Expected benefits on and off farm from including lucerne (*Medicago sativa*) in crop rotations on the Broken Plains of north-eastern Victoria

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Abstract

Deep drainage to groundwater in the Broken Plains area has been predicted to bring the watertable to within two metres of the surface over the next 66 years. However, with reduced rainfall as a result of climate change, this may not happen for 113 years. The rising watertable will lead to waterlogging and dryland salinity. A solution is to introduce deep-rooted perennial species such as lucerne. Lucerne extracts more water than annual crops and pasture. Results of this analysis show that private investment decisions to change to cropping with lucerne as the legume component in the crop sequence, instead of subterranean clover, increases expected profitability and cumulative net cash flow of crop sequences. Still, farmers in this area generally believe that lucerne is riskier than annual legume pastures which constitutes a barrier to its widespread adoption. From the public perspective, keeping watertables below two metres prevents damage to infrastructure, roads, wetlands and bio-diversity. Policy instruments may be required to overcome farmers' resistance to growing lucerne, especially for them to do so on the 50 per cent of the arable area of the Broken Plains that would need to be growing lucerne to prevent watertables rising to the surface. The amount of grants per hectare of lucerne that would be required to achieve 50 per cent of the land growing lucerne are calculated.

Keywords: Farming systems, dryland salinity, risk analysis

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1. Introduction

The research reported in this paper is about the expected net benefits on farm (private) and off farm (public) from including lucerne *(Medicago sativa)* in cereal crop and pasture rotations in the Broken Plains sub-catchment of north eastern Victoria, in south-eastern Australia.

The Broken Plains is a sub-catchment of the dryland section of the Goulburn Broken Catchment. The arable area of the Broken Plains is approximately 198,000 hectares. The climate is winter rainfall temperate. Annual average rainfall from 1889 to 2008 was 513 millimetres with growing-season rainfall of 339 millimetres from April to October (Australian Bureau of Meteorology 2012).

Farmers on the Broken Plains sub-catchment grow winter crops of barley, canola, triticale and wheat. The traditional farming system is to grow six years of these crops followed by four years of annual ley pasture comprising subterranean clover (*Trifolium subterranean*) as the legume species. Eighty per cent of livestock activities are sheep and 20 per cent are cattle. The sheep activities are mainly prime lamb production; there are also Merino sheep activities for wool production. Cattle activities are predominantly self-replacing herds producing 15-to-18-month-old steers and heifers.

The problem in this area that has prompted this research inquiry is that almost the whole area is threatened with land degradation by secondary salinisation (Sinclair Knights Merz 1999; Trapnell 2012). Secondary salinisation was initially identified by Woods (1924) as being caused by salty watertables rising to two metres below the natural surface. Clearing of native woodlands in the Broken Plains by European settlers over the past 160 years has led to a loss of hydrologic balance in the landscape, resulting in rising saline watertables. The hydrologic imbalance has been exacerbated by trees being replaced with annual crops and pastures that have shallow and diffuse root systems. These shallow roots fail to intercept soil moisture which descends through the soil profile and recharges the underlying saline groundwater (Allison 1990, p.1; Macumber 1991, pp.30-40; Hatton and Nulsen 2001, p.203). The rising soil water tables that result from increased infiltration of water dissolve and mobilise stored salts, primarily sodium chloride (NaCl). Once they reach levels of two metres below ground level, they are extremely detrimental to the physiology of crops and pastures (George *et al.* 1997, p.10). Initially, the soil is waterlogged which limits the supply of oxygen to the roots of crops and pastures. This prevents strong root systems developing. Subsequently weak plant roots restrict the uptake of nutrients, affecting plant health and constraining yields of crops and dry matter production of pastures (Passioura 1992, p.987; Marschner 1995, pp.626-643). Next, saline water is drawn upwards by capillary action and salt seepage of surface soils follows (Coram *et al.* 2001, p.57). Ultimately, secondary salinisation of farm land reduces the net benefits derived from farming on the Broken Plains. Soil salinity has a further detrimental effect on public assets such as roads, urban infrastructure, wetlands and bio-diversity in the environment (Cary *et al.* 1983, p.22; Oliver *et al.* 1996, p.10; Goulburn Broken Catchment Management Authority 2002, p.11, Goulburn Broken Catchment Management Authority 2009, pp.14, 17, 23).

The depths to watertables below the surface are shown for the Broken Plains sub-catchment in November 2008 in Figure 1.

1.1 Change in land use to prevent private and public problems of secondary soil salinity

Introducing deep-rooted perennial species into farming systems reduces recharge of soil water and protects against secondary salinisation (Walker *et al.* 1999, pp.5-6; Stirzaker *et al.* 2000, pp.10-18; Bathgate and Pannell 2002, p.122). Trees are a deep rooted plant and an alternative to shallow rooted crops and pastures, but on the Broken Plains where average annual rainfall is around 500 millimetres per annum, agro-forestry plantations have a slow rate of growth which makes them unprofitable and financially unattractive (Kingwell *et al.* 2003, p.95). Lucerne (*Medicago sativa*) is a deep-rooted legume that has proven to have many advantages in a range of Australian farming systems (Kingwell *et al.* 2003, Ransom *et al.* 2006).

1.2 Hydrological modelling

To explore how cropping with lucerne might restore hydrologic balance across the Broken Plains, requires a temporal and spatial hydrological model of the Broken Plains sub-catchment. The Catchment Analysis Tool, CAT1D Version 32 (Beverly *et al.* 2005; Beverly 2009) was used. For an average rainfall of 510 millimetres per annum in the duplex Sodosols and Chromosols with clay loam overlying medium clay, rates of recharge to groundwater were predicted to be 53 millimetres per annum. With a specific yield of 0.1, the consequent average rise in the level of watertable was estimated at 0.53 metres per annum. For a scenario of climate warming, annual rainfall was estimated to decrease exponentially to 410 millimetres per annum over 30 years until 2038. Under these conditions, recharge would decline to 33 millimetres per annum with watertables rising by an average of 0.33 metres per annum. Depths to watertables, areas and the number of years to reach two metres below the surface, for scenarios with and without climate warming, are displayed in Table 1.

