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Uncertainty and Adoption of Sustainable Farming Systems [+]

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Abstract

Uncertainty has been under-recognised as an impediment to the adoption of innovative land conservation practices. High levels of uncertainty inhibit adoption because (a) most farmers are psychologically averse to risk and uncertainty, (b) uncertainty leaves room for misunderstanding and misperceptions about the innovation and (c) in some cases there can be an option value from *not* trialing. A framework is presented that emphasises that adoption is a process involving collection, integration and evaluation of new information (i.e., reduction in uncertainty over time). Thereafter the paper discusses the range of factors that contribute to high uncertainty about conservation innovations, factors that reduce the potential for trials to reduce this uncertainty, and factors that contribute to the high cost of trials of conservation technologies. Some clear implications for policy approaches to land degradation are identified.

Introduction

There is wide interest among agricultural policy and research institutions in the process of adoption of innovations that promote land conservation, impediments to that adoption, and possible measures to promote adoption. Implicit in this interest is a perception that, despite programmes such as Landcare, adoption by farmers of "sustainable" [1] farming practices has been lower and slower than would be socially optimal (e.g. Lockie and Vanclay 1997; Rae and Gruen 1997). Many factors have been suggested as contributing to this (e.g. Pannell 1999; Vanclay 1997; Cary and Wilkinson 1997; Sinden and King 1990), including:

- High implementation costs,
- Lack of direct payoff from implementation,
- Lack of physical and human capital,
- Lack of a sufficient "stewardship" ethic among farmers,
- Farming subcultures and social pressures,
- Lack of a suitable regulatory framework, and
- Risk and uncertainty.

This paper focuses on the last of these factors. It is argued that uncertainty has been under-recognised as one of the key factors inhibiting uptake of land conservation practices. In part, this under-recognition may be because the majority of the enormous volume of research conducted on adoption of agricultural innovations has focussed on innovations with short-term productivity-oriented benefits. It will be argued here that the problems of uncertainty about "sustainable" innovations are much more profound and intractable than for most farming innovations.

In addition, it seems that uncertainty has been under-recognised as an impediment to adoption even for productivity-oriented innovations. Risk and uncertainty have often been considered as factors reducing the rate of adoption of rural innovations (Lindner *et al.* 1982; Tsur *et al.* 1990; Leathers and Smale 1992; Shapiro et al. 1992; Smale and Heisey

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[1] No attempt is made here to rigorously define "sustainability". Its usage should be interpreted broadly, in line with Pannell and Schilizzi (1999), to signal a concern for conservation and the long term.

1993; Feder and Umali 1993). However, this has largely been assumed, rather than known, as they have rarely been addressed adequately in empirical studies of adoption (Lindner, 1987). The lack of empirical research may largely be attributable to the great difficulty of accurately measuring the relevant uncertainty-related variables.

However, in a recent study, Abadi and Pannell (1998) have shown that uncertainty plays a clear, measurable and substantial role in the adoption of a new type of crop. Their conceptual framework (based on Bayesian decision theory) and empirical findings have profound implications for adoption of "sustainable" farming innovations, and it is these implications that are the focus of this paper.

To introduce important background, the next section is an informal outline of the conditions for adoption of an agricultural innovation. Then the more formal framework of Abadi and Pannell (1998) for consider the role of uncertainty in adoption decisions is presented briefly. Thereafter, the various roles of uncertainty in the adoption process are expanded on, drawing on available evidence and numerical examples. Finally, implications for extension and policy are discussed.

The Conditions for Adoption of an Agricultural Innovation

Pannell (1999) argues that farmers are likely to come to any radical innovation with scepticism, uncertainty, prejudices and preconceptions. Unless they are new to farming, they will have trialed other innovations in the past and concluded that at least some of them fell far short of the claims made for them. They will be particularly wary of a system that is radically different from that with which they are familiar and comfortable. They will probably hold an attitude that the people advocating such a radical system do not understand the realities of farming, or at least of their farm.

In getting past this initial set of attitudes and beliefs, there are several specific hurdles that must be overcome. The following sub-sections describe the states of farmer awareness or knowledge that must be achieved.

