1 Introduction

Weeds are a major problem in the Australian grazing industry. Weeds compete with desirable species reducing available pasture, poison livestock, inhibit stock movement and cause physical injury. For those producers involved in the livestock industry, weeds have been estimated to cost $315 million in direct costs and $1,870 in lost production (Sinden *et al.* 2004). This combined cost of nearly 2.2 billion dollars represents 7% of Australia's gross value of production for all agricultural industries ($30 billion). There is clearly a need to improve the management of weeds in the Australian grazing industry.

It has been widely suggested that integrated weed management strategies are required to sustainably overcome the weed problems facing Australian graziers (Dowling *et al.* 2000; Huwer *et al.* 2002; Sindel 2006). Despite this belief, the integration of weed management methods in Australian pastoral systems has not been widely researched, developed or extended. Little is known about how graziers currently integrate controls or the rates of adoption of those few integrated weed management strategies developed through empirical science. Indeed, empirical scientific research faces many obstacles in its endeavours to examine the potentially innumerable combinations of control options that could be used in an integrated weed management strategy. An alternative research methodology which has been slowly gaining credibility is the harvesting of local knowledge through the concept of best management practice, a process which seeks to capture and distil producer perceptions. This project primarily seeks to use this methodology to better understand integrated management for pasture weeds. However, understanding the ways producers integrate weed management strategies and identifying potentially successful controls is of little use if they are not applied by producers. And so, this project also examined the potential challenges to adoption of some of the controls and integrated weed management strategies identified in this study.

Whilst the main objectives of this study were to identify the best management practices for pasture weeds and the challenges that producers face in implementing them, there were two additional, related objectives examined. The first was to validate the producer perceptions which were relied upon for much of this study. The second was to identify the pasture weeds of most concern to graziers throughout southern Australia.

To achieve these four main objectives this project involved five major research activities. The first involved interviewing key informants to gain an understanding of the issues involved in pasture weed management. The information acquired in these interviews was used to shape the next stage of the project, the postal survey. The postal survey was the major research component of this project and involved formulating the survey instrument which was used to gather information on a number of weed related issues. The postal survey was effectively a number of surveys combined into one questionnaire, allowing relationships to be examined between the issues of interest. Following the postal survey a ground truthing study was undertaken to examine the validity of a subset of the results found in the survey. The postal survey results were analysed and a telephone survey was undertaken to provide a deeper understanding of the ways producers integrate weed management practices. Finally, focus groups were used to further explore postal survey results examining the challenges to adoption of weed management strategies. This project was funded by Meat and Livestock Australia and was initially targeted at meat sheep producers but was later broadened to include beef, wool and mixed grazing enterprises.

Following this introduction (chapter 1) a further seven chapters are presented. This chapter provides a brief background to the project, outlines the major activities undertaken during the project and outlines the thesis format.

In chapter 2 a review of the relevant literature concerning integrated weed management (IWM), the innovation, transfer and adoption process, local knowledge, its harvest through best practice management (BPM) and the challenges to adoption of weed management strategies are presented. This review chapter seeks to introduce the background information necessary to understand this project. The overall objective of this review is to provide an understanding of the theory of knowledge systems in which this project is operating.

The methodology chapter (chapter 3) details the development of the various surveys and focus groups that were undertaken to achieve the four main objectives of this study. For each survey technique used a review of literature of the methodological issues is presented and then the methodology is outlined.

Chapter 4 reports on a study undertaken to validate producer perceptions. This part of the study was to determine whether the information provided by producers in survey form accurately represented the weed status of their properties. This study only begins to uncover the complexity of validation of producer perceptions; however it does provide insight into this vexed issue.

The broad results from the postal survey about the occurrence and distribution of weeds as reported by respondents are outlined in chapter 5. This chapter provides an understanding of the geographic, production and demographic characteristics of the respondents, identifies producer perceptions of the most important pasture weed species and introduces four key weed species which will be investigated further in this thesis.

Having identified four key weeds in the previous chapter, chapter 6 seeks to identify best management practices for each of them. To achieve the above aim, a series of questions is asked leading from the most simple to the more complex concepts. Which controls do producers perceive to be successful? Is the use of individual controls on a farm correlated with the long term change in weed problem? If graziers use multiple control methods against weeds, what are the most frequently used combinations? What is the context in which different combinations of controls are used? Is there a correlation between the most frequently used combinations and the long term weed problem? And, are graziers integrating multiple control methods in a strategic way to manage weeds?

In chapter 7 the challenges to adoption of best weed management practices, as identified in chapter 6, are explored drawing on information from both the postal survey and focus groups. Through an in depth examination of the issues related to the adoption of one control method (spray grazing) and the barriers to adoption of controls for two nominated weeds, blackberry and serrated tussock, it is intended to clarify some of the challenges associated with adoption of weed management strategies.

The final chapter (chapter 8) draws conclusions from all the preceding chapters to provide a broad understanding of the validity of producer perception of weeds, the weeds of most concern to graziers in southern Australia, the best management practices for weeds and the challenges that producers will face in implementing these. This chapter also describes the direction that future research might take to investigate the issues raised in this thesis.

2 Review of literature

The objectives of this review were to: 1) provide a conceptual understanding of integrated weed management; 2) understand the human behaviour process that leads to change and, to examine the process of innovation, transfer and adoption; 3) review the idea of local knowledge and its context in this project; 4) review the process of best management practice as it seeks to capture local knowledge; and 5) examine the challenges that face graziers to the adoption of weed management strategies.

2.1 INTEGRATED WEED MANAGEMENT

It has been widely suggested that integrated weed management strategies are required to sustainably overcome the weed problems facing Australian graziers (Dowling *et al.* 2000; Huwer *et al.* 2002; Sindel 2006). Because of this, the concept of integrated weed management (IWM) is an integral part of this thesis.

Integrated weed management (IWM) has been defined simply as "a sustainable management system that combines all appropriate weed control options" (Sindel 2000). Although this simple definition captures the essence of IWM, it masks the complexity of the issues that surround the development and application of such strategies.

The historical development of the theory and terminology surrounding integrated weed management has been thoroughly reviewed by Thill *et al.* (1991) and Sindel (2000). The development of IWM closely follows the theory of Integrated Pest Management (IPM), which was initially used to describe management systems for insect pests of crops and pastures (Thill *et al.* 1991; Sindel 2000). Pesticide resistance was an important contributor to the development of both IPM and IWM; however, benefits other than overcoming chemical resistance also shaped their progress (Sindel 2000). Both IPM and IWM depend on an understanding of the ecology and population dynamics of the pest species and the pasture or crop as well as the economics, and potential influence of control agents on the farm system. Despite IWM being considered a component of IPM, very few texts investigating IPM actually touch on weed management (Thill *et al.* 1991).