Not included in Table 1 is an area of 5,634 hectares where the watertable was less than two metres below the surface in November 2008. This area would already be subject to waterlogging. Lucerne is unable to persist in waterlogged areas because root systems become depauperate from lack of oxygenation (Passioura 1992). The area was therefore excluded from the study. Excluded, too, was an area of 5,888 hectares where watertables were at a depth of greater than 50 meters below the surface. In that area, such as the Warby Range on the eastern boundary of the study area, the land was not arable, having a slope greater than 18 degrees and mainly native woodland.

The number of years for watertables to reach two metres below the surface shown in Table 1 is based on watertables rising linearly. In reality, change in depth to watertable in a particular year is determined by annual rainfall received over the previous year (Dragovich and Dominis 2008). For example, in the Broken Plains sub-catchment, low rainfall years occurred from 2002 to 2009. Over that period, the depth to watertable increased. However, high rainfall years in 2010 and 2011 had the effect of increasing recharge to groundwater causing watertables to rise. The effect if farmers persist with cropping with annual pasture ley phases, instead of switching to cropping with a lucerne ley phase, is that the area susceptible to being degraded by secondary salinisation is 192,260 hectares, which is 97 per cent of the sub-catchment.

1.3 Previous research about cropping with lucerne

Research in the Rutherglen district, adjacent to the Broken Plains, was conducted on cropping with lucerne for two to four years followed by three to four years of crops, compared with farming using the traditional rotation of six years of crops followed by four years of annual ley pasture (Hirth *et al.* 2001; Ridley *et al.* 2001). The finding from Hirth *et al.* (2001), and Ridley *et al.* (2001) was that the optimum rotation for producing a better hydrological outcome than that achieved by the current annual-plant based cropping systems was four years of lucerne followed by no more than four years of crops.

Whilst cropping with four years of lucerne followed by four crops is likely to be hydrologically sound and prevent the onset of secondary salinisation, profitability and the attractiveness of its net cash flow compared with that of the traditional system of cropping with annual pasture remains an important and unanswered question. This is significant because farmers are unlikely to make a change to their farming systems if they are not convinced that they will at least have equivalent profits and net cash flows with no greater risk from adopting the innovative technology (Rogers 1962; Sinden and King 1990; Cary and Wilkinson 1997; Kingwell 2011).

The aim of this study, therefore, was to estimate the comparative whole farm economic and financial benefits and risks for farmers from switching from cropping with subterranean clover to cropping with lucerne using the hydrologically balanced rotation of four years of lucerne followed by four years of annual crops propounded by Hirth *et al.* (2001) and Ridley *et al.* (2001). The change in farming systems were to be investigated for scenarios with and without climate changing.

2. Materials and methods

2.1 Case study method

The case study research method was used. Case study research is about why decisions were made, how they were implemented and the results from making the decisions (Yin 2003, p.13). Accordingly, six farmers who had made the switch from cropping with subterranean clover to cropping with lucerne were the subjects for case study research. These farmers represented the multiple sources of evidence required in case study research and were questioned about why they changed their farming system, how they implemented the change, and the net benefits that they believed they received as a result of adopting the innovation (Eisenhardt 1989; Paton 1987; Ragin 1987; Yin 1998, Sterns *et al.* 1998).

Data from case study farms were used for the analysis of net benefits that could be derived from changing from a soil-degradable system of farming to a farming system that would prevent the advent of secondary salinisation. However, none of the farmers who used lucerne in their rotation used the hydrologically balanced rotation of four years of lucerne followed by no more than four crops.

It was therefore necessary to assume that all farmers on the Broken Plains sub-catchment would change from the traditional rotation of cropping with annual pastures to cropping with lucerne using the hydrologically balanced rotation of four years of lucerne followed by the same four annual crops as in the traditional rotation. In doing so, the method used by case study farmers, in changing their farming system and the resulting net qualitative benefits that they experienced, were applied to all farmers on the Broken Plains sub-catchment who changed their farming systems.

2.2 Analytical Method

Whole-farm budgets of all income and costs, and their associated variability, are essential for weighing up the relative net benefits and risks to choose between investment options that are mutually exclusive. Whole-farm budgets are especially suitable for taking account of the effects of risk, time, and the dynamic nature of farming systems in the decision making process (Malcolm 1990).

Economic (profit) and financial (cash) analyses were conducted on whole-farm systems cropping with lucerne compared with cropping with subterranean clover. The criterion used for comparison was the Net Present Value (NPV) as a measure of contribution to wealth from alternative, mutually exclusive farming systems (Hirshleifer 1970, p.48). Following Prest and Turvey (1965), p.703, Chisholm and Dillon (1971), p.2, and Sinden and Thampapillai (1995), p.145, the NPV for a particular investment project is calculated from the following equation.

$$NPV = (B_0 - C_0) + \frac{(B_1 - C_1)}{(1 + i)^1} + \ldots + \frac{(B_t - C_t)}{(1 + i)^t}$$

where B_0 is a benefit (income) that occurs at the beginning of the investment period (that is, on day 1), C_0 is the initial capital investment at the beginning of the investment period, B_1 is a benefit at the end of year 1, C_1 is the project cost at the end of year 1, B_t is the benefit occurring at the end of year t, C_t is the cost occurring at the end of year t, and *i* is the interest rate used for discounting future benefits and costs over time to express them in present day dollars.