Awareness of the innovation

In this context, "awareness" means not just awareness that an innovation exists, but awareness that it is *potentially* of practical relevance to the farmer. Reaching this point of awareness is a trigger which prompts the farmer to open his or her ears and eyes - to begin noting and collecting information about the innovation in order to inform their decision about whether or not to go to the next step of trialing the innovation.

Perception that it is feasible and worthwhile to trial the innovation

There is strong evidence that, the world over, most farmers are "risk-averse" (Antle 1987; Bardsley and Harris 1987; Myers 1989; Pluske and Fraser 1996). This is evident from the observation that they will not leap into large-scale adoption of a new innovation. Rather, they generally employ small-scale trials, adjusting the scale either upwards towards full adoption or downwards towards disadoption as they gain knowledge and confidence in their perceptions about its performance.

Conducting a trial incurs costs of time, energy, finance and land that could be used productively for other purposes. To be willing to trial an innovation, the farmer's perceptions of it must be sufficiently positive to believe that there is a reasonable chance of adopting the innovation in the long run. It is not necessary for the innovation to be thought to be better than current practice, because the farmer realises that the results of a trial may revise his or her perceptions upwards. However, it cannot be too much worse or the chance of recovering the cost of the trial through later productivity improvements will be too low.

This trial phase is very important. If small-scale trials are not possible or not enlightening for some reason, the chances of widespread adoption are greatly diminished. This is because farmers will be very unlikely to leap to full-scale adoption due to the real risk that the innovation will prove a full-scale failure.

Perception that the innovation promotes the farmer's objectives

Lindner (1987) in a wide-ranging review of the adoption and diffusion literature concluded that the objectives of individual farmers figure centrally in the adoption and diffusion process. He found that,

"there is compelling empirical support for this emerging consensus that the final decision to adopt or reject is consistent with the producer's self interest." (p. 148)

"Self interest" in this context is considerably broader than merely "profit". It may, for example, include objectives related to risk, leisure and environmental protection. Nevertheless, profit is a particularly important element of "self-interest". Indeed, the available evidence indicates that although the speed of uptake of innovations is influenced by a range of factors (including social and demographic factors), the final level of uptake seems to depend primarily on economic factors (e.g. Marsh et al. 1995). There is also evidence that even for innovations oriented towards resource conservation, economic considerations are the most important determinants of actual adoption decisions (Cary and Wilkinson 1997; Sinden and King 1990).

Impacts of Uncertainty on Adoption

Within the adoption process, uncertainty has several negative influences. The key ways in which uncertainty inhibits adoption are as follows.

1. The fact that the final result of adopting a particular practice is highly uncertain is an intrinsic discouragement to adoption for most people. As noted earlier, most farmers are averse to risk and uncertainty, meaning that they place greater weight on potential negative outcomes than on positive outcomes. This relates to the condition above of meeting the farmer's objectives. For some farmers, avoidance of risk and uncertainty is an important objective.

2. Even if farmers are not discouraged by uncertainty per se, they may well be discouraged by the consequences of that uncertainty, particularly if it results in inaccurate perceptions or misinformation. This also relates to the condition regarding farmers' objectives. If a farmer perceives incorrectly that an innovation is not consistent with their objectives, this misperception is an impediment to adoption. The condition relating to trialing is also relevant here. If the farmer does not conduct trials, a chance to correct the misinformation is missed. Indeed, if the farmer is badly

misinformed, this in itself may cause the farmer to believe that a trial is not worthwhile, trapping him or her in a state of ignorance.

3. Irreversibility of environmental damage is often proposed as a reason for action to enhance conservation. This is a different motivation than aversion to uncertainty. It relates to the concept of “option value” whereby keeping open the options for resource use has a positive value due to the potential for unforeseen circumstances. To the extent that an option value is relevant to the farmer’s objectives, it may influence his or her behaviour. This appears to act in favour of adoption. However, if a conservation practice is itself irreversible to some extent (or expensive to reverse), there is then an option value in *not* adopting it. For example, this would apply to the planting of trees on crop land to avert salinity.

Conceptual Framework

The adoption process consists, in large part, in the collection, integration and evaluation of new information. In other words, it is a process in which uncertainty is reduced steadily over time. Early in the process, uncertainty is very high, and the quality of decision making may be low. As the process continues, if it proceeds at all, uncertainty falls and better decisions can be made. Viewed in this light, it would be fair to say that the adoption process is never completed, in the sense of reaching zero uncertainty. All options are continuously open to question and review, as new information is obtained and/or circumstances change. The conceptual framework presented below is included to reinforce and clarify these ideas. The framework highlights the role of learning in the dynamics of adoption, and clarifies the benefits of trialing.

