interaction with a broad range of weed control strategies, including crop sequences, selective and non-selective herbicides, and cultural methods, such as burning. This framework portrays the management of a single field on an average sandplain soil in the eastern wheatbelt of Western Australia.

Ryegrass RIM contains 35 weed treatments, with compatibility varying by enterprise, available across different times of the year. Each herbicide mode-of-action group can only be used a limited number of times before resistance occurs. For example, only two herbicides in Group A can be used in the model before ryegrass becomes resistant to further applications. However, this assumption and most other parameters in the model can be altered by the user to make the model more specific to a given system. Seven different enterprise options may be selected. These are wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), canola (*Brassica napus* L.), lupins, self-regenerating subterranean clover (*Trifolium subterraneum* L.), French seradella (*Ornithopus sativa* Brot. cv. Cadiz), and a volunteer pasture. For this analysis, we have extended the 2002 version of the Ryegrass RIM model to incorporate a lucerne enterprise and groundwater recharge.

Information concerning lucerne management and the effectiveness of different weed treatments available during a perennial pasture phase came from a variety of sources. The majority were drawn from unpublished data provided by the Department of Agriculture Western Australia (DAWA), information provided by DAWA staff and researchers at the Western Australian Herbicide Resistance Initiative (WAHRI), and published work. Recharge values are taken from estimates for a good sandplain soil in the eastern Wheatbelt region listed in O'Connell (2003). The buffer created by lucerne is established using the default values used in the Leakage/Buffer Model (LeBuM) model (Ward and Asseng 2002).

The aim of management is to maximise Net Present Value (NPV) from a 20 year planning period utilising a low-input weed management strategy. Different management options in the simulation model are compared by observing their effect on this objective. Strategies are believed to be near-optimal but no guarantee of optimality can be given because of the high number of possible combinations incorporated in this framework.

Following Monjardino *et al.* (2004), strategy one is a continuous cropping sequence (denoted below as CC for convenience) and consists of a barley-lupin-wheat-wheat rotation. Strategy two involves the tactical use of a two-year pasture phase. Volunteer pasture is heavily grazed and desiccated in the first year. French seradella is sown in the second year and is also heavily grazed and desiccated. This strategy permits cropping phases of significant length, provides excellent weed control, and is very low-cost. The pasture phase is used when weed burdens are significant following an extended cropping cycle, represented in the model as recurring rotations of strategy one. This strategy is denoted in the following discussion as CC+VZ. Strategy three involves the repetition of one cycle of strategy one (four years of crop) followed by three years of lucerne pasture. Strategy four incorporates two cycles of strategy one (a total of eight years of crop) followed by a three-year lucerne phase. Strategies three and four (each of which commence with a lucerne phase) are represented as 4C+3L and 8C+3L respectively. Finally, strategy five involves a typical ley farming system, consisting of two years of subterranean clover pasture followed by two years of wheat. Subterranean clover is sown in the first year of the planning period and then regenerates from hard seed in subsequent phases. This strategy is denoted below as 2P2W.

Barley and the first year of wheat is always sown using a high crop seeding rate and is planted 20 days after the break of the season following the use of an autumn tickle and a single application of a knockdown herbicide (glyphosate). The second year of wheat is the same except that Spray.Seed™ is used as a knockdown in place of glyphosate. Barley is always swathed. Lupins are always sown at the break of season. Selective herbicides (Hoegrass™, Fusilade™, simazine, and trifluralin) are used tactically across all enterprises in response to observed weed burdens. Lucerne pasture is sown 50 days after the break of the season following an autumn tickle and a double application of knockdown herbicide. It is heavily grazed in the second and third years and winter-cleaned with Spray.Seed when required. It is removed in the spring of its third year with 1.0 L of glyphosate and 1.5 L of 2,4-D Amine. In strategy five, subterranean clover is spray-topped with Gramoxone™ in its second year.

RESULTS AND DISCUSSION

Crop sequences incorporating pasture phases are predicted to be as profitable or more profitable than continuous cropping in the RIM model (Figure 1). The most profitable strategy is that including the most frequent appearance of pasture in rotation, a traditional ley farming sequence (2P2W). The tactical use of a low-input pasture phase for weed control (CC+VZ) is also effective in significantly increasing profit above that for continuous cropping (CC). Those rotations containing lucerne are also of value, with that incorporating a longer cropping phase (8C+3L) earning a slightly higher NPV.