Two issues are important in using discounted cash flow techniques to make decisions about alternative investments. First, the higher the discount rate used for adjusting the future value of benefits and costs, the lower will be the resulting NPV. Second, because benefits and costs are discounted over time, the further out an event occurs, the less effect it will have on the NPV for the option being examined (Makeham and Malcolm 1993, p.317).

2.3 Time for secondary salinisation of soil to occur

Dragovich and Domonis (2008) made a study of the rate at which land degradation through secondary salinisation occurred in the Little River catchment near Baldry, 39 kilometres northeast of Parkes in New South Wales. The area was in the Murray-Darling Basin 500 kilometres north east of the Broken Plains sub-catchment. Soil orders were the same as those in the Broken Plains. Agriculture was mixed farming for wheat and canola with grazing of sheep and cattle; the same as in the Broken Plains. Based on the utilisation of aerial photography over a period of 38 years, linked with changes in rainfall patterns over that period, with an average annual rainfall of 584 millimetres they calculated that the rate of increased degradation of land by secondary salinisation was at an average exponential rate of 2.84 per cent per annum.

The long-term average annual rainfall in the Broken Plains sub-catchment, for the scenario without climate change, of 513 millimetres per annum was lower than the average rainfall of 584 millimetres per annum received in the Little River Catchment. Consequently, a lower rate of soil degradation of 2.5 per cent per annum through secondary salinisation caused by ‘leaky’ annual crops and pastures was assumed to occur.

For the scenario with climate warming, with a reduction in annual rainfall to 410 millimetres per annum, the rate of soil degradation through secondary salinisation was assumed to be an exponential rate of 2.0 per cent per annum.

2.4 Discount rates to use in long term investment strategies

Soil degradation through secondary salinisation occurs over the long term. The question arises as to the discount rate to use in benefit-cost analyses for long term investment strategies. Discounting over periods up to 30 years is uncontroversial because it is about the limit in time over which capital markets operate to determine the marginal productivity of capital and return on investments (Cline 1999, p.137; Randall 2006, p.108; Schilizzi 2006, p.151). However, when considering the scope for future generations to enjoy future benefits derived from land that has not been degraded beyond repair by current generations, it is necessary to use discount rates appropriate to times longer than 30 years.

An analysis of the literature, (Rabl 2006; Weitzmann 1998; Philibert 1999; Newell and Pizer 2003; Randall 2006; Garnaut 2008), revealed that after 30 years, discount rates should be lowered based on the assumption that the pure rate of time preference becomes increasingly important. In this study, the discount rate up to 30 years after 2008 was a nominal rate of 8.5 per cent which was the average percentage yield for investing in risk-free 10 year government bonds from 1988 to 2008. That nominal rate was reduced to a nominal rate of 7.34 per cent from year 31 to year 99 after 2008. For periods over 100 years after 2008, a nominal rate of 5.92 per cent per annum was used for the discount rate.

2.5 Catering for risk in farming

Farming is a risky business (Dillon 1980, p.258; Anderson *et al.* 1977, pp.189-238; Boehlje and Eidman 1984, pp.441-442; Makeham and Malcolm 1993, p.274). To cater for risk in the analyses, Excel® spreadsheets in which data for income and costs was entered were linked to a Crystal Ball® stochastic simulation model. The Crystal Ball® stochastic simulation model was used to define each of those uncertain variables such as prices, yields, inflation and discount rates with normal probability distribution functions for calculating NPVs that would operate over the long term. Normal distributions applying to the far distant future were used because they obeyed the Law of Great Numbers (Keynes 1921, p.333), and the Central Limit Theorem (Tijms 2004, p.168). As well, Baumol (1986, p.1084) had reservations about using data from short-term trends that deviated from normal probability distribution functions for applications that occurred over the long term: 'The long run is important because it is not sensible for economists and policymakers to attempt to discern long-run trends and their outcomes from the flow of short-run developments, which may be dominated by transient conditions'.

Multiple trials of 10,000 were made by repeatedly sampling values from the probability distributions for the uncertain variables. A probability distribution of values was therefore generated for the NPVs of the farming systems being analysed.

2.6 Stochastic dominance

Displaying the forecast chart of NPVs as cumulative distribution functions (CDFs) enabled application of the concept of stochastic dominance to compare the two alternative crop systems. First degree stochastic dominance criteria are applicable in situations that involve a single decision maker whose risk preferences are not known precisely. They are also useful in situations where more than one decision maker is involved and in analysing policy alternatives or extension recommendations for a group of many individual decision makers (Hardaker and Lien 2003, p.1). Further, first degree stochastic dominance rests on the assumptions that decision makers prefer more wealth to less and have absolute risk aversion with respect to wealth., $r_a(w)$, between the bounds $-\infty < r_a(w) < +\infty$ (Anderson *et al*. 1977, pp.282-284; Boehlje and Eideman, 1984, pp.465-465; King and Robison, 1984, pp.68-81; McConnell and Dillon, 1997, pp.293-297).

By considering the CDFs for cropping with lucerne compared with cropping with subterranean clover, the former will dominate the latter by first degree stochastic dominance if the curve of its CDF is always to the right of the latter (Anderson *et al.* 1977, pp.282; Boehlje and Eideman, 1984, pp.465-465). That is, the cropping with lucerne option would dominate the cropping with subterranean clover option if it had a smaller probability of being less than, or equal to, each value of NPV (Bawa 1975, p.97; Vose 2000, p.402).

3. Results for private benefits

For farmers on the Broken Plains, benefit-cost analyses using whole-farm budgets were used to calculate the profitability from cropping with the hydrologically balanced rotation of four years of lucerne followed by four years of crops (Hirth *et al.* 2001, Ridley *et al.* 2001) compared with the traditional system of cropping with subterranean clover.