The literature suggests that integrated weed management is characterised by several key features (Table 2.1). An IWM strategy, by definition, does not rely solely on one control method; rather it combines both pro-active and re-active control methods (Bhowmik and Inderjit 2004). Proactive controls are those which seek to encourage desirable species whilst re-active controls target the weed species directly. Not only does IWM combine more than one control, it specifically seeks to promote synergistic relationships between different controls whilst reducing any possible negative interactions (Sindel 2000). IWM also avoids strategies that create intense selection pressures such as the repetitive use of effective methods (e.g. herbicides) against genetically adaptable weed populations (Sindel 2000).

IPM places particular emphasis on economic thresholds as guides to management decisions; some authors suggest that this should also be an important component of IWM (Thill *et al.* 1991; Huwer *et al.* 2004). However, in practice, there appears to be far less information on economic thresholds available to weed managers compared with those controlling insect pests.

IWM targets different stages of a weed's lifecycle. Whereas weed control has been defined as the practice of removing an existing weed population, IWM seeks to prevent weed reproduction, reduce weed emergence, promote seed bank depletion and minimise weed competition with the desirable species. IWM also places constraints on the different stages of incursion of a weed (Buhler 2002; Sindel 2006).

IWM considers the influence of control on more than just the targeted area; ideally it is applied in the context of the entire farming system. The farm and surrounding area must be considered part of an entire agro-ecosystem (Buhler 2006). Some authors suggest that IWM reduces the impact of controls on the natural environment and social contexts in which the farm system operates (Swanton and Weise 1991; Thill *et al.* 1991; Swanton and Murphy 1996).

Finally, and as a consequence of many of the features discussed above, it has been noted that unique IWM strategies must be developed for each site and point in time. The proposal of specific programs and tactics to be applied over a wide range of situations does not fit the model of IWM (Buhler 2002). With particular reference to IWM, it has been suggested that landholders have a range of site specific problems for which they can best work out how to apply control methods (Jordan *et al.* 2006).

This list (Table 2.1)

Applying IWM in pasture systems is not a simple process. One of the major limitations to the development of integrated weed management strategies is the potentially large number of possible combinations of individual controls that could be combined into an IWM strategy (Sindel 2006). In addition, the inability to predict or model the outcomes of applying one of the many possible combinations of controls also impedes the development of IWM (Swanton and Murphy 1996; Sindel 2006). Scientific research has been used to produce individual integrated weed management strategies for pastures (e.g. Huwer *et al.* 2004), however empirical scientific research is limited to examining only a small number of possible control combinations and IWM strategies. This project provides a unique opportunity to examine a vast number and variety of IWM strategies through an examination of the activities of graziers, and local knowledge held by producers. Whilst this does not replace the detailed objective knowledge gleaned by replicated experiments it will provide some valuable insights as the processes of innovation and adoption are understood and the value of local knowledge revealed as is demonstrated in the following section.

Table 2.1 A summary of the key features of integrated weed management

Integrated weed management:

1) uses more than one individual control method;

2) uses both re-active and proactive control methods;

3) promotes synergies amongst multiple control methods;

4) avoids strategies that instigate intense selection pressures;

5) uses economic thresholds in deciding control applications;

6) places constraints on the different lifecycle stages of the weed;

7) places constraints on the different incursion stages of the weed;

8) considers the influence of the control on more than just the targeted area of the property;

9) reduces the impact of the control on the natural environment;

10) reduces the impact of the control on the social environment; and

11) is as a result of many of the above criteria site and time specific.

2.2 INNOVATION, TRANSFER AND ADOPTION

This project examines the dynamics of the human behaviour process that leads to change. This process has had various labels, however for the purpose of this study we will define it as the "innovation, transfer and adoption process" which follows the theories of a number of key authors (e.g. Rogers and Shoemaker 1971; Chamala 1987; Guerin and Guerin 1994).

In a theoretical context, it has been suggested that the innovation, transfer and adoption process is made up of three distinct stages. The first stage is the process of innovation development is where a new idea or practice is formed. The second is innovation transfer where the idea or practice is taken from its place of development to where it can be put into operation. The final step in this theoretical model is adoption where the innovation is put into practice (Rogers and Shoemaker 1971; Rogers 1983; Guerin and Guerin 1994).

The innovation, transfer and adoption process (Figure 2.1) has historically been seen as a unidirectional movement of ideas and technology from the innovator, usually a research institution, through extension officers such as government agricultural officers to farmers as the end receivers (Marsh and Pannell 1998; Stephenson 2003; Teixeira *et al.* 2004). The current thinking on this subject (represented in Figure 2.2) has seen this concept change significantly with the development of programs (e.g. participatory and farmer first research) which acknowledge and foster feed back and communication between the various parties and realise the changing roles that organisations and individuals now play (Nicholson *et al.* 2003; Teixeira *et al.* 2004; Dart 2005).

Historically the term "extension" has been used to describe the processes that are involved in the transfer component of the model when there were more clearly defined boundaries between each component of this technology change model. As research has developed and scientists began to acknowledge the interactions between the components the term "extension" has been used to cover more than just the transfer component of the model (Leeuwis 2004; Pannell *et al.* 2006). Current trends in this field suggest that the term extension is no longer helpful with new definitions such as "communication for innovation" attempting to capture the complexity of the interactions between the different components and players in the game (Leeuwis 2004).

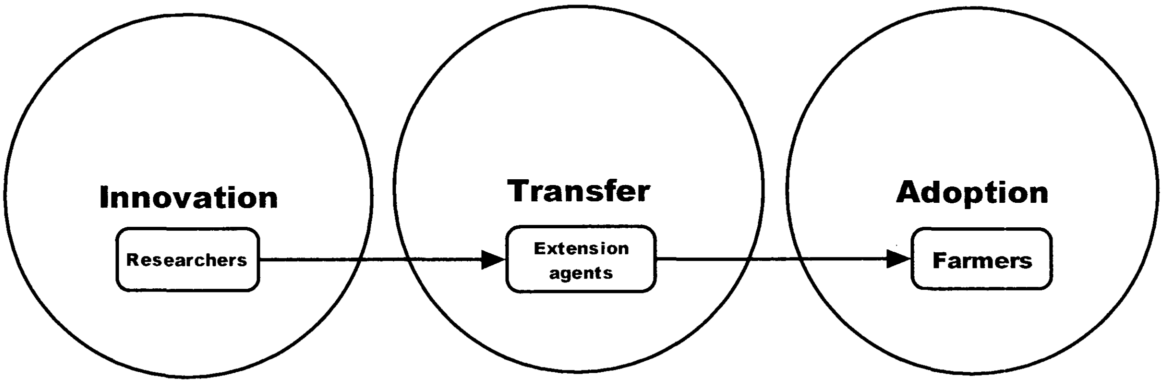

Figure 2.1 A basic model describing the traditional view of the innovation, transfer and adoption process adapted from Marsh and Pannell 1998; Stephenson 2003; Teixeira *et al.* 2004.