The framework represents a farmer’s decision problem regarding the allocation of land to a new “sustainable” farming system and to traditional methods. For simplicity it is assumed that the decision involves only a single new system and a single traditional system. The sustainable system is characterised by short-term costs and long term benefits. It is assumed in this discussion that a single-year trial of the system gives useful information about its performance. Potential flaws in this assumption are considered later.

- Let
- A_s =Area of sustainable farming system,
- A_n = Area of traditional farming system,
- A_T = Total arable area on the farm = $A_s + A_n$,
- g_s = Gross margin of sustainable farming system, and
- g_n = Gross margin of traditional farming system.

Assume that the farm’s land is heterogeneous (e.g. in soil structure, chemical composition of the soil, weed species present) so that g_s and g_n vary within the farm. For any given value of A_s it is possible to calculate G_s and G_n, the mean gross margins of sustainable and traditional farming across the areas on which they are grown. Assuming profit-maximising behaviour, G_s will fall as A_s is increased, due to the heterogeneity of land with respect to the value of $g_s - g_n$. Profit (π) is:

$$\pi = G_s \, . \, A_s + G_n \, . \, A_n \qquad (1)$$

If the farmer maximises profit for the current period, some area of the sustainable farming system will be grown so long as the gross margin of sustainable farming is greater than that of traditional farming on any part of the farm. Of course, such a simplistic approach is inappropriate for the assessment of sustainable farming systems. The framework below includes the key elements of time, risk, and learning. A quantitative implementation may also need to include spatial linkages or interactions between the farming systems and, depending on the purpose of the analysis, off-farm effects.

It is assumed that the farmer's objective is to maximise the expected value of the net present value of profits[2]. Therefore the farmer is concerned with the gross margins of the alternative farming systems in future years beyond year 1[3].

Consider that the farmer is uncertain about the economic performance of the sustainable farming system. There will be uncertainty about its biological productivity and its capacity to prevent land degradation and there may also be uncertainty about sale prices and input costs, especially if it involves production of a new product unfamiliar to the farmer. A trial of the system will provide information about its yields, prices and impacts on the resource base. This information is likely to reduce the farmer's uncertainty in future years and allow better decision making.

Before conducting a trial of the sustainable system, the farmer is uncertain about the value of G_s for any given A_s, but is able to subjectively state a probability distribution for it. From the information generated by the trial, the farmer revises his or her subjective beliefs about the profitability of the system. Based on this revised (probably more accurate) perception, the farmer decides whether or not to continue with the new system and, if so, what area of the farm to devote to it. With each year of trialing, this decision is refined and improved. A trial in year t provides information that allows improved estimates of G_s for subsequent years. This in turn allows improved selection of A_s for subsequent years.

If the farmer decides to trial the sustainable system, the dynamic profit function can be expressed as:

$$\Pi = G_{s1} \cdot A_{s1} + G_{n1} \cdot (A_T - A_{s1}) + NPV_{t=2..\mathrm{N}}[G_{st} \cdot A_{st} + G_{nt} \cdot (A_T - A_{st})] \qquad (2)$$

where

- Π = the net present value,
- A_{st} = the area of the sustainable system in year t,
- G_{st} = the average gross margin of sustainable farming in year t given A_{st}. In this and subsequent equations, G represents the (unknown) actual gross margin, not the farmer's subjective estimate.

The gross margins have time subscripts in part because they are changing due to land degradation, and in part because the sustainable system is likely to have up-front costs and delayed payoffs.

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[2] The framework can readily be extended to include risk aversion.

[3] Calculation of "gross margins" should include any relevant spatial linkages between the systems, such as reduced salinity within the traditional area as a result of high water use in the sustainable area.

If the farmer chooses not to trial the sustainable system in year 1, the profit function is:

$$\Pi_0 = G_{n1} \cdot A_T + NPV_{t=2..\mathrm{N}}[G_{st0} \cdot A_{st0} + G_{nt0} \cdot (A_T - A_{st0})] \quad (3)$$

The 0 subscripts signify that these values may be different to those in equation (2) due the absence of a trial in year 1. A_{st0} is different to A_{st} because information collected in the trial in year 1 affects subsequent decision making about the area of the sustainable system. G_{st0} is different to G_{st} because G_s depends on A_s (which has changed) and also because the absence of a trial in year 1 means that the impacts of the sustainable system on resource conservation are delayed.