The analyses were carried out for areas with four different depths to watertables being 5.2 metres, 10.5 metres, 21.0 metres and 37.2 metres below the surface. Income and costs were inflated by an annual inflation rate of 3.8 per cent which was the average percentage increase in the consumer price index for the Australian economy from 1988 to 2008. The same inflation rate was applied to both income and costs because, for broadacre farms over that period, the average annual percentage increases in productivity was the same as the average annual percentage decline in their terms of trade (Mullen 2007).

As described above, discount rates used in the benefit-cost analyses were a nominal rate of 8.5 per cent for 30 years after 2008. That nominal rate was reduced to a nominal rate of 7.34 per cent from year 31 to year 99 after 2008. For periods over 100 years after 2008, a nominal rate of 5.92 per cent per annum was used for discounting.

Note that care was taken to express NPVs for discounting net income after tax for cropping with lucerne compared with cropping with subterranean clover for depths of watertables below the surface in November 2008 of 5.2 metres, 10.5 metres, 21.0 metres and 37.2 metres in 2008 dollar values. For example, for cropping with subterranean clover, the net income after tax in year 2040 of $20,414,691 was discounted to a value of $2,116,274 in 2008 dollar values. That is: $\$20,414,691 \times 1/(1+0.0734)^{32} = \$2,116,274$.

Similarly, for cropping with lucerne, the net income after tax in year 2040 of $40,363,597 was discounted to a value in 2008 dollars of $4,184,263. The large difference in net income after tax for cropping with lucerne compared to cropping with subterranean clover reflects the fact that, from the time that the watertable rose to a level of two metres below the surface, for the scenario without climate warming, soil degradation took place for cropping with subterranean clover at an exponential rate of 2.5 per cent per annum. That is, soil degradation had the effect of lowering annual gross income at the exponential rate of 2.5 per cent per annum. Variable costs, too, were similarly lowered. Allowances for owner's management and labour were also lowered every five years. With a loss of productivity through secondary salinisation, property owners would realise that they would have to reduce their allowances for management and labour accordingly.

NPVs in 2008 dollar values were calculated by the addition of annual discounted net incomes after tax. NPVs were annualized then divided by the number of hectares for the four areas with different depths to water table below the surface to produce Annualized NPVs per hectare.

In Table 2 and Table 4, summaries of the statistical output from the Crystal Ball® stochastic simulation model are displayed. In Table 2, information is shown for areas on the Broken Plains with watertables at various depths below the surface for mean, minimum and maximum annualised NPVs per hectare and coefficient of variability for cropping with lucerne compared with cropping with subterranean clover for scenarios without and with climate warming.

Coefficient of variability is a measure of variability in the magnitude of annualised NPV per hectare for cropping with and without lucerne over time. Lower values indicate less variability.

Characteristics of the cumulative net cash flows for cropping with lucerne compared with cropping with subterranean clover for areas of the Broken Plains sub-catchment with different levels of watertables below the surface are displayed for scenarios without and with climate warming in Table 3 and Table 5.

In Table 2 it is evident that, for the scenario without climate warming, at all areas of the Broken Plains sub-catchment with different depths of watertables at November 2008, the mean values of annualised NPV per hectare for cropping with lucerne expressed in 2008 dollar values are considerably higher than the mean values for cropping with subterranean clover pasture. This is because net income after tax is higher for cropping with lucerne than for cropping with subterranean clover. The lower net income for cropping with subterranean clover is exacerbated because soil degradation over time reduces annual gross income, annual variable costs and allowance for owner-operator's management and labour at an exponential rate of 2.5 per cent per annum. Further, the coefficient of variability for cropping with lucerne was always lower than the coefficient of variability for cropping with subterranean clover. That is, cropping with lucerne produced more profit with less risk.

The results revealed in Table 4 for the scenario with climate warming also indicate that, for all areas of the Broken Plains with different depths of watertables below the surface, the mean value of annualised NPV for cropping with lucerne is higher than the mean value for cropping with subterranean clover. The differences are not as great as in the scenario with no effects of a change in climate because, with a lower rainfall, the rises in watertables occur later. Therefore, when the values are discounted back to 2008 over a longer period the differences are smaller than for the scenario without climate warming. With a lower rainfall, annual gross income for cropping with subterranean clover was reduced by an exponential rate of 2.0 per cent per annum. The coefficient of variability for cropping with lucerne, too, was smaller than the value for cropping with subterranean clover. Again, lucerne was estimated to be more profitable and less variable than cropping with subterranean clover.

Tests for stochastic dominance revealed that, for all depths to watertable below the surface, the CDF for cropping with lucerne dominated that of cropping with subterranean clover and would be the preferred investment option.

The financial (cash) analyses depicted in Table 3 for the scenario without climate warming showed that cropping with lucerne was more cash-liquid than cropping with subterranean clover. Peak debt was lower and pay-back periods of debt were shorter. The same was true for the financial analysis in Table 5 for the scenario with climate warming where peak debts were lower for cropping with lucerne and pay-back periods were again shorter than cropping with subterranean clover. Cropping with lucerne had superior cash flow profiles than cropping with subterranean clover.

In summary, the results of this study show that cropping with lucerne for scenarios without and with climate warming was estimated to be markedly more profitable for farmers with a smaller variation in profitability over time. Tests for first degree stochastic dominance showed that for all depths of watertable below the surface, the CDF for cropping with lucerne dominated that for cropping with subterranean clover and would be the preferred investment option. Further, cropping with lucerne was more financially attractive than the traditional system of cropping with subterranean clover.

4. Implications of rising soils salinity for public assets

4.1 Physical effects of dryland salinisation

Dryland salinity has a severe impact on urban infrastructure, roads, wetlands and bio-diversity in the environment (Cary *et al.* 1983, p.22; Oliver *et al.* 1996, p.10; Goulburn Broken Catchment Management Authority 2002, p.11, Goulburn Broken Catchment Management Authority 2009, pp.14, 17, 23).