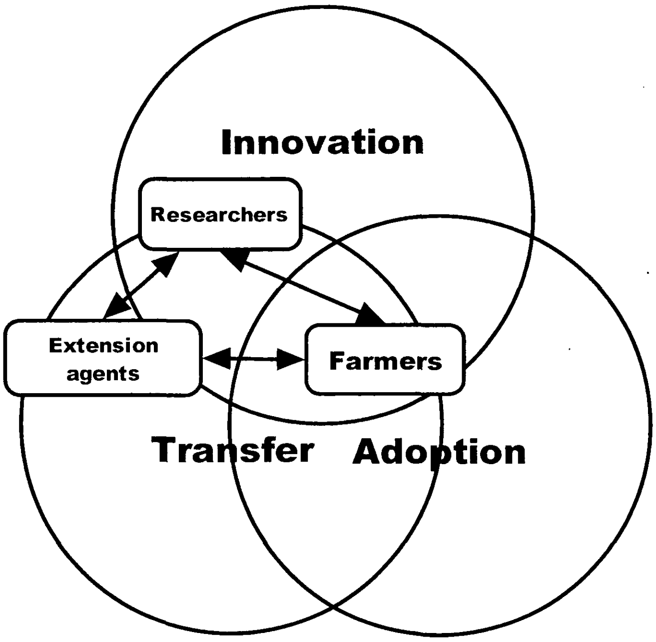

Figure 2.2 A representation of the current thinking of the interactions and changing roles of participants in the innovation, transfer and adoption process. This project places particular emphasis on farmers moving into the position of innovators.

2.3 LOCAL OR INDIGENOUS KNOWLEDGE

We have seen from the previous section that the traditional ideas of roles and functions in the innovation, transfer and adoption process have been challenged in recent times. One of the most fundamental challenges has been the increasing awareness amongst scientists of the value of indigenous or local knowledge which places the farmers in the position of innovator (Figure 2.2).

Local (or indigenous or traditional) knowledge is knowledge and insight acquired through extensive observation of a subject. This may include knowledge passed down in an oral tradition or shared among users of a common resource (Huntington 2000). Local knowledge has been widely researched and used in developing countries (Raedeke and Rikoon 1996; Walker *et al.* 1999). The progress of local knowledge in these developing countries is thought to be due to the failure of western ideas of technology innovation and diffusion (Briggs *et al.* 1998; Leeuwis 2004). In developing countries, local knowledge can be seen as providing essential information about local farming systems and is responsible for a large proportion of behavioural change (Millar and Curtis 1999). Despite this, local knowledge has traditionally been seen as being in opposition to scientific knowledge. Indeed, there are important distinctions between local and scientific knowledge, however, scientific knowledge has long been held up as the best, most objective form of knowing, at least in Western cultures. In contrast, local knowledge has often been viewed as context specific, un-objective and consequently unscientific (Agrawal 1995; Millar and Curtis 1999). These views have been challenged by many authors arguing that diversity in knowledge should be valued and that there may, in reality, be little distinction between local and scientific knowledge (Agrawal 1995; Raedeke and Rikoon 1996; Millar and Curtis 1999; Leeuwis 2004). An important point to understand is that in developed countries local knowledge will be particularly affected by this merging of knowledge systems. Farmers in a developing country may only have local knowledge that incorporates information passed down by traditional means (e.g. oral traditions). In contrast, farmers in developed countries will have these traditional means along with the various sources of scientific information that have been formally extended over time. These farmers in developed countries will have combined all sources of information to develop their own unique local knowledge. Once scientific knowledge is applied by a farmer in their unique situation it effectively becomes local knowledge.

In some cases local knowledge is now recognised as having been developed with an empirical basis as holders of local knowledge have applied their own scientific method to produce information (Huntington 2000; Leeuwis 2004).

Despite its widespread acceptance in less developed countries and the general move to value local knowledge even in Western cultures, there appears to be little discussion of its existence or importance in the agricultural production systems of developed countries (Millar and Curtis 1999). Studies of producers in developed countries commonly focus on constraints to adoption but fail to recognise producers as innovators (Millar and Curtis 1999). This may be due to the difficulties involved in harvesting this local knowledge. As little of this information is formally recorded, researchers must employ social science methods to study biological systems. This cross-disciplinary undertaking has been described as a formidable task (Huntington 2000).

Despite the obvious challenges, it is clear that local knowledge exists in Western farming systems and is important. The documentation and distillation of this information is likely to be of great potential. This project seeks to undertake this process for weed control amongst graziers in Southern Australia.

2.4 BEST MANAGEMENT PRACTICE

It is clear that understanding local knowledge has great potential but there are substantial difficulties in harvesting and unlocking this information. A related concept which has been around for some time that has become popular is Best Practice Management (BPM) and has been described by Camp (1989) as the search for industry best practices that lead to superior performance, although there is a great deal of variation in what defines BPM. Best Practice Management is also referred to as benchmarking, best practice and best management practice, although, at times, these terms are also used to describe subtly different processes. Best Practice Management is essentially a methodology that has been developed to harvest and refine local knowledge. This process is by no means new; however, it is believed to have been formalised by the manufacturing firm Xerox in the early 1980s (Spendolini 1992) who applied it to their manufacturing processes to increase production efficiencies.

In its purest form, BPM seeks to identify a single best management practice which should be emulated by others to achieve productive improvement. Having been developed in the manufacturing industry, it has been relatively successful as external influences are limited and production systems reasonably similar. This contrasts greatly with production systems that incorporate biological systems with varying environmental influences as is found in agricultural production. Despite this, BPM has been applied to agricultural production systems (Boyce 1995; Lacy 1998; Trotter and Sindel 1998; Williams and Walcott 1998). In some of these cases a single best management practice is recommended, an undertaking that fails to recognise how context specific local knowledge can be. On closer inspection, these cases of application of best management practice within agriculture are either quite general (Williams and Walcott 1998) or targeted at production systems which are similar (Lacy 1998).