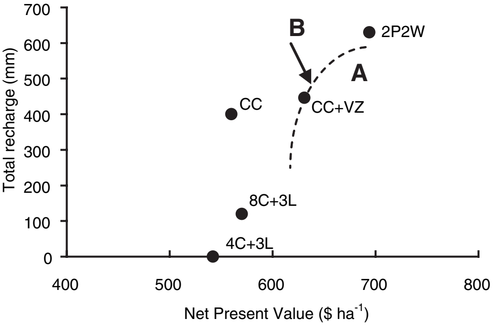

Figure 1. Profitability and total recharge over the planning period (20 years) for each strategy.

There is a positive relationship between long-term profitability, as measured by Net Present Value, and the total level of recharge over the planning period (Figure 1). Recharge declines as the proportion of a rotation that consists of lucerne increases. The true value of a lucerne phase in terms of salinity mitigation is difficult to quantify. Soil, hydrological, and climate characteristics are heterogeneous both spatially and temporally, particularly across the diverse cropping regions of Western Australia. This complicates endogenising a saline watertable and its interaction with yield dynamics. A number of analyses (for example that of O'Connell 2003) have therefore focused on the identification of generalised trade-off curves representing relationships between profit and recharge.

The positively sloped line inferred by the data points in Figure 1 is an example of such a trade-off curve. This can help to identify a sustainable rotation through the use of standard graphical utility maximisation techniques from economic theory (Varian 1992). Assuming that increased recharge will lead to eventual decreases in yield for the producer, a sound assumption for Western Australian conditions given low land gradients and a high incidence of local aquifers (Pannell *et al.* 2001), a superior policy can be thought of one lower and further to the right in Figure 1. This infers a family of inverted indifference curves, similar to that portrayed as a dashed line and denoted by **A** in Figure 1. The convexity of the indifference curve reflects the rate of substitution between an additional unit of recharge in relation to a decrease in

NPV. Preferences for sustainable levels of recharge can be derived from hydrological models of a farm unit and the consideration of their long-term implications for profit. Such a relationship can also theoretically be identified for producers on land above a regional aquifer, where models may be used by catchment managers to identify farm-specific targets. The point of tangency between indifference curves representing these preferences and the trade-off function can then theoretically be used to identify the optimal rotation. An example is point **B** in Figure 1.

There are a number of important drivers underpinning the higher profitability of crop sequences incorporating pasture phases displayed in Figure 1. These are observable by comparison of the annual gross margins for the eight-year crop rotation followed by three years of lucerne (8C+3L) and the continuous cropping (CC) scenario (Figure 2).

The gross margins for the continuous cropping strategy are low over the first half of the planning period relative to the potential, such as seen with the wheat crop in year six (black bar, Figure 2). This occurs for two reasons. First, yields are reduced because of significant weed populations. Second, costly treatments are required to reduce the seed-set of annual ryegrass to decrease competition in subsequent crops.

The gross margin for the first year of cropping after the lucerne phase (the black bar in Figure 2 for Year 4) reflects a yield increase associated with higher nitrogen levels, improved soil structure, and reduced disease. This is significant even after initial estimates are controlled for possible detrimental effects, such as overdrying of a soil and crops competing with lucerne plants persisting after pasture removal. A yield response for crops following lupins is also represented in the model. However, this effect is dominated by losses associated with significant weed burdens and expensive treatments in subsequent crops, as weeds cannot be controlled as easily or effectively as in a pasture phase. This cost is additional to the lower gross margin earned in the year that lupins are used, for example Year 2 of the continuous cropping strategy in Figure 2.

The lucerne phase is used in the first three years of the planning period for the 8C+3L rotation to reduce the initial weed burden to sustainable levels. The significant loss in the first year in Figure 2 is the cost of establishing this pasture. This contributes to lowering the profitability of the lucerne pasture phase, in comparison with those strategies involving either a volunteer-French seradella sequence (CC+VZ) or a subterranean clover (2P2W) component. There are no establishment costs for a volunteer pasture but those for French seradella and subterranean clover are significant (-\$62 and -\$74 respectively). However, these are minimised because French seradella is only used sporadically and subterranean clover in a ley farming system only requires one sowing at the beginning of the planning period. In addition, these costs can be reduced through the grazing of the pasture in the first year and on-farm harvesting of seed. Lucerne is comparatively more expensive to establish, particularly because only light grazing can be supported in its first year. This highlights the importance of decreasing the establishment costs for lucerne, a result consistent with the recommendation to inter-crop with companion crops when establishing this perennial (Latta 2003).