Saline groundwater rising to within two metres of the natural surface continues to rise by capillary action when upward suction from evaporation overcomes the downward force of gravity (Loveday and Bridge 1983, pp.848-849; White 1997, p.121; Liddicoat *et al.* 2008, p.36). Sodium ions in saline water replace calcium cations on the surface of the clay colloids by a process of 'cascading cations' (Tucker 1983, pp.412-413). Consequently, the soil disperses in aqueous solution losing its structure and load-bearing capacity (Emerson 1983, pp.484-495; Tucker 1983, p.414). Its durability as a foundation for buildings and roads is therefore reduced substantially (Corey and Corey 1997, pp.79-80).

Saline groundwater has the ability to invade permeable concrete structures such as slabs and mortar between bricks. As building materials undergo periodic cycles of wetting and drying, salt crystals grow within confined pore spaces. The result is a loss in integrity of the structure as the distressed concrete cracks and mortar turns to dust (Leake 2003, pp.1-2).

Corrosion of underground encased pipes disables systems for the distribution of urban water and the conduct of sewerage to treatment plants. Saline water entering sewerage treatment plants results in increased operating expenses and a loss in the efficiency of the treatment system (Wilson 2003, p.2).

Bitumen sealed roads suffer damage caused by the capillary rise of saline water that leads to bituminous surfacing lifting away from its underlying base material where it blisters, cracks, and eventually disintegrates (Fookes and French 1977, pp.11-13).

Concrete road structures are also affected when saline groundwater enters permeable concrete causing embedded steel reinforcement to corrode. Corrosion leads to expansion of the steel which exerts a force on the surrounding concrete causing the concrete structures to lose their structural strength through a process of concrete spalling (McRobert and Foley, 1999, p.3; Leake 2003, p.1-2).

4.2 Cost of damage to public assets on the Broken Plains by dryland salinisation

The cost of damage to public assets on the Broken Plains by dryland salinisation has not been evaluated. However, since the Broken Plains sub-catchment is surrounded by the same environmental conditions as those pertaining to the City of Wagga Wagga, that is, same climate, rainfall and soil types, the values for damage to urban infrastructure used by Hill (2000) for Wagga Wagga have been transferred to cities and towns on the Broken-Plains sub-catchment (Kirchhoff *et al.* 1997, Morrison and Bennett 2004). The values were then inflated by the annual percentage increases in the Consumer Price Index of the Australian economy from 2000 to values applying at November 2008.

Similarly, the increased cost of repairs to roads in Western Australia reported by Graham (2005) has been transferred to roads in the Broken Plains (Kirchhoff *et al.* 1997, Morrison and Bennett 2004) because it was assumed that roads in the two localities were identical.

Annualised present extra public costs per hectare of maintaining urban infrastructure and roads for arable land with varying depths to watertable in November 2008, if farmers do not change to cropping with lucerne, are shown in Table 6 for the scenario without climate warming and Table 7 for the scenario with climate warming. This was undertaken using the same inflation rates per annum and the same discount rate as that used for calculating NPVs for private benefits of cropping with lucerne rather than cropping with subterranean clover.

5. Increase in economic welfare from cropping with lucerne

The increase in national economic welfare for the Broken Plains for cropping with lucerne instead of cropping with subterranean clover is displayed in Table 8 for scenario without climate change over 90 years and in Table 9 for scenario with climate warming over 134 years. For scenario with climate warming, the extra 44 years for the arable land of the Broken Plains sub-catchment to have watertables reach two metres below the surface and undergo degradation by secondary salinisation is a function of lower rainfall producing less recharge of groundwater and a longer time for watertables to rise to two metres below the surface. From Dragovich and Dominis (2008), the rate of soil degradation, too, is slower at two per cent per annum for scenario with climate warming compared with 2.5 per cent for the scenario without climate change.

In Table 8 it is revealed that the increase in national economic welfare would amount to an extra 31.26 million dollars over a period of 90 years, were farmers to change from the degradable land use system of cropping with subterranean clover to the hydrologically balanced non-degradable system of cropping with lucerne for the scenario without climate warming. In Table 9, for the scenario with climate warming, the extra increase in national economic welfare would amount to 19.3 million dollars over a period of 134 years.

6. Farmer adoption of cropping with lucerne

The adoption by farmers in the Broken Plains of cropping with lucerne compared to cropping with subterranean clover was low (Hunter pers. comm.). This is despite the private and public benefits that could be achieved if they changed their farming system. Continued pollution of groundwater, through mobilisation of salt in the soil profile draining into it, and its ongoing rise to eventually cause land degradation by secondary salinisation is an externality associated with cropping with subterranean clover. The negative externality is a result of market failure. Market failure occurs because the farmers' actions cause an effect on others but does not affect their decisions for production on their farms. A subsequent market failure, in this case information failure, arises when farmers incorrectly perceive that increased transaction costs for switching to cropping with lucerne from cropping with subterranean clover are too high to elicit the change.

7. Government intervention to promote cropping with lucerne

7.1 Method of government intervention

Market failures are the prime justification for intervention by governments in the operation of the economy. Government intervention to internalise the negative externality could commence with a programme of extension and education. If this did not achieve the required increase in lucerne grown, in theory the public (the government) could pay farmers on the various areas of the Broken Plains with different depths to watertables in November 2008 a grant of an amount equal to the extra cost of repairing damage to public assets. A net public benefit would result. However, in doing that, the implication would be that all farmers would have the same increase in transaction costs as a result of changing their farming system. Transaction costs in changing their rotational system would embody costs of increasing knowledge or information costs, the costs of trialling new farming systems, personal traits such as tactical opportunism, sunk costs, their planning horizon and, extremely importantly, the levels of their aversion to risk. In effect, not all farmers would experience the same transaction costs and, in particular, different farmers would experience different levels of of disutility, given their their aversion to risk, from changing their farming system. In awarding grants to encourage adoption of the hydrologically balanced system of cropping with lucerne it would be politically and fiscally sound for government to discover what grants farmers may require to change their farming system according to their levels of aversion to risk.