Because of the many environmental interactions that can occur, a single optimal procedure or best management practice may not be appropriate for systems involving primary production as there are often so many variables which differ between farms. This by no means reduces the value of the process of best management practice; it simply means that we cannot expect that there will be a single optimal solution to managing pasture weeds. In this sense I am straying from the original strict definition of best management practice and suggest a more context specific definition needs to be adopted. This project aims to highlight the control methods and integrated strategies that are working for many producers. When the results of the various surveys are discussed it will be seen that there is no one IWM strategy that is recommended for all situations. Instead, controls and strategies are reported in terms of how commonly they are used, their reported success rates and, where possible, the context in which they are most frequently used. Although some IWM strategies are recommended as producing more favourable results than others, this does not mean that they are suited for universal application. If these results are to be transferred to the farming community it is up to each producer to examine the control methods or integrated strategies and determine if they can be applied to their unique, environmental, financial and social situation.

2.5 CHALLENGES TO ADOPTION OF WEED MANAGEMENT STRATEGIES

This review is designed to identify the issues and challenges surrounding the adoption of weed management strategies. More specifically it aims to: 1) understand the process of innovation adoption; 2) identify the challenges to adoption of innovations in agriculture; 3) highlight the limited research available on the challenges to adoption of weed management strategies; and 4) develop a list of possible issues and challenges that might be expected to affect the adoption of weed management strategies as elucidated in this project.

The innovation, transfer and adoption model is not simple; the boundaries between the three components blur and are not clear cut (Figure 2.2). Despite this fact it is helpful in that it allows us to understand that there are at least vaguely different components to the process. This section of the review focuses on the adoption component of the model, keeping in mind that it will affect and be affected by these other factors.

1) UNDERSTANDING INNOVATION ADOPTION

There are a several ways of understanding innovation adoption, developed in various disciplines. Within an agricultural context several authors have suggested that a good way to understand innovation adoption is to examine the decision making process of the farmer (Chamala 1987; Guerin and Guerin 1994; Barr and Cary 2000). Several models of the decision making process have been developed (Rogers and Shoemaker 1971; Chamala 1987; Guerin and Guerin 1994).

One of the most comprehensive, developed by Barr and Cary (2000), is a model relating to the decision making process for innovation adoption in the context of implementation of practices to alleviate land degradation. These authors go on to describe some of the barriers to adoption that can occur at each of the stages that they have defined. This model, summarised in Table 2.2 is particularly useful as land degradation is often closely associated with weed management.

One of the most recent models has been developed by Nicholson *et al.* (2003). This model, shown in Figure 2.3, was developed to explain the adoption process relating to pasture management practices found through the Sustainable Grazing Systems project.

Pannell *et al.* (2006) expands on economic modelling undertaken by Abadi Ghadim and Pannell (1999) and suggest that adoption is a dynamic learning process with two distinct aspects. The first is the collection, integration and evaluation of information by the producer and the second is the development of skills in the implementation of the innovation. Like other authors, Pannell *et al.* (2006) identify different phases in the adoption process (Table 2.3). Some helpful definitions suggested by these authors have been developed for further use throughout this thesis. "Adopters" are those producers who intend to continue using and adapting an innovation. Those producers who after non-trial evaluation dismiss an innovation can be considered "non-adopters". Those farmers who trial or use an innovation but then cease applying it can be considered "dis-adopters".

A summary of the innovation, transfer and adoption process along with the adoption decision making process is presented in Figure 2.4. What is apparent from this summary model and expressed by many other authors is that challenges exist throughout the adoption process (Guerin and Guerin 1994; Abadi Ghadim and Pannell 1999; Pannell *et al.* 2006). A further critical point is that this process is dynamic and ongoing so that innovation adoption does not have a finishing stage; it continues for as long as the innovation is applied (Guerin and Guerin 1994; Barr and Cary 2000; Nicholson *et al.* 2003; Pannell *et al.* 2006).

Table 2.2 The stages of the innovation adoption decision process suggested by Barr and Cary (2000) using land degradation as a case study.

Stage	Details	Possible challenges
Anticipation of land degradation	Farmer anticipates that land degradation that will affect them in the future.	Anticipation of loss is psychologically difficult. Farmers need to realise that there is a serious problem. Farmers need to realise that they will be affected by the problem.
Seeing land degradation	Farmer observes that land degradation is affecting them.	Farmers need to know what to look for.
Seeking information	Once a problem is identified the farmer seeks out information on the available options.	Priorities with other searches for information.

Stage	Details	Possible challenges
Weighing the alternatives and risks	The options sought out are compared.	Expectations of financial return for investment. Consistency of the practice with other farm objectives. The inability to observe the practice on neighbouring farms. Stress in decision making. Concern about appearances in a social context.
Making a decision	Social support for the decision is sought out.	Social opposition.
Undertaking a trial	If uncertain a trial may be undertaken.	Trial failure.
Making a change	Time and money are invested into implementing the change.	Financial restrictions from lenders.
Reaffirming the decision	If expectations are satisfied the innovation will continue to be applied.	A lack of social support.

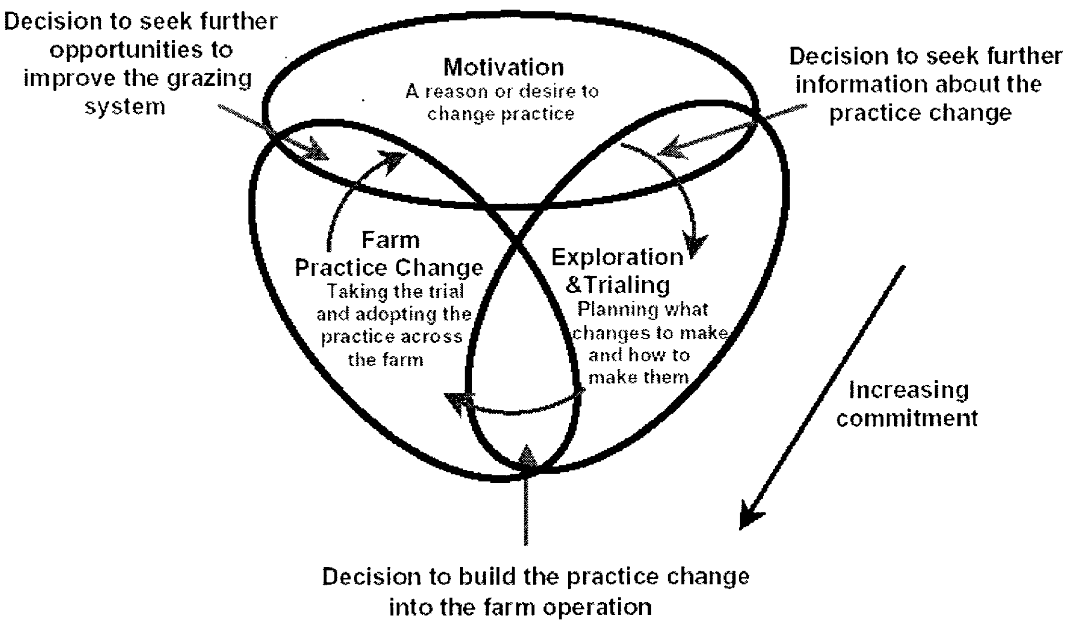

Figure 2.3 The three stage model of innovation adoption proposed by Nicholson *et al.* 2003).