The difference between the two equations indicates whether the benefits of the trial outweigh the opportunity costs.

$$\Pi - \Pi_0 = G_{s1} \cdot A_{s1} - G_{n1} \cdot A_{s1} + I \quad (4)$$

where I represents the benefits in later years of trialing in year 1.

$$I = NPV_{t=2..\mathrm{N}}[G_{st} \cdot A_{st} + G_{nt} \cdot (A_T - A_{st}) - G_{st0} \cdot A_{st0} - G_{nt0} \cdot (A_T - A_{st0})] \quad (5)$$

Rearranging gives:

$$I = NPV_{t=2..\mathrm{N}}[(G_{st} - G_{st0}) \cdot A_{st0} + (G_{st} - G_{nt}) \cdot (A_{st} - A_{st0})] \quad (6)$$

Thus, the benefits of trialing can be decomposed into two elements: the gain in profitability for the area that would have been allocated to the sustainable system in future years even without the trial in year one, $(G_{st} - G_{st0}) \cdot A_{st0}$, plus the gain in profit on the area converted from the traditional to the sustainable system in future years as a result of the trial, $(G_{st} - G_{nt}) \cdot (A_{st} - A_{st0})$.

The first element springs from actual biophysical changes set in place directly by the trial. In cases where the trial is conducted on a small scale, this element is likely to be small in magnitude. The second element springs from changes in perceptions due to the trial, leading to changes in subsequent management.

At the start of the next year, exactly the same decision problem is faced again, with the exception that perceptions about the sustainable system are likely to be different than they were in year 1, especially if a trial has been conducted. When viewed in this light, the trial can be seen as the first step in adoption. Indeed, it might be considered that trialing is indistinguishable from adoption - that each production system is always and forever on trial, with different decisions made as perceptions and expectations evolve.

Factors that Contribute to High Uncertainty About Conservation Innovations

“Sustainable” farming systems are prone to high levels of uncertainty for a range of reasons.

1. Lack of experience. Early in the process of any innovation, uncertainty is high. Indeed, the remaining level of uncertainty may provide a useful, measurable index of the extent to which the adoption process has progressed. In the case of adoption, the problem of

uncertainty due to lack of experience has a "Catch 22" style mirror problem: lack of experience due to uncertainty. If uncertainty is so high as to inhibit trialing, it is also inhibiting the key tool available for reducing uncertainty. Information from observing other farmers' experiences with the innovation provides a potential way out of this vicious cycle, but in cases where adoption levels are persistently very low (as with some conservation measures), even this solution is unavailable. The social process of diffusion of innovations is very important (e.g. Rogers 1995), but it depends on early adoption by a minority to seed the process.

2. Partial relevance of off-farm information. Even if some farmers have adopted an innovation, the relevance to other farmers of their experiences will vary. For an innovation such as a slightly modified cropping input, the potential to extrapolate results to other farmers is probably high. On the other hand, results from some land conservation practices may be more regionally-specific. Consider dryland salinity in Western Australia (WA). The key strategy to avoid dryland salinity in WA is to attempt to use a greater amount of the water which falls in rain, to prevent it draining deep into the soil and raising the naturally saline water table. To this end, practices such as establishment of high-water-using perennial plants are advocated. The problem is that the underground geology throughout most of the agricultural region of WA is very complex, so that most farmers have little precise idea about which land is contributing to a raised water table in a particular site. Thus even if perennial plants successfully treat a salinity problem at one site, they may fail to do so at another, depending on the underground rock and soil formations.

3. Externalities. Some land degradation problems have important "external" impacts. For example wind erosion on one farm may impose costs on another farm, such as "sand-blasting" of crops, or burial of fences. Externalities can contribute two different types of uncertainty about the consequences of adoption of land conservation practices. Firstly, a farmer may be uncertain about who will be the beneficiary if he or she does adopt. If there is a risk that the benefits will flow mainly to farmers other than the adopter, the incentives to adopt are reduced. Secondly, a farmer may be uncertain about whether their adoption will be ineffective if other farmers do not adopt. For example, some hydrological catchments span more than one farm, such that all farms in the catchment contribute to rises in the saline water table. In such cases, adoption by any one individual will probably make a relatively insignificant contribution to preventing rises in the water table, although further rises would be prevented if all farmers adopted.