7.2 Determination of grants according to changes in farmers levels of risk aversion

Determination of what grants farmers may make could be refined by employing the stochastic efficiency with respect to a function (SERF) method (Hardaker *et al.* 2004). SERF partitions various alternative investments in terms of their certainty equivalents (CEs) as a selected measure of risk aversion is varied. SERF was used to calculate CEs for cropping with lucerne and cropping with subterranean clover at risk aversion coefficients (RACs) ranging from 0 to 0.035 (Hardaker *et al.* 2004). The *minimum grant* required by a farmer would be the difference in CEs for cropping with lucerne versus cropping with subterranean clover at a particular RAC. The *maximum grant* that government could justify paying is the amount that would break-even with the extra costs of maintaining public assets if farmers did not change their farming system from cropping with subterranean clover to the hydrologically balanced rotation of cropping with lucerne. The actual grant, that is, the amount that farmers would require, lies somewhere between the minimum and the maximum estimated in the above manner.

The need for obtaining adoption of cropping with lucerne is greatest where watertables are 5.2 metres and 10.5 metres below the surface. The area involved is 42 per cent of the Broken Plains sub-catchment. For farmers whose farms lie on areas of the Broken Plains catchment where the watertable was 5.2 metres below the surface in November 2008, the minimum value of grants in 2008 dollar values was between $100 per hectare for an RAC of zero and $94 per hectare for an RAC of 0.035. The maximum grant that the government could justify paying was $139 per hectare. The grants that the government could pay would be between those minimum and maximum values.

For areas where the watertable was 10.5 metres below the surface in November 2008, if the government waited for 10 years until 2018 before awarding grants, the watertable would have risen to a level of 5.2 metres below the surface. At that time the difference in CEs in 2018 value dollars would be $106 per hectare for an RAC of zero and $105 per hectare for an RAC of 0.035. The maximum grants per hectare that could be justified by the government would inflate from $109 per hectare in 2008 dollar values to $159 per hectare in 2018 dollar values.

7.3 Method for government awarding grants

It is suggested that government could implement auctions (McAfee and McMillan 1987; Wolfstetter 1996; Klemperer 2002; Chan *et al.* 2003) based on farmers' sealed bids as market-based policy instruments to award temporary grants to farmers who sign contracts to change in perpetuity from cropping with subterranean clover to the hydrologically balanced rotation of four years of lucerne followed by no more than four crops; that is, over one rotation of crop and pasture. Grants would be a risk free amount of money that farmers would receive for changing their farming system. They would be made on a temporary basis because increases in private benefits showed that cropping with lucerne was more profitable and financially feasible than cropping with subterranean clover (Freebairn 1978, p.194; Pannell 2001, p.541).

As stated previously, intervention to increase the growing of lucerne on areas of the Broken Plains where watertables are 5.2 metres and 10.5 metres below the surface is needed to prevent damage to private and public assets by secondary salinisation. If farmers do not rotate crops with lucerne, an average rise in watertables of 0.53 metres per year would cause watertables to reach a depth of two metres below the surface over 42 per cent of the Broken Plains sub-catchment within 16 years from November 2008. Further, the payment would likely have to be based on the scenario without climate warming because detecting clear change in climate amongst fluctuations around a trend over a short period is problematical.

Payments of grants could be paid to farmers who sign contracts that commit them to adopt the eight year rotation of four years of lucerne followed by four years of crops. Payment of grants would be made annually at the beginning of the pasture-crop rotation. They could be made on a per hectare basis for the total area of lucerne pasture and crops for the various farms. The amount of the annual payments would be indexed annually according to changes in the Consumer Price Index for the Australian economy.

Assistance may not be needed for farmers on areas of the Broken Plains where watertables were 21.0 metres and 37.2 metres below the surface in November 2008. Watertables in those two locations would not reach two metres below the surface until 2044 and 2074 without climate warming or 2061 and 2121 with climate warming. Probably, assistance would not be required because Rogers' model of technology transfer (Rogers 1962, pp.300-307) supplemented by participatory approaches in agricultural extension (Guerin and Guerin 1994) suggests that learning would occur from the experiences of farmers who adopted the more profitable and financially advantageous system of cropping with lucerne.

8. Discussion and conclusion

Degradation of the Broken Plains sub-catchment in north eastern Victoria by secondary salinisation can be prevented if farmers switched from cropping with subterranean clover to the hydrologically balanced system of cropping with lucerne. The change would lead to increases in private benefits through higher profitability, reduction in the variability of annual profits over time and a more attractive net cash flow. Public benefits, too, would be realised through avoidance of damage to roads, railways, urban infrastructure, wetlands and bio-diversity in the environment.

Farmers, however, have been reluctant to make the change. Unwillingness to change probably stems from a belief that cropping with lucerne will be a more complex and higher-risk system of farming. Such fears add to the transaction costs of changing from a well-known traditional cropping system to a new, unfamiliar system.

Excessive transaction costs could be offset by government providing temporary grants to farmers who change to the hydrologically balanced rotation of following four years of lucerne with no more than four crops, thereby internalising the market failure. Grants would be temporary because cropping with lucerne has substantial private benefits which one would expect to reinforce the adoption. Grants could be awarded by using auctions as market-based policy instruments determined by farmer's sealed bids. Grants could be paid to individual farmers on a per hectare basis for the total annual area of their pasture-crop rotation. Grants could be paid annually from the beginning of the pasture-crop rotation. They would be increased over the eight years according to the Consumer Price Index for the Australian economy.