Table 2.3 The sequence of phases of innovation adoption as described by Pannell *et al.* (2006)

Innovation adoption stage	Details
Awareness of the problem or opportunity	The producer becomes aware of an innovation that has relevance and can provide a benefit.
Non-trial evaluation	The landholder begins to collect information to inform the next steps.
Trial evaluation	If possible, the producer will trial the innovation enhancing both information collection and skill development aspects of the adoption process.
Adoption	Depending on trial results the innovation may be applied to a greater extent. There may be little distinction between a trial and full scale adoption as the innovation is gradually implemented across a property.
Review and modification	Trialling effectively never ceases as the innovation is reviewed and modified.
Non-adoption or dis-adoption	The innovation may be abandoned at any time during the adoption process. Trial results may be unfavourable, seasonal conditions may change or a new and better technology may become available. The innovation may go through a scaling down process.

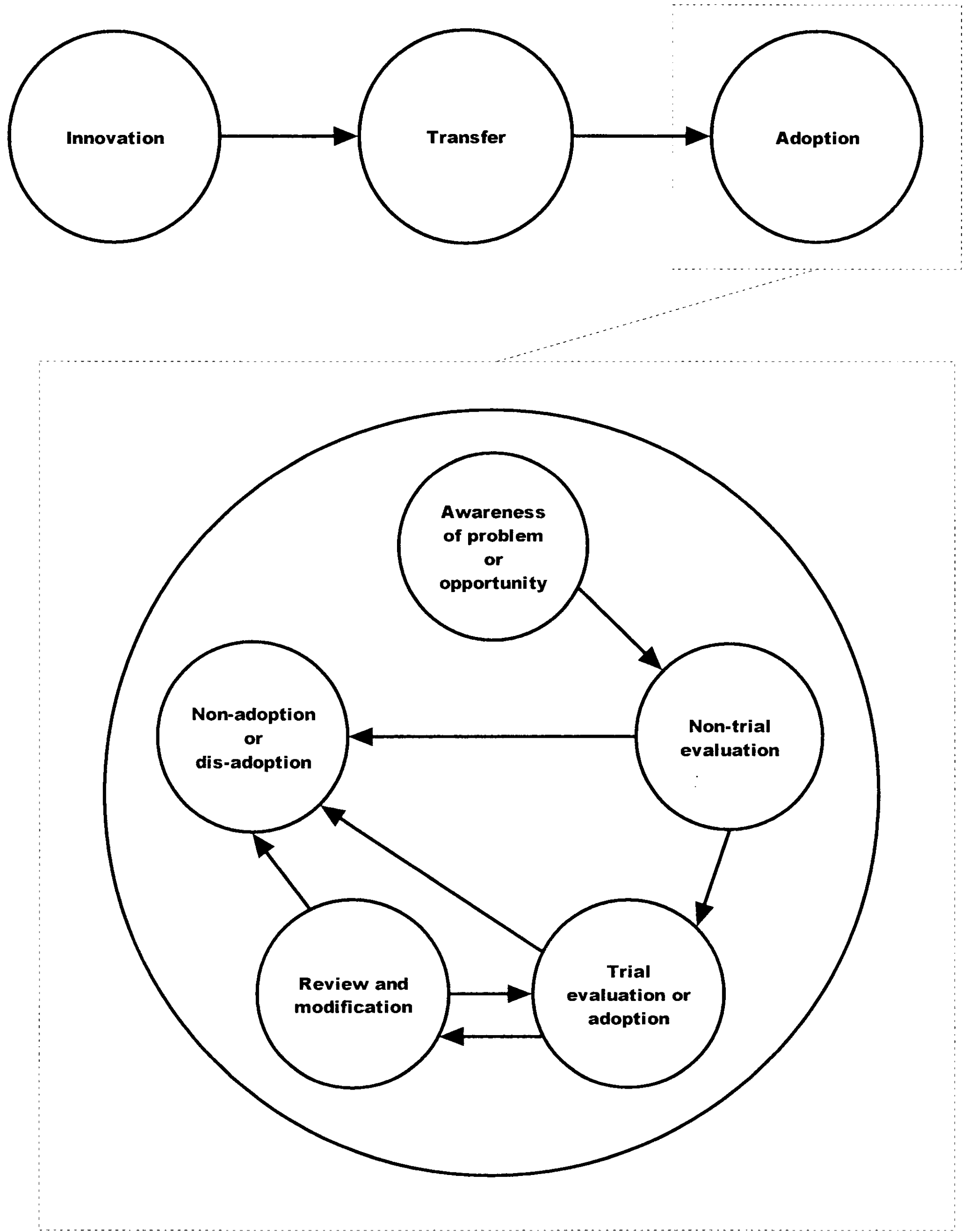

Figure 2.4 The theoretical model of the innovation, transfer and adoption process (Guerin and Guerin 1994) with the decision making process for the adoption component further detailed (Pannell *et al.* 2006).

2) CHALLENGES TO INNOVATIONS ADOPTION IN AGRICULTURE

The term "challenge" has been deliberately chosen and was developed in this context by Leeuwis (2004). The terms "barrier" or "limitation" have traditionally been used, however it is argued by Leeuwis (2004) that these terms give a negative connotation suggesting an insurmountable, almost impossible task to be overcome. The term "challenge" provides a more positive connotation, suggesting that there may be some way of overcoming the apparent barriers or limitations.

There have been several reviews that examine the theoretical challenges to adoption of innovations in agricultural research (Chamala 1987; Guerin and Guerin 1994; Guerin 1999; Barr and Cary 2000; Vanclay 2004; Pannell *et al.* 2006). Whilst there are many similarities amongst these reviews, each applies a unique structure to explain the challenges to innovation. In addition, these reviews identify many common challenges, although each presents a different view point and some identify unique and unexpected challenges.