An additional benefit of a crop sequence incorporating a pasture phase is slowing the rate of herbicide resistance. Reliance on highly effective selective herbicides in a continuous cropping system leads to

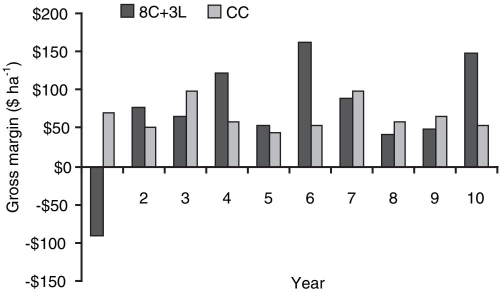

Figure 2. Annual gross margins for the 8C+3L (lucerne Year 1) and the CC sequence for the first half of the planning period.

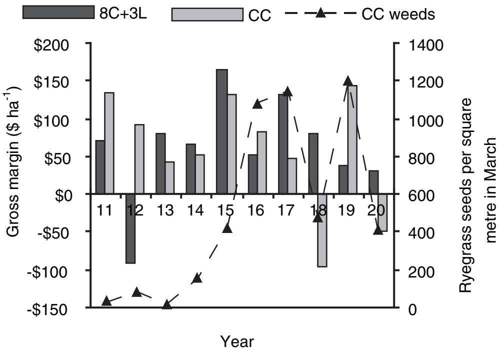

Figure 3. Annual gross margins for the 8C+3L rotation and the CC sequence and the dynamics of the annual ryegrass seedbank under continuous cropping for the second half of the planning period.

their exhaustion as annual ryegrass becomes resistant to their mode of action. Weed burdens subsequently become significant without the incorporation of a pasture phase (Figure 3).

The significant loss in Year 18 is experienced after green-manuring is required to control a burgeoning weed population, represented in Figure 3 as the number of annual ryegrass seeds per square metre in March. After earning a significant gross margin in Year 19, reflecting yield benefits from the green-manuring of the prior lupin crop, weed burdens are again significant. This requires cutting the wheat crop in Year 20 for hay in order to limit the weed population in the terminal period. This result highlights the substantial value of conserving selective herbicides through the adoption of pasture phases, as exhaustion will lead to reliance on expensive non-chemical treatments in the long-term.

The profitability of a pasture phase in a crop sequence depends greatly on the relative prices received for cereal and livestock products. Therefore the sensitivity of model output to changes in returns per dry sheep equivalent (DSE), away from the default value of $15, is investigated (Table 1).

Reductions in the price received for livestock products shifts the lower profitability of the two rotations incorporating lucerne into negative values (the shaded cells in Table 1). The stocking rates for lucerne are higher than those for other pasture options in the model because of increased production and the high value of biomass during the traditional ‘feed gap’. Rotations incorporating this perennial are therefore more greatly affected when livestock prices are altered. This identifies that lucerne phases may be unprofitable in relation to continuous cropping when livestock prices are low, even when benefits for weed management are considered.

These results show that pasture phases have high value to crop sequences when benefits for weed management are considered. This follows from effective weed control and substitution for expensive in-crop treatments. Lucerne pastures can achieve this together with significantly reducing recharge, the length of the cropping phase depending on sustainable levels identified by hydrological modelling and the weighting that producers allocate to short versus long-term production. Lowering the cost of establishing lucerne will improve its profitability relative to other, less sustainable pasture phases. The identification of methods to achieve this and its effect on the value of this perennial, relative to other pasture species, is worthy of further research.

Table 1. The profitability of rotations containing pasture (measured in dollars) relative to a continuous cropping sequence at different levels of livestock prices (shaded values represent losses).

Price received ($ DSE^{-1})	2P2W	CC + VZ	8C + 3L	4C + 3L
11	+43	+40	-56	-111
13	+88	+55	-23	-65
15	+134	+70	+10	-19
17	+179	+85	+43	+27
19	+224	+100	+76	+74

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