It should be only necessary to target farmers in 42 per cent of the Broken Plains where watertables were 5.2 metres and 10.5 metres below the surface in November 2008. It should be unnecessary to provide assistance to the remaining 58 per cent of farmers in areas where the watertable was 21.0 metres and 37.2 metres below the surface. It is ossible assistance would not be required if Rogers' model of technology transfer (Rogers 1962, pp.300-307), supplemented by participatory approaches in agricultural extension (Guerin and Guerin 1994) were to apply the experiences of farmers who adopted the more rewarding system of cropping with Lucerne came to be widely recognized and reduced the extent of an initial reluctance to adopt the change.

Finally, the crux of the problem that this study seeks to inform is that, if farmers on the Broken Plains sub-catchment changed from cropping with subterranean clover to cropping with lucerne, the extra economic benefit to the Broken Plains sub-catchment, and hence to the Australian economy, expressed in 2008 dollar values would amount to an estimated $31.26 million over 90 years for the scenario without climate warming or $19.3 million over 134 years for the scenario with climate change.

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Appendix

Figure 1: Depth of watertable below the surface of the Broken Planes sub-catchment in November 2008

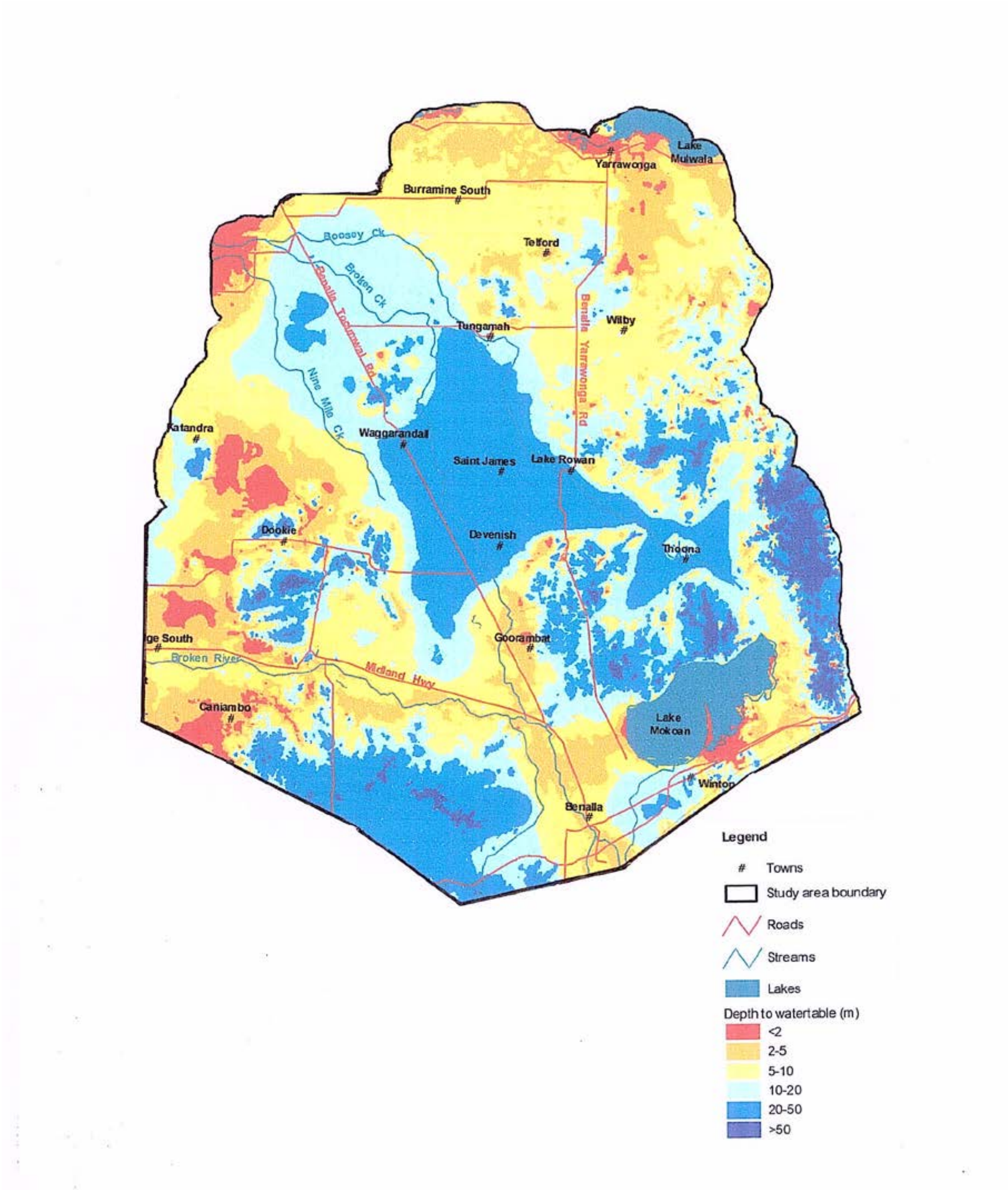

Table 1: Depths to watertables at November 2008, areas and number of years to reach two metres below the surface, for scenarios with and without climate warming.

Depth to watertable at November 2008	Area	Number of years for watertables to rise to two metres below the surface	
		Without climate warming	With climate warming
Metres	Hectares	Years	Years
5.2	26,202	6	7
10.5	52,349	16	19
21.0	54,084	36	53
37.0	53,991	66	113

Table 2: Mean, minimum and maximum annualised net present values per hectare in November 2008 dollar values and coefficient of variability for cropping with lucerne compared with cropping with subterranean clover for Broken Plains' farms for scenario without climate warming for areas with various depths of watertables below the surface

Depth to watertable	Cropping with lucerne				Cropping with subterranean clover				Difference in means
	Mean	Minimum	Maximum	Coefficient of variability	Mean	Minimum	Maximum	Coefficient of variability	
Metres	$/ha.	$/ha.	$/ha.		$/ha.	$/ha.	$/ha.		$/ha.
5.2	154.34	2.28	317.39	0.2003	-42.92	-144.84	17.61	-0.2970	197.26
10.5	196.36[A]	96.53	304.19	0.1356	1.45	-70.74	90.37	-0.2966	194.91[A]
21.0	67.28	21.22	117.14	0.1242	-1.89	-80.49	63.95	-0.4211	69.17
37.2	40.20	25.00	60.47	0.1121	2.06	-13.64	-17.44	0.5410	38.14

[A] These values increase with depth of watertable below the surface from 5.2 metres to 10.5 metres because the discount rate was lowered for the benefit-cost analysis when the time over which the analysis was conducted exceeded 30 years from November 2008.