An alternative and useful way of thinking about these issues is presented by Vanclay (1992) in his review of the social principles related to extension of sustainable practices in agriculture. Vanclay (1992) presents twelve categories for the reasons that producers give for not adopting innovations. These categories were further developed by Vanclay (2004) with particular, although not exclusive, reference to sustainable land management practices (Table 2.4).

Pannell *et al.* (2006) also explored the issues of adoption of land conservation practices. This extensive review identified three broad categories of issues involved in innovation adoption. These were: 1. the process of learning and experience to inform adoption decisions; 2. the social, cultural and personal influences on adoption decisions; and 3. the attributes of the practices that affect the adoption of innovations. Pannell *et al.* (2006) further divided the process of learning and experience into two distinct categories. First is the collection and evaluation of information and the second is the development of the landholder's skill in applying the innovation. This learning process was affected by the social, cultural and personal factors as well as the attributes of the innovation (Table 2.5). In considering the attributes of practices that affect the processes mentioned above, Pannell *et al.* (2006) indicate that there are two categories into which they fall. The first is relative advantage and the second is the trialability of the innovation.

Table 2.4 The categories of reasons for non-adoption of an innovation as developed by Vanclay (1992; 2004).

Reason	Details
Too complex	The more complex the innovation the more resistance there is to adoption.
Not easily divisible into manageable parts	If an innovation can be broken down into components it can be partially adopted and is more likely to be taken on.
Not compatible with farm and personal objectives	Not compatible with farm or personal objectives. If an innovation does not line up with the farm or personal objectives it is unlikely to be adopted.
Not flexible enough	Farmers like flexibility as it allows them to meet market demands. Anything that reduces their flexibility will be unlikely to be taken on.
Not profitable	If a new practice cannot be shown to be profitable it is unlikely to be adopted.
Capital outlay is too high	Even if an innovation is profitable the capital outlay required to implement it may be restrictive.
Too much additional learning is required	There are intellectual costs to innovations as farmers have to learn how to do new things. Some individual farmers may be unwilling to invest sufficient thought.
Risk and uncertainty is too great	Farmers may perceive that the risk of a desired outcome from implementation of an innovation is too great.

Reason	Details
There is conflicting information	Farmers receive information from many sources and those sources frequently contradict each other. This is particularly apparent with new technology.
Don't see (or appreciate) that there is a problem	A lack of appreciation that there is a problem.
Lacking the physical infrastructure	This is concerned with external infrastructure such as product handling facilities.
Lacking the social infrastructure	This refers to the social networks of farmers which forms a knowledge bank. An aversion to adoption might occur as a farmer has no-one with which to discuss the innovation.

Table 2.5 The influences on adoption developed by Pannell *et al.* (2006)

Reason	Details
Social, cultural and personal influences on adoption	
Personality	A land holder's personality and particularly their perception of influence on their circumstances (locus of control) can affect their ability to make adoption decisions.
The existence and strength of landholders' social networks	Membership of certain organisations may be associated with increased adoption although causality is unclear.
The physical proximity to other adopters	The closer to other landholders using a practice the greater the likelihood of adoption.
The physical distance of the property from sources of information	More distant landholders are less likely to adopt.
Relationships with extension agents	A history of respectful relationships with advocates of the innovation can encourage adoption.
Ethnic and cultural divisions	These can act as a barrier to communication.
Extension, promotion and marketing programs	These can encourage adoption.
Profit expectations	The overall profitability of the farming enterprise can influence adoption..
Access and reliance on off-property income	Off-farm income can increase adoption through financial security however some innovations may not be compatible with the off-farm employment.
Property size	Property size is often, although not always, related to adoption.

Reason	Details
Age	Age may have a direct effect, particularly with innovations that have a long lag time. Age might also have indirect effects through physical health.
Education	There can sometimes be relationships between education and adoption of conservation practices. A farmer's general level of education is likely to be less important as a predictor of adoption than their participation in specific relevant training courses.
The reason for holding the land	Commercial landholders have different reasons for owning land than those residing on the land for lifestyle choices. These landholders will have different preferences in innovation adoption.
Attributes of innovations that influence adoption – that influence relative advantage	
Short term profitability	The short term input costs, yields, and output prices of the innovation or other farm systems that it affects.
Medium and long term profitability	The impact of the innovation on the medium and long term profitability of the farm system.
Impacts on other farm systems	The impact of the innovation on other parts of the farm system.
Adjustment costs	The capital and set up costs involved in adoption of the innovation.
Impact on production risk	The innovation's impact on the overall production risk.
Compatibility with existing resources	The compatibility of the innovation with the existing set of technologies, practices and resources held by the farmer.
Complexity	The complexity of the innovation.
Government policies	The support or legislative programs that encourage innovation adoption.
Advantage over existing methods	The costs or profitability of the traditional practice which the innovation would replace.
Compatibility with existing beliefs	The compatibility of a practice with existing beliefs and values.
Impact on family lifestyle	The impact of the innovation on the family lifestyle.
Self image and brand loyalty	The impact of the innovation on the social standing of the adopter.

Reason	Details
The perceived environmental credibility of the practice	Although expected to increase adoption it may not always be the case. Some producers may partially adopt environmental innovations to make a show of concern.
Spillovers	Some benefits from conservation practices can extend to individuals other than the adopters.
Attributes of innovations that influence adoption – that influence trialability	
Divisability	The ability of an innovation to be used on a small scale or the use of a component of the innovation.
Obervability	The more observable the results the less uncertainty.
Time lags	The longer the time lags the less trialable is the innovation.
Complexity	The greater the complexity the more information is required to be certain about the consequences of adoption. Greater complexity also increases the risk of technical failure of the trial.
Cost of trial	The higher the cost the less likely the innovation is to be trialled.
Biological threats	Drought, diseases, pests and establishment failure could undermine a trial.
The relationship between trial results and full scale innovation consequences	The trial needs to reflect the results to be expected under full scale adoption.
Similarity with existing practices	The similarity of the innovation to existing practices can increase trialability.
Spill-overs	Spill-over effects can reduce the perceived value of trial results.

3) CHALLENGES TO THE ADOPTION OF WEED MANAGEMENT STRATEGIES

Until recently, little research has been undertaken to identify the challenges to adoption of weed management strategies, particularly in pastures. There have however been several studies examining the challenges to adoption of a number of specific agricultural innovations. These can provide some insight into the issues for weed management. The areas studied have been diverse and include an examination of the challenges to adoption of precision agriculture technologies (Ambrosio *et al.* 2006), sustainable manure use (Battel 2005), crop varieties (Eberle *et al.* 2004) and irrigation technologies (Maskey *et al.* 2001; Keeble *et al.* 2004).