Factors that Reduce the Information Value of Trials

Given that farmer uncertainty about some land conservation practices is high, the importance of conducting on-farm trials to reduce this uncertainty is highlighted. Unfortunately, there is a range of reasons why trials of land conservation practices may produce information of low quality, and so be ineffective at reducing uncertainty.

1. Long time scales. In the conceptual framework presented earlier, it was assumed that a trial provides useful information in the first year. For many agricultural innovations, this is realistic (e.g. a new crop variety). However, many land degradation processes are slow relative to the time frames used for most management decision making (e.g. dryland salinisation, soil acidification). In evaluating a trial, one requires the

degradation to be continued under the old farming system for long enough for differences under the new farming system to become apparent. Obviously, the slower the degradation process, the longer it will take to be convinced about differences in degradation rates. Unfortunately the great variability inherent in extensive agricultural production further delays the confident recognition of any such difference. Further, long time scales mean that uncertainty about other variables (e.g. prices) over the relevant time scale is much greater than for a short-term problem, further adding to the difficulty of decision making.

2. Heterogeneity of the land. In the last section, the spatial heterogeneity of land degradation problems was recognised as an impediment to diffusion of innovations from farm to farm. The same issue applies at the scale of a single farm. A large part of the potential information value of a trial is derived from its relevance to other parts of the farm. If a farmer perceives that the trial results are less than fully transferable, the trial's benefits are reduced.

3. Minimum scale needed. For many agricultural innovations, it is possible to conduct trials on a small scale without sacrificing much of the information content of the trial. For example, in Western Australia new crop species are typically trialed on a scale that represents just a few percent of the total area of crop on the farm. As knowledge of and confidence in the crop increases, the scale of production increases. By contrast, for innovations intended to prevent dryland salinity by increasing water use, a small scale trial may have no measurable impact. Especially when combined with long time scales and geological heterogeneity, the scale necessary to have an observable impact in a reasonable time may be little smaller than full-scale adoption. Farmers would naturally be reticent about leaping to such full-scale adoption given their state of high uncertainty.

4. Observability. Related to the problem of minimum scale is the issue of observability. Clearly, low observability of results reduce the information value of a trial. Again salinity provides an example. The relevant movements of water are underground, and so poorly observable. Of course there can also be aspects of the innovation that are highly observable, such as the above-ground production of perennial plants. However, if the prime motivation for adoption is prevention of additions to the water table, above ground production provides a highly imperfect indicator.

Low covariance with traditional practices. Even if a conservation practice is easy to trial on a small scale, giving observable results quickly and providing information that is relevant to the whole farm, the information value of the trial may be low relative to most productivity-related innovations because of the problem of low covariance. For example, when wheat farmers trial a new variety of wheat, they expect its yields and prices to be highly correlated with traditional varieties. It may well differ in mean yields, but the farmer would assume that climatic conditions that result in high yields of one variety would also result in relatively high yields of another variety. This is an enormous benefit in the interpretation of trial results. It makes it possible to extrapolate results with some confidence to climatic conditions that have not been experienced in the trial, on the basis that they *have* been experienced with traditional varieties. This is commonly not the case for land conservation innovations. They typically are radically and fundamentally different to any existing practices on the farm. Each observation of the trial's impacts is an isolated observation, poorly correlated with other observations of events on the farm. This problem appears to apply to many conservation innovations including, for example, liming to reduce soil acidity, and tree planting to reduce salinity.

5. Poor implementation. If an innovation is not implemented properly in a trial, the results of the trial are clearly compromised. Unfortunately, this outcome is more likely with land conservation practices than for productivity-oriented innovations because (a) they are commonly less familiar to the farmer and less similar to existing farm practices, and (b) they can be more complicated, with more scope for errors. For example, implementing trials of an agroforestry system integrating trees with cropping or livestock would clearly be more prone to poor implementation than trials of a new crop or a new type of a traditional crop input.