Table 3: Characteristics of the cumulative net cash flows for cropping with lucerne compared with cropping with subterranean clover for farms on the Broken Plains with watertables at various depths below the surface for scenario without climate warming

Depth to watertable	Cropping with lucerne				Cropping with subterranean clover			
	Peak debt	Year of peak debt	Pay-back period	Terminal net cash flow	Peak debt	Year of peak debt	Pay-back period	Terminal net cash flow
Metres	$ m.	Year	Year	$ m.	$ m.	Year	Year	$ m.
5.2	9.7	1	2	494	11.8	1	4	261
10.5	29.2	1	2	1,736	34.3	1	4	762
21.0	64.0	1	2	4,835	108	1	5	1,583
37.2	198	1	2	14,857	233	1	4	5,092

Table 4: Mean, minimum and maximum annualised net present values per hectare in November 2008 dollar values and coefficient of variability for cropping with lucerne compared with cropping with subterranean clover for Broken Plains' farms for scenario with climate warming for areas with various depths of watertables below the surface

Depth to watertable	Farming with lucerne				Farming with subterranean clover				Difference in means
	Mean	Minimum	Maximum	Coefficient of variability	Mean	Minimum	Maximum	Coefficient of variability	
Metres	$/ha.	$/ha.	$/ha.		$/ha.	$/ha.	$/ha.		$/ha.
5.2	50.97	-76.45	157.37	0.4973	-90.26	-193.95	2.49	-0.2046	141.23
10.5	63.84	-42.36	153.31	0.3367	-45.57	-136.08	73.16	-0.3674	109.41
21.0	-8.62	-28.58	14.99	-0.2196	-23.69	-94.14	19.24	-0.3967	15.07
37.2	0.56	-12.57	62.79	-0.1973	-7.97	-20.98	48.66	-0.4241	8.53

Table 5: Characteristics of the cumulative net cash flows for cropping with lucerne compared with cropping with subterranean clover for farms on the Broken Plains with watertables at various depths below the surface for scenario with climate warming

Depth to watertable	Cropping with lucerne				Cropping with subterranean clover			
	Peak debt	Year of peak debt	Pay-back period	Terminal net cash flow	Peak debt	Year of peak debt	Pay-back period	Terminal net cash flow
Metres	$ m.	Year	Year	$ m.	$ m.	Year	Year	$ m.
5.2	10.3	1	2	362	11.9	1	4	201
10.5	36.6	1	3	1,197	40.7	1	5	524
21.0	143	1	6	3,508	206	1	12	1,150
37.2	1,544	1	6	31,208	1,606	1	11	11,441

Table 6: Annualised present extra public costs per hectare of maintaining urban infrastructure and roads for arable land with varying depths to watertable in November 2008 for scenario without climate warming if farmers do not change to cropping with lucerne

Item	Depth to watertable in November 2008			
	5.2 metres	**10.5 metres**	**21.0 metres**	**37.2 metres**
	$/ha.	$/ha.	$/ha.	$/ha.
Mean	138.65	109.02	12.68	1.17
Maximum	162.37	124.96	19.47	3.06
Minimum	121.05	97.61	8.04	0.59

Table 7: Annualised present extra public costs per hectare of maintaining urban infrastructure and roads for arable land with varying depths to watertable in November 2008 for scenario with climate warming if farmers do not change to cropping with lucerne

Item	Depth to watertable in November 2008			
	5.2 metres	10.5 metres	21.0 metres	37.2 metres
	$/ha.	$/ha.	$/ha.	$/ha.
Mean	125.92	98.96	1.13	0.92
Maximum	153.37	147.86	4.48	1.03
Minimum	108.71	74.40	1.02	0.81

Table 8: Mean increases in national economic welfare if farmers changed from cropping with subterranean clover to cropping with lucerne on the Broken Plains for scenario without climate warming over 90 years

Item	Unit	Depth to watertable in November 2008			
		5.2 metres	10.5	21.0	37.2
Mean private benefits	$/ha.	197.26	194.91	69.17	38.14
Mean public benefits	$/ha.	138.65	109.02	12.68	1.17
Total mean benefits	$/ha.	335.91	303.93	81.85	39.31
Arable area	ha.	26,202	52,349	54,084	53,991
Mean benefits per ha. hacategory	$ m.	8.80	15.91	4.43	2.12
Total mean increases in economic welfare	$ m.	31.26			

Table 9: Mean increases in national economic welfare if farmers changed from cropping with subterranean clover to cropping with lucerne on the Broken Plains for scenario with climate warming over 134 years

Item	Unit	Depth to watertable in November 2008			
		5.2 metres	10.5 metres	21.0 metres	37.2
Mean private benefits	$/ha.	141.23	109.41	15.07	8.53
Mean public benefits	$/ha.	125.92	98.96	1.13	0.92
Total mean benefits	$/ha.	267.15	208.37	16.2	9.45
Arable area	ha.	26,202	52,349	54,084	53,991
Mean benefits per ha. category	$ m.	7.00	10.91	0.88	0.51
Total mean increases in economic welfare	$ m.	19.30			