The barriers to adoption of sustainable land use practices have received particular attention with research covering areas such as no-tillage adoption in Australian cropping systems (D'Emden and Llewellyn 2006), New Zealand deer farms (Payne and Bewsell 2006) and vegetable growers (Drost 1998).

Of particular relevance are the studies examining the challenges to adoption of integrated pest management (Alston 1998). Despite the obvious link between integrated pest management and weed control (Bhowmik and Inderjit 2004), little of this research actually mentions weed management, focussing instead on insect pests (Thill *et al.* 1991).

Despite this relative wealth of information on the adoption issues of many agricultural innovations, little research has been published on the challenges to weed management strategies. This lack of information is confirmed by many other authors (e.g. Bhowmik and Inderjit 2004; van der Meulen *et al.* in press). This absence of literature is not isolated to complex integrated weed management strategies as there is also a distinct lack of information available on the adoption of simple single weed control practices.

RECENT DEVELOPMENTS

At the time of developing this project there was little research information available on the challenges to adoption of weed management strategies. Since then, several projects have come to light and a review of these follows.

With reference to adoption of weed management strategies in cropping systems, Llewellyn *et al.* (2004) found that certain non-chemical weed management practices were more likely to be adopted by farmers experiencing herbicide resistance. The apparent challenge to adoption amongst croppers without resistance was the comparative cost and unreliability of these non-chemical controls. Llewellyn *et al.* (2004) concluded that these barriers might be overcome if producers could be made aware that some of the non-chemical controls benefited the farm systems in ways other than weed control. Taking this work further, Llewellyn *et al.* (2005) identified nine factors that influence the adoption of weed management strategies (Table 2.6).

Sell *et al.* (2000) investigated the impediments to controlling leafy spurge (*Euphorbia esula* L.) in the United States. Landholders identified several issues that appeared to be limiting the implementation of control programs. Expense of chemicals and time constraints were identified as the most significant problems. Some landholders reported an unwillingness to increase control attempts as previous attempts had not met their expectations in terms of efficacy. It appears that landholders were led to believe that the use of certain controls would eradicate the weed. As this had not occurred landholders were apparently less trusting of new control methods. Neighbouring landholders that failed to control leafy spurge were reported as an impediment. In some cases these were absentee land owners or the government. Other barriers to adoption of control methods included rugged terrain, a loss of contract sprayers, a lack of information on the technical aspects of using biological control and a lack of any regulatory or economic mechanism to force landholders to control leafy spurge. It was also suggested that landholders needed to shift their goal from one of eradication of leafy spurge to acceptance and management of this weed.

In their study of Australian graziers, van der Meulen *et al.* (in press) described three factors which could be used to define the different weed management styles they encountered. The three factors were diversity, diligence and deliberation. Graziers where categorised into eight groups according to the use of these three factors (Figure 2.5). These authors suggest that improvements in weed management will come about as producers move from one point to another within this space, increasing diversity, deliberation and/or diligence. Most importantly van der Meulen *et al.* suggest that adoption paths may be different and have distinct barriers depending on the initial location of the grazier within this conceptual framework. Fixed environmental features such as a rugged terrain and a lack of finance are identified as important universal barriers to an increase in diversity, deliberation and diligence. Within the proposed theoretical framework, deliberation and diversity are seen as closely related. The complexity of integrating multiple weed controls and the increased learning requirements are suggested as significant barriers to an increase in diversity and deliberation. A major limitation to the increase in diligence is suggested to be the perception of the weediness of individual species. These authors suggest that this is related to the limited information on the economic cost of certain weed species and the benefits of controlling them.

The issue of perceived impact is important with some weeds in pastures having beneficial uses, thus reducing their apparent weediness. Similarly, in developing countries the adoption of control methods for some pasture weeds was hampered as certain species can provide alternative benefits such as firewood or medicines (Munyasi *et al.* 2003). Rush (1996) particularly mentioned the difference in attitudes and tolerances to weeds amongst graziers to be a problem. Finally, van der Meulen *et al.* (in press) report an increase in diligence is said to be affected by the priority of weed management amongst other farm tasks. Again, informing producers of the financial cost of weeds is suggested as a possible solution.

Table 2.6 Factors affecting the adoption of integrated weed management practices amongst grain growers in Western Australia with particular reference to herbicide resistance in ryegrass (Llewellyn *et al.* 2005).

Factor	Detail
Perceived economic value of practice for weed control	Growers perceiving higher economic value from adoption are more likely to adopt.
Education	Growers with higher levels of education are more likely to adopt.
The resistance status of the farm	Those with more weed resistance are more likely to adopt.
Perceived ryegrass control provided by a practice	Those who believe the practice will provide higher ryegrass control are more likely to adopt.
The amount of information/extension to which the grower is exposed	Growers accessing larger amounts information through advisors, agronomists, farmer groups, etc. are more likely to adopt.
Perceived number of years until the grower expects a new post-emergence, selective herbicide will become available.	Growers who believe that a replacement herbicide is further in the future are more likely to adopt.
Uncertainty of when a new herbicide will become available	Growers more uncertain of when a replacement herbicide will become available are more likely to adopt.
The proportion of the farm in crop	Growers with more of their farm in crop are more likely to adopt.
Future income discount rate	Growers who do not have a relatively strong preference for income received today compared with in the future were more likely to adopt.

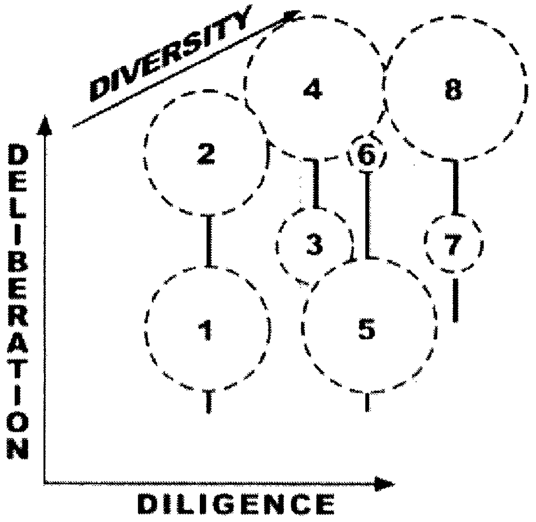

Figure 2.5 The conceptual framework proposed by van der Meulen *et al.* 2006 to explain the weed management styles of graziers. The figure shows the distribution of respondents across eight octants. The size of each circle is proportional to the number of respondents in each group.

4) CONCLUSIONS, WHAT MIGHT BE EXPECTED?

After reviewing the relevant literature a list was constructed of the issues and challenges that might be expected to be identified by farmers asked about the barriers to adoption of individual controls and integrated weed management (Table 2.7). These issues and challenges were later used to classify responses presented as results in chapter 7.

Table 2.7 The issues and challenges to the adoption of a weed control methods and integrated weed management strategies.

Challenge or issue	Details	References
The impact or congruence of the weed management strategy on the farm operation		
Profitability and expense	The cost of inputs, expected returns and the impact of the weed management strategy on the profitability of the farm system. The availability of funds to implement is also included.	(Vanclay 1992; Sell *et al.* 2000; Vanclay 2004; Llewellyn *et al.* 2005; Pannell *et al.* 2006; van der Meulen *et al.* in press)
Resources and infrastructure	The compatibility of the control with existing farm resources and infrastructure.	(Pannell *et al.* 2006)
Adjustment costs	Capital and set up costs involved in implementing the new management strategy.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006)
Intersystem impacts	The impacts of the weed management strategy on the other farm systems. In some cases this might be negative (side effects) or positive.	(Llewellyn *et al.* 2005; Pannell *et al.* 2006)
Fixed environmental features	The compatibility of the weed management strategy with the fixed environmental features on the property (e.g. topography, water courses).	(Sell *et al.* 2000; van der Meulen *et al.* in press)
Operational priorities	The priority of the weed management strategy amongst other farm tasks.	(van der Meulen *et al.* in press)
Production risk	Any changes in production risk that might be brought about by adoption of a new weed control.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006)
Herbicide resistance	The perception and understanding of herbicide resistance and the occurrence, of any on the landholders property.	(Llewellyn *et al.* 2005)
Characteristics of the weed management strategy that might affect adoption		
Complexity	The more complex and integrated the weed management strategy the less likely may be its adoption.	(Rogers 1983; Vanclay 1992; Sell *et al.* 2000; Vanclay 2004; Pannell *et al.* 2006; van der Meulen *et al.* in press)

Challenge or issue	Details	References
Divisibility	This relates to the ability of the weed management strategy to be broken down into components which might be individually applied.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006)
Trialability	The ability of the weed management strategy to be trialled or applied on a small scale.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006; van der Meulen *et al.* in press)
Observability	The more observable or measurable the results of a weed management strategy are the more likely is its adoption.	(Rogers 1983; Reeve *et al.* 2000; Pannell *et al.* 2006)
Time scale	Weed management strategies with long time scales for implementation and returns may be less likely to be adopted.	(Pannell *et al.* 2006)
Flexibility	The degree to which a management strategy might lock a landholder into a specific way of farming, enterprise or market.	(Vanclay 1992; Vanclay 2004)
Intellectual demand	The amount of learning that is required to implement a weed management strategy.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006; van der Meulen *et al.* in press)
Relative advantage	The overall advantages of a new weed management strategy over existing approaches.	(Rogers 1983; Pannell *et al.* 2006)
External influences on the adoption of a weed management strategy		
Externatilities	The "spillovers" or external benefits or negative impacts on other landholders that might occur from the implementation of a weed control practice. This also includes the issues that might affect the landholder that are external to their property.	(Sindel 1996; Pannell *et al.* 2001; Pannell *et al.* 2006)
Government policies	The support programs that encourage or the legislative regulations that enforce weed management.	(Sell *et al.* 2000; Pannell *et al.* 2006; van der Meulen *et al.* in press)

Challenge or issue	Details	References
External infrastructure	The availability of external infrastructure required to support a weed management strategy, e.g. contract sprayers.	(Vanclay 1992; Sell *et al.* 2000; Vanclay 2004)
The characteristics of the landholder that might affect adoption of a weed management strategy		
Beliefs and objectives	The relationship between any new weed management strategy and the beliefs, values and subsequent farm objectives held by a producer.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006; van der Meulen *et al.* in press)
Brand loyalty	A landholder may hold a keen sense of loyalty to certain types of farming (e.g. stud cattle breeders show fierce loyalty to their breed).	(Pannell *et al.* 2006)
Social networks	The social support networks that exist around a farmer to reaffirm (or discourage) adoption decisions.	(Vanclay 1992; Vanclay 2004; Pannell *et al.* 2006)
Family and lifestyle	The objectives held by the producers for their lifestyle and family.	(Pannell *et al.* 2006)
Personality	Some studies have found certain personalities to be dominant in farmers. A farmers locus of control (external verse's internal) could affect management decisions.	(Pannell *et al.* 2006)
Profit expectations	The degree to which a farmer seeks short term profits over long term income.	(Llewellyn *et al.* 2005; Pannell *et al.* 2006)
Off farm income	Off farm income may increase funds for control but decrease time availability.	(Pannell *et al.* 2006)
Property size	Property size has been found to affect the adoption decisions of farmers.	(Pannell *et al.* 2006)
Age	Age appears to play a role in weed management adoption decisions. It is probably related to a number of other demographic variables.	(Pannell *et al.* 2006; van der Meulen *et al.* in press)

Challenge or issue	Details	References
Education	Education has been found to be a factor in the adoption of weed management strategies amongst grain growers.	(Llewellyn *et al.* 2005; Pannell *et al.* 2006)
Expectation of future innovations	A producer's expectation of the development of future innovations that might supersede any currently considered innovation.	(Llewellyn *et al.* 2005)
Reason for land holding	The difference in priorities between lifestyle block owners and production orientated farmers is a key example of this barrier.	(Pannell *et al.* 2006)
Land tenure/ownership	Whether land is owned or leased appears to influence management decisions.	(Sell *et al.* 2000)
The influence of the innovation or transfer process on adoption		
Extension programs	Extension programs will influence adoption decisions.	(Pannell *et al.* 2006)
Extension agent relationships	The relationships of farmers with extension agents will influence the effectiveness of extension programs.	(Pannell *et al.* 2006)
Availability of information	This includes the proximity of the producers to information sources and other adopters.	(Llewellyn *et al.* 2005; Pannell *et al.* 2006)
Conflicting information	Weed management strategies like all innovations suffer from conflicts in application information.	(Vanclay 1992; Vanclay 2004)
Identification of problem or opportunity		
Anticipation and observation of the problem	The degree to which a weed problem might be anticipated or observed will affect the adoption of weed management strategies. This will also include the ability of a land holder to observe the economic impact of a given weed.	(Barr and Cary 2000; Vanclay 2004; van der Meulen *et al.* in press)

3 Methodology