Factors that Increase the Cost of Trials

Compounding the problems outlined above is a set of factors that contribute to trials of conservation practices being highly costly.

1. Time and effort needed. Point 6 in the last section flagged the greater-than-average complexity of some land conservation innovations. This is likely to mean that the amount of time and effort needed to prepare for and conduct a trial is higher than for simpler innovations.

2. Minimum scale needed. If the minimum scale for a trial is large (see point 3 in the last section), this further increases the time and effort required. Probably even more importantly, it also increases the opportunity cost of land devoted to the trial.

3. Irreversibility. The concept of “option values” was outlined earlier. If a practice is irreversible or expensive to reverse, the resulting inflexibility imposes a cost on the farmer due to lost option value. Establishment of trees provide a good example. Suppose that a farmer establishes a large area of trees to reduce land degradation, but subsequently a highly effective conservation technology becomes available that allows traditional farming to continue without dedicating large areas of land to trees. Because it is expensive to remove the trees, the farmer may be worse of than if he or she had never established the trees. If a farmer considers such an outcome to be realistically possible, it would provide a disincentive to adoption. This is, at heart, a problem of uncertainty. If the farmer knew in advance whether an improved technology would become available, there would be no risk of mistaken non-adoption.

Impications

Based on this discussion, a number of clear implications can be identified. Firstly, it appears that the problem of uncertainty in adoption of land conservation practices is much greater and more far reaching than normally recognised. The fact that farmers have been slow to take up some innovative land conservation practices is highly understandable when viewed within the context of the issues raised here (even without considering the range of other negative influences on adoption of these practices - Pannell, 1999).

It does appear that uncertainty is an important cause of market failure in this case.

However, it is not clear whether government intervention can reduce the extent of this failure. On one hand, government agencies may be in possession of information from scientific research and other sources that is in some sense better than that held by at least some farmers. On the other hand, even if this is true, its accuracy at particular sites may be unknown, and assessment of its management implications for particular farmers will certainly be outside the capacity of agencies. Given the heterogeneity discussed here, such an assessment depends very much on local knowledge and individual circumstances. Farmers understand this well, and so are most unlikely to be influenced by advice from agencies that they should adopt particular practices. Even if the advice is good, it will probably not be believed, and for sound and prudent reasons. Information on bio-physical aspects that does not attempt to draw management implications for individual farmers is less susceptible to this problem.

One prominent government response to land degradation problems in Australia has been the National Landcare Programme, a central feature of which is the formation of formal farmer groups. These play a role in collection and sharing of information, and in this they appear to be partially addressing the problems of uncertainty addressed here. In particular the following advantages of the Landcare group approach might be expected.

- It can speed the flow of information between individuals in the group,
- It may help to facilitate joint trials. If farmers agree to share costs, the problem of high trial costs can be partially avoided. (In practice, this appears to be uncommon).
- Joint trials, because they are local and farmer-run, have greater local relevance and credibility than agency information from other regions.
- Perhaps the joint effort involved may reduce the risk of poor implementation.

Although these are important advantages, it appears that there has been excessive optimism in some quarters about the extent to which the Landcare approach can solve the problems of information and uncertainty, especially for the most intractable problem of dryland salinity. In particular, it seems unlikely that Landcare groups could do much to address the following problems discussed earlier.

- The contribution of externalities to high uncertainty.
- The contribution of heterogeneity to high uncertainty.
- Long time scales.
- Cases where the minimum scale needed for trials is large.
- Low observability of some trial impacts.
- Low covariance of the behaviour of the innovation with traditional practices.
- The high cost of ceasing a trial.

It may be worthwhile for the Landcare programme to devote resources to attempting to devise innovative methods for addressing these aspects of uncertainty.

Another strategy that would avoid several of these remaining problems would be to attempt to develop technologies which are profitable in their own right, but which have resource-conservation benefits as a side effect. This strategy is being actively pursued by the Department of Conservation and Land Management (CALM) in WA in its programme to develop tree species that can be commercially viable on what have traditionally been crop and pasture-based farms (Bartle et al. 1996). Although primarily motivated by a wish to tap into the profit motive of farmers (e.g. Sinden and King 1990; Cary and Wilkinson

1997), an additional benefit of success by CALM would be that problems such as low observability of below-ground hydrological impacts would become much less important as an impediment to adoption